CORRESPONDENCE

FOR YOUR GUIDANCE

You are about to commence a course of training which can have a tremendous influence for the good upon your future career. I know that you are enthusiastic to make the very most of your training, and that is why this guidance booklet has been written.

In the pages which follow, I want to set out clearly before you all the main advantages and facilities the Australian Radio College offers you. I want to go further than this, I want to show you how you can use these facilities to get the very most out of your association with the College.

Before you commence studies, read right through this booklet, from beginning to end - make sure that you are thoroughly acquainted with what it contains. When you have finished, do not place it where it may be lost, but keep it carefully filed, for preference, with your lessons. Keep it where you can refer to it at any time.

This booklet can mean £.S.D. to you in every way, because it is the fingerpost to all those extra A.R.C. Services which will help you to spell "SUCCESS" after your name.

Finally, I want you to feel that even after you have completed your training we continue to be interested in your welfare. All the A.R.C. Services will be gladly extended to you at all times. They are not just for the period of your training, but are lifetime services, which will be always available to help and guide you in <u>all</u> radio matters.

M.I.R.E. (Aust.) Fellow of the Television
Society (England)

PRINCIPAL.

STUDY PROCEDURE.

To obtain the greatest benefit from this course of radio training and in order to master it rapidly and easily. you should carefully follow these simple rules. Throughout your course you should make frequent references to these 'guide posts'. In this way you will make more rapid and thorough progress.

This course has been carefully planned and prepared. The practical experience of many famous engineers has contributed to make this the most up to date and thorough radio training available.

1. First, take one lesson at a time and read through it easily, as if you were reading an interesting book. This will give you a general idea of what the lesson is about. But - it is not enough to just read your lessons. You must study them. So read through it again, this time studying it carefully, and, if necessary, taking notes of the most important points. Just half an hour of concentrated and uninterrupted application to your lessons will benefit you more than three or four hours of half-hearted application.

   NOTE: When you have answered the examination questions to the first lessons, post them to the College in the envelope provided. In the meantime, carry on with your study of Lesson No. 2. When we receive your answers to Lesson 1, they will immediately be corrected and returned to you with your next lesson.

2. Make sure that your whole mind is on your subject. Never be careless in your study. Habits are made merely by doing one thing three or four times. Therefore, every time you carelessly study your lesson you are strengthening a habit that is bad for you. On the other hand, if you study your lessons properly by giving your full attention to them, you are strengthening a good habit.

   Always keep your mind on the subject in the lesson under review. Do not read any part of your lesson while you are thinking of something else.

3. A certain time set aside each day will benefit you more than two hours to-day, none to-morrow and one the next day and so on. Be systematic in your work and your progress will be more rapid. Learn a little at a time. Retain what you learn by not trying to cover too much ground immediately. A little each day will result in surprising progress by the end of a few weeks.

4. Never lay aside a lesson to pick up the next one unless you are sure, in your own mind, that you understand everything taken up in that lesson.

That is the most important thing I can tell you at this time. It's so important that had I room, I would print these few words in letters the size of this page. It's so important that nothing I can say would be too strong on this point .... You will, I am sure, read your lesson sheets carefully, just as I have asked you to do.

5. There are questions at the end of each lesson sheet. These questions are based on subjects covered in that particular sheet. Should you find yourself unable to answer any question, don't give up and let it go at that. Instead, go back over the lesson sheet until you locate that part of the lesson covering the question you can't answer --- there you will find the information that will enable you to answer the question that was bothering you ... But answer the question tomorrow, not at the moment of reference.

   This information is always there. No questions are ever asked that are not fully covered in the text of each lesson, and by reading or studying each lesson carefully you will always be able to answer each and every question easily and correctly. So, again .... read each lesson sheet carefully.

6. When doing examinations write out the question on your answer sheet before you write your answer. Make sure that your name and address are clearly shown at the top right hand corner on the front or first sheet. While neatness and spelling are not essential, it will be of benefit to you to be as neat and correct as you can. It is only by striving towards perfection that we reach it.

7. Finally, I want you to look on us as friends. The aim of every member of the staff is to assist you. Do not hesitate to write in if you require help and advice with your studies.

SYLLABUS.

TELEVISION, FREQUENCY MODULATION AND FACSIMILE COURSE.

1. What television, frequency modulation and facsimile are.
2. Source of television signals.
3. Cathode ray tube—principles and operation.
4. Electronic scanning and television camera tubes.
5. Video amplification.
6. Transmission of television signals.
7. Aerials.
8. Television receivers.
9. Image reproduction.
10. Beam deflection synchronisation.
11. Receiver power supplies.
12. Colour television.
13. Recent television developments.
14. General characteristics of frequency modulation.
15. Frequency modulated transmitters.
16. Frequency modulated receivers.
17. Audio frequency systems and typical receivers.
18. Alignment and servicing of frequency modulation receivers.
19. Facsimile transmission.
20. Facsimile receivers.

PLEASE NOTE.

"TELEVISION, FREQUENCY MODULATION AND FACSIMILE COURSE."

It is brought to the notice of students engaged upon the above course, that this guidance booklet was originally compiled as a prefix for the student about to commence our Radio Service Engineering Course. However, with the exception of minor details, all information contained herein, is applicable to students engaged upon our Television, Frequency Modulation and Facsimile Course.

Minor alterations are.........

Page Reference.

Page 6....The T. F.M. and F. Course is comprised of one section only, therefore the one original set of service covers is supplied for the complete course.

Page 8....Average rate of study is two lessons per month.

Page 12...Since the A.R.C. Fault Finder refers to servicing work, it is not supplied with the T. F.M. and F. Course. However, if you require one, these are available from the A.R.C. Sales Department.

Page 12...Two sets of stiff covers are required if you wish to bind the complete course.

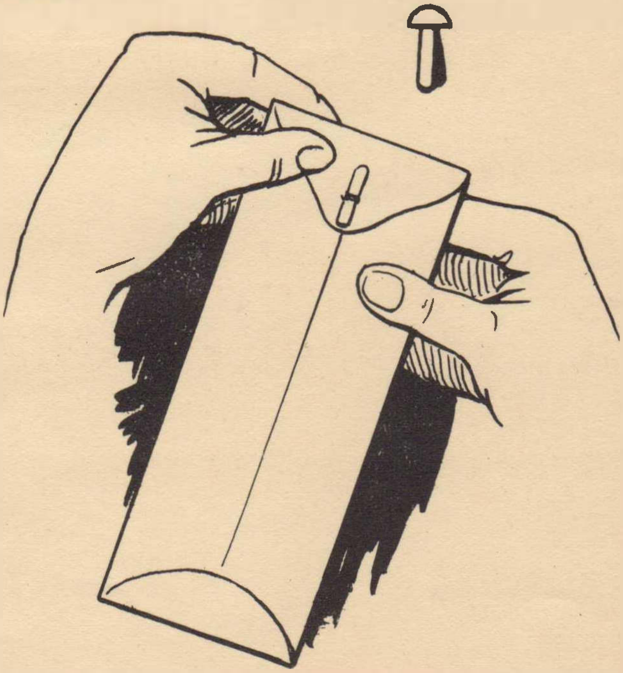
POSTAGE ON LESSONS

The College pays postage on all lesson matter and correspondence sent to you. You pay postage on all lesson matter and correspondence sent to the College.

The Post Office allows a special rate on lesson matter sent by students to the College provided it is unsealed. The rate for unsealed lesson matter is only 3d. for the first 2 ozs. For each additional 2 ozs. an extra amount of 2d. is charged. This means that all average lesson examination papers you return, which normally weigh under the 2 ozs., will only cost you 3d. Any sealed matter must be paid for at ordinary postage rates. With every lesson, you receive a printed return envelope for your examination answers. There are two methods of treating these envelopes when taking advantage of the special unsealed postage rate.

1. You can fold the flap over the contents of the envelope. This method makes it possible for the contents to be shaken out and cannot, therefore be high recommended, although it is used extensively.

Be sure to fasten your return envelope carefully. Also never send your fees with lessons, unless you seal the envelope and for preference, register it.



2. You can fasten the back of the envelope and the flap together with a round edged paper fastener. Make sure it is a round edged paper fastener, and not a pointed one, because the latter are banned by the Post Office through their habit of cutting the Postman's hands.

When your examination questions reach the College, they are corrected the same day, or at the latest the day following, and immediately returned to you with another lesson and return envelope.

THE A.R.C. BADGE.

The College badge is given to every student, free of charge, when he enrols. It is designed to screw into the buttonhole on the lapel of your coat. You should wear this badge always because it will help you in many ways. The wearers of this badge are joined in a bond of fellowship which extends around the world. You will find A.R.C. students in all parts of Australia and the Empire ---- they are recognised by the blue and gold badge.

Many a student who has successfully applied for a radio position has attributed his success in becoming placed in large measure to the fact that he was immediately recognised, by means of the badge, as a Student of the Australian Radio College.

It helps in many ways too. The A.R.C. badge has opened many a prospective customer's door for the student in business for himself.

This badge is recognised by the Radio Industry and public alike, as the hall mark of all that is excellent in radio training.

EXAMINATIONS & AWARDS.

Your first lessons reach you in the special service covers supplied with each Section of the course. You will notice from the training syllabus that there are three Sections to the Course. When you commence a new Section, you receive another pair of service covers, making in all, three sets of covers. The purpose of these service covers is to help you keep your lessons always fresh and clean. When you have finished studying all the lessons in your Course, and all your lesson examination papers have been returned to, and corrected by the College, it will be necessary for you to thoroughly revise right through the entire course. However, you will be notified of revision procedure when you reach that stage. After you have completed your revision, a Final Examination paper will be sent to you. Note, you do this examination in your own home, it is not necessary to travel to the College for the Final Examination. It is left to the student's own sense of honour not to refer to his lessons when doing the Final Examination. In any case, the fellow who copies from his lessons in any examination, however insignificant that examination might be, is definitely defrauding only himself. It proves beyond doubt that he has not absorbed the knowledge, and sooner or later it will prove fatal to whatever object he had in view when commencing the Course.

If by any chance there are any points upon which you are not quite clear, do not hesitate to communicate with the College immediately. We are always only too pleased to give you any advice and co-operation you require with your studies. A.R.C. Instructor Engineers are helpful, friendly and completely reliable men. They all have many years' experience of radio engineering work - student's problems in particular. Call on them always, for advice and assistance with your lessons.

Upon successfully passing the Final Examination to the "Radio Engineer's & Serviceman's Course", you are awarded the A.R.C. Certificate, and Certification Card. The Certificate should be framed and hung upon the wall of your study or workshop. The Certification Card should be kept in your pocket and produced when you are making Service Calls or at other times when certification of your technical qualifications might prove to your advantage.

The Diploma, which is the highest recognition made by the College, is only awarded after the student has successfully studied the A.R.C. Advanced Radio & Television Courses.

At Right: The A.R.C. Certification Card.

Below: The A.R.C. Diploma, Certificate & Lessons.

AUSTRALIAN RADIO COLLEGE
SYDNEY, N.S.W.

CERTIFICATION CARD

This is to Certify that ....

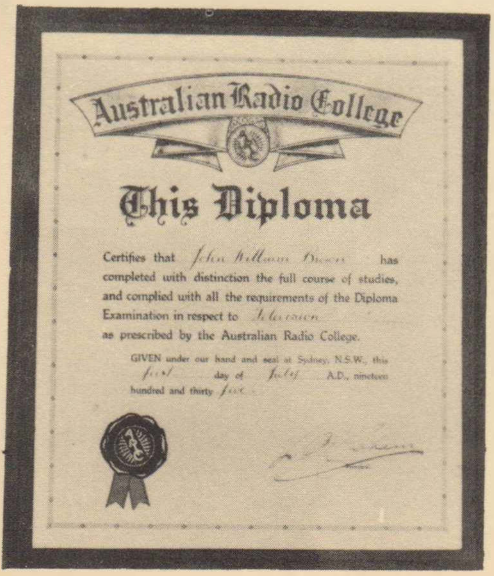
has studied our Radio Training Course .... and

obtained a satisfactory pass.

.... Signature.

.... Issue Date

.... Principal.

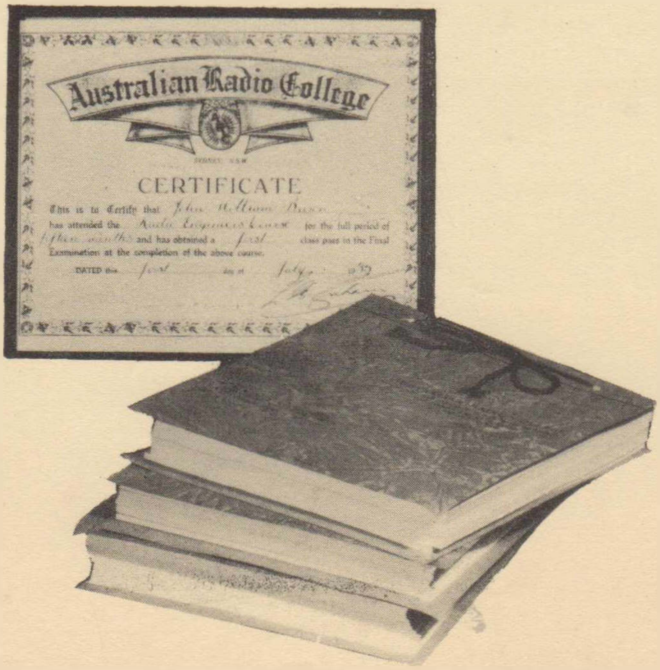


Australian Radio College

This Diploma

Certifies that John William Brown has completed with distinction the full course of studies, and complied with all the requirements of the Diploma Examination in respect to Television as prescribed by the Australian Radio College.

GIVEN under our hand and seal at Sydney, N.S.W., this first day of July A.D., nineteen hundred and thirty five.



Australian Radio College

SYDNEY, N.S.W.

CERTIFICATE

This is to Certify that John William Brown has attended the Radio Engineers Course for the full period of fifteen months and has obtained a first class pass in the Final Examination at the completion of the above course.

DATED this first day of July [illegible]

WHEN SENDING MONEY.

Be very careful when you are sending money for fees, etc. to the College. First, it should definitely not be included with your lesson examination answers, unless the envelope containing them, is sealed. If there is any possibility of the letter going astray, it is far better for you to register it.

Make all money orders, postal notes, cheques, etc, payable to

AUSTRALIAN RADIO COLLEGE PTY. LTD.
Broadway.

and see that your envelope is addressed to the College, and not to individual members of the staff.

We make a practise of returning all receipts immediately we receive a remittance. Therefore, if you do not receive your receipt within a reasonable time of the despatch of your remittance, please notify our accounts department, and the necessary search will be carried out.
Make sure your name and address accompanies your remittance.

RATE OF STUDY.

So that you should see exactly where you stand with the amount of study your fees payments will allow you to do, the following should be noted carefully.

1. Students paying cash in advance for the whole course, may progress through their training at as great a speed as they wish.

2. Students paying for the course by the alternative cash payment plan of three cash payments within six months, may progress through the First Section as fast as they wish after their first cash payment. After their second cash payment they may progress through the Second Section, as fast as they wish, and after their third and final cash payment, they may complete the course as fast as they wish.

3. Students paying for their training on the monthly plan, will, if they progress at a good average pace, complete the course at about the same time as they finish paying for it, namely in about sixteen months. Under this payment plan, students may be trained at the rate of approximately three lessons per month. This is quite a good speed for anyone who is employed during the day time and only has his spare time to devote to training. Actually, one lesson per two weeks would be a medium pace.

The monthly fees payments were arrived at after due attention had been paid to the average fellow's rate of progress, and were designed so as not to retard his rate of progress in any way.

In the case of a student who finds that he has much more than the average amount of time to devote to lessons, and wishes to progress quickly with his training, it would be to his advantage to pay either cash in advance for the balance of his course, or make the three cash payments within six months. Either of these two plans will save him money. If he cannot see his way clear to pay according to either of these two plans, he can arrange with the College to increase his usual monthly payments to a figure which will enable him to progress at the pace he wishes. Everyone will agree that this is quite a fair and equitable basis of fees payments.

In any case, no matter what your problems, if any, might be in regard to fees, you will always find us ready to co-operate with you in a sincere effort to see that you get the very most out of your training.

Just as some students wish to progress at a faster rate than average, so there are some who through illness, pressure of work or some other urgent reason can only proceed at a slow rate. Although the majority of students can comfortably complete the Radio Service Engineering Course in the normal time of 17 months (complete Radio & Television Course, 26 months) the College is happy to allow an extra 6 months (complete Radio & Television Course, 9 months) without any extra charge. However, if a student is so slow that the normal period plus the extra free period is exceeded, then a small extra charge will be made, the extent of the charge depending upon the amount of the course remaining to be completed at the time.

The reason for this surcharge will be readily understood in these days of rapidly rising costs, when it is realised that the fees for the course are determined prior to enrolment and the College is committed to supply instruction and material for a period of two years or so ahead; regardless of the way costs increase during this period. However, if a student wishes to prolong his course beyond even the extra free period granted by the College, then obviously a small charge will be necessary to cover the increases in the cost of labour and materials for the uncompleted part of the course.

If you regularly complete two and a half or three lessons per month you will not have to pay extra, so endeavour to study regularly.

PAYING FEES

We ask students wherever possible to have their monthly fees payments sent to the College on or about the 15th of each month. This helps us to keep our records efficiently by recording all fees payments at about the same time each month. A few days before the 15th of the month, we send a fees reminder statement, to remind the student that the month's fees day is approaching.

To save confusion and delay, please make all fees payable to "Australian Radio College Pty. Ltd." In the case of postal notes, money orders, etc., they should be made payable at BROADWAY, which is our nearest Post Office. Do not, under any circumstances, make the money payable to individuals, but always to the College.

FREE EMPLOYMENT SERVICE

If you aim to become placed in a radio position, the College will give you every co-operation to find a job, both whilst you are a student, and at any time after you have finished your course.

Naturally, we cannot guarantee to find a position for any student because so much depends both upon the manner in which a student progresses with his training, and the number and variety of positions available when he has completed his training. However, many hundreds of students have been placed in worthwhile jobs in the past, and the demand by employers on the employment service is increasing.

A point to be kept in mind is that employment cannot necessarily be found for a student shortly after commencing the course. Quite frequently, especially in the case of junior students, we are able to place them after a short period. In the case of senior students, the rule is, that a student must have a thorough knowledge of the principles of radio engineering before any employer would consider an application for employment. These engineering principles are only obtained by the student absorbing his training right to the final lesson in his course.

Throughout your training, you are urged to endeavour to apply the knowledge we give you in every possible manner. This can be done in various ways. To engage in radio set building, and spare time radio service work are the two most profitable that can be suggested.

When you reach a stage of proficiency in your training, make enquiries for employment in suitable radio quarters in your district. Quite frequently, students are able to find good positions without the assistance of the College. One thing the College does guarantee is to give students every assistance and co-operation in finding suitable Radio Employment. Thousands have been placed in the past, and the efficiency and scope of the Employment Service is actually increasing. You stand an even better chance than those who have been placed by the College in the years that have passed.

FREE BUSINESS ADVICE SERVICE.

If you have any radio business problems, do not hesitate to seek the advice of the College Business Executives. They will at all times, gladly extend to you their sound advice which is based upon many years experience of all radio business matters.

You may intend commencing a radio business of some description, maybe you have a plan drawn up for a sales campaign; perhaps you have some special mailing pieces in mind, - no matter what your business problems might be, the College is always ready to assist and co-operate in any direction if required. This Service also operates for the lifetime of the student, and not just for the period whilst he is studying.

FREE TECHNICAL CONSULTATION SERVICE.

If you require any technical advice or information, the College engineers are always at your service.

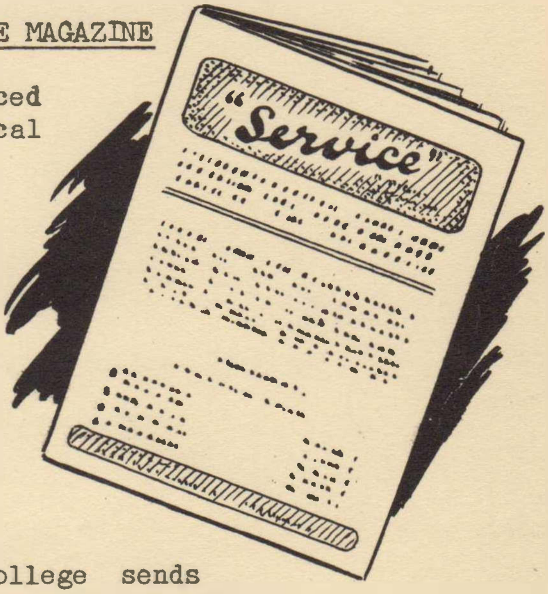
It frequently happens that when a student first starts in a radio position, or commences a service business he comes across a knotty problem which may puzzle him for the time. A.R.C. students never need worry about such problems because the Free Technical Consultation Service is always ready to help them out.

This Service is as close to you as your nearest telephone or letter box. All you need is to give us full details of your problems, and your queries will be answered immediately.

This Service is a lifetime Service - which means that you may use it, not only whilst you are training, but even after you have finished your Course, - in fact for the rest of your life.

You should gain confidence from the knowledge that such a service exists, confidence to tackle each and every technicality that may come your way.

"SERVICE" OUR COLLEGE MAGAZINE



This is a magazine originated and produced by Members of the College, Business and Technical Staff. In "Service" you will find articles on business management, sales campaigns, the latest technical improvements, vocational and employment aids. From time to time details of new circuits and how to build them are given, the latest in test equipment, what other Countries are doing in Radio, Refrigeration notes, and indeed any articles which are considered of value to A.R.C. Students are included in "Service". It is YOUR paper, designed to keep you up to date with trade and technical matters.

There is no charge for "Service", the College sends it to you post free as each edition is produced. When you have finished your course, you may continue to receive "Service" by paying the small annual subscription of eight shillings (8/-d). You should keep your copies carefully filed, because you will find it extremely useful at all times.

A.R.C. FAULT FINDER

The A.R.C. Fault Finder is a series of bound foolscap size service sheets, dealing with all faults found in radio receivers. It folds into quite a small chart and is designed to slip into your pocket. Originally designed by the College engineers, this Fault Finder is printed and compiled specially for the College. Its purpose is to supply the serviceman with a quick reference chart which can be carried with him when he is "on the job".

Each fault common to radio receivers is taken in turn, it's probable cause given, how to locate it, and finally how to rectify the trouble. There's not a radio service engineer can afford to be without this pocket service aid. They are given to you free when you enrol.

EXAMINATION WRITING PAPER.

You will find it an excellent plan to carefully file all of your corrected lesson examinations. They will prove of distinct benefit to you later on for reference purposes. The handiest and perhaps best place to file them, is with your lessons, for preference, immediately following the lesson to which they refer.

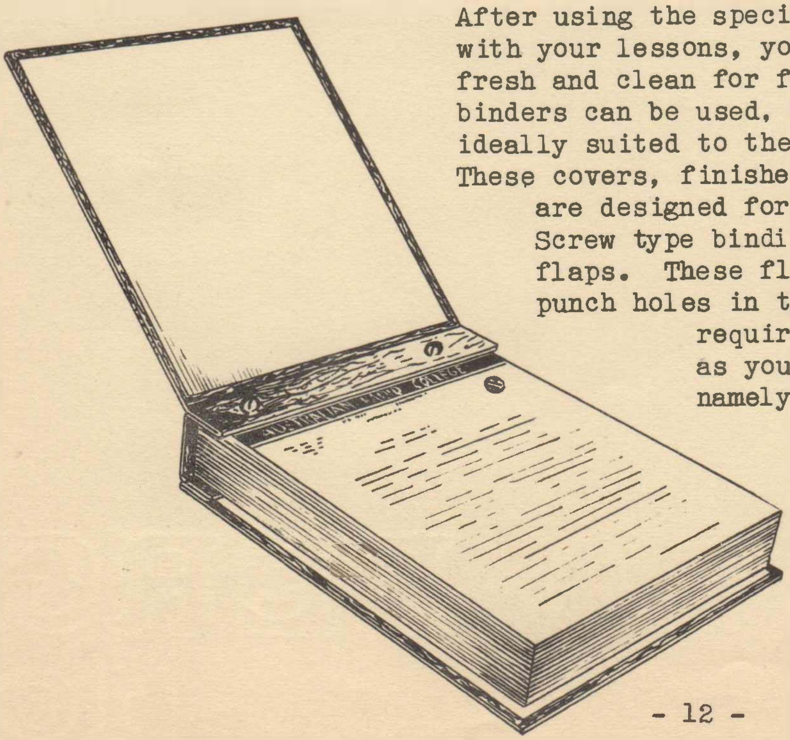
At the same time it is nice to have them clean and uniform, - it gives an air of efficiency of the manner in which you go about your training.

The A.R.C. printed examination writing pads will help you do all this. They are punched precisely the same as your lessons, to allow you to file them with the lessons. The pads are appropriately printed at the top, with special provision for your name, address, percentage of marks, etc. In addition to the punched printed pads, plain pads, similarly punched are available for use as plain follower pages for your examination answers. Full prices are shown on a separate sheet.

REPLACEMENT LESSONS.

If you have the misfortune to lose or damage any of your lessons, you can obtain replacement copies from the College Lesson Department. See separate list for prices.

STIFF LESSON BINDERS.



After using the special flexible service covers supplied with your lessons, you will want to keep your lessons fresh and clean for future reference. Various types of binders can be used, but the College has designed covers ideally suited to the purpose.

These covers, finished in attractive leather grained fabric, are designed for filing your lessons. Nickel plated Screw type binding posts fasten them to the inside flaps. These flaps are punched to coincide with the punch holes in the lessons. Three sets of covers are required to bind the complete Course, which, as you know is divided into three sections namely, Lessons 1 to 18A - 19 to 34 - and 35 to 50. (See Price List)

A.R.C. Buying Service.

If you are interested in building radio receivers, experimental apparatus, or in radio business activities of any kind the College can save you pounds. The A.R.C. Buying Service will introduce you to Firms which will supply your requirements at the very lowest prices. Arrangements have been made with a well known Trade Distributor to specially cater for A.R.C. Students requirements. Should you anticipate commencing either a full time or part time radio business, the Buying Service will advise you of the best agencies to take on, will help you obtain them, and will gladly give you any information upon running such a business.

Flexible Study Covers.

If you wish to keep your lessons clean and tidy whilst studying them, you should obtain one of the special flexible covers produced for the College. These covers are made of strong imitation leather fabric with two press studs at the top. The studs are spaced to suit the punched holes in your lessons. Up to three lessons at a time can be accommodated in these covers. They are ideally suited for studying purposes whilst travelling, and allow the lessons to be conveniently rolled up without damage or creasing to lessons or covers.

AUSTRALIAN RADIO COLLEGE

E. S. & A. BANK BUILDINGS, Corner CITY RD. and BROADWAY, SYDNEY
Telephones: M 6391 and M 6392. Post Lessons to Box 43, Broadway

TELEVISION, FREQUENCY MODULATION AND FACSIMILE COURSE.

LESSON No. I.

WHAT TELEVISION, FREQUENCY MODULATION AND FACSIMILE ARE.

Time in retrospect is ever an absorbing study - just as occurrences in past years are affecting our lives and activities at the present, so many happenings of today provide a pointer to the future. Our parents remember, perhaps more vividly than we, the advent of the motor car (so-called "Horseless Carriage"), aeroplane, telephone, telegraph - all milestones marking the road of civilisation's progress. From the turn of the 20th Century, almost every branch of the sciences has made what may only be called amazing strides, due in no small measure to the tremendous fillip given to these matters by the stern requirements of the two Great Wars. This is unfortunate, and reflects badly on the weaknesses and shortcomings of human nature as a whole. Facts remain however; and it is probable that this 20th Century of ours will go down in history as the period of greatest and most rapid scientific progress!

It is hopeful to reflect that (during his allotted span of life) each of us in his own way contributes something to the well-being or otherwise of his fellows - good or bad, important or insignificant, depending on the character, abilities and intelligence of the individual. The calibre of men like Marconi, Baird, Armstrong, de Forest, Fleming and Hertz, is well-known, for these names, together with many others, are those of the pioneers in the particular branch of the sciences which interest us so much. So, in our backward glance at the early workers in the field of Television, we encounter a German gentleman named Nipkow, who virtually made this business of "seeing by wireless" possible. Paul Nipkow's contribution to the art was the avowedly simple device known as a "Nipkow Disc", of which he completed a first experimental model in 1884. Just how it works will be told later on. As the years rolled on, many another name was added to the ever growing list of experimenters, engineers and scientists, each adding, in his own way, to the progress of Television towards the goal of perfection.

It is logical to assume that any intelligent person who has the necessary fundamental knowledge of Television could, in time, contribute to the art, and this course has been prepared to provide a thorough grounding, not only in Television, but in Frequency Modulation and Facsimile as well. Although these three services are more or less in commercial use at the present time, much remains to be done, and in this direction, individual experiment and research are likely to prove the most fruitful sources of discovery.

At this juncture, we must all realise, quite obviously, that in general, academic schooling of a very high order is essential to understand fully the complex mathematical treatments which all engineering sciences involve, Television, Frequency Modulation and Facsimile being no exception. Equally, on the other hand, much useful work may be done by we humbler folk with practical ability, and the right kind of basic and thorough training, as will be imparted to the diligent and conscientious student, by this course. Further, in this latter regard, unbounded opportunities will be available in this entirely new industry of Television as it becomes established in this country. The phrase "new industry" is used advisedly above, and applies also to Facsimile to some extent, and to an obviously lesser degree to Frequency Modulation. Personnel requirements, for the factories set up to manufacture Television apparatus, will be met mainly by local resources, so the future holds promise, not only on the manufacturing side as a tester or assembler, but in the service and maintainence of these new types of apparatus, and possibly in the laboratories associated with the factories. In addition operators and servicemen will be required on the transmitting side. It is refreshing to note that in 1938, in London alone, there were over ten thousand television receivers--the thought occurs here that for "sales minded" technicians, a very large field will present itself.

In answer to a question, as yet unasked, it is considered appropriate to explain here, why the three subjects of Television, Frequency Modulation and Facsimile, have been incorporated into a single course of study. Well, in the main, all three have a measure of common ground. First, and perhaps foremost, an ultra high frequency carrier wave is utilised in each case, (for reasons you will appreciate as the course unfolds) and so the practice and principles involved in working at these frequencies are the same. Then, there is the consideration that Television and Facsimile differ only in the basic fundamental that, whereas the former deals with an image or scene in motion, the latter concerns only "still" pictures or objects in an inert state, such as post cards, photographs, or pictures and newsprint in a newspaper or magazine--in effect the difference between a motion picture and a photograph.

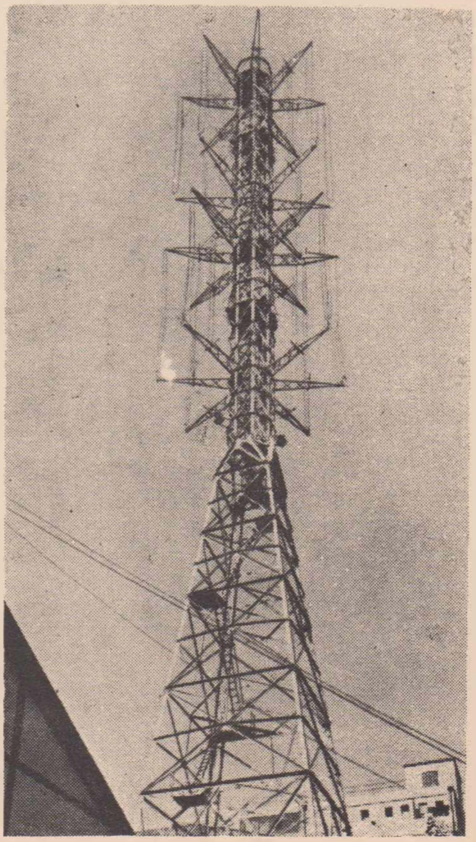


Fig. 1.
View of Television Transmitting Aerials at Alexandra Palace, London.

After this short preamble, let us digress a little, divide the following text into three sections, "A", "B", and "C", and treat in some detail the history and progress of Television, Frequency Modulation and Facsimile up to the present day.

SECTION "A". TELEVISION.

First, what is television to the man in the street? Definitions a-plenty are given by various authorities with slightly divergent viewpoints, but we can safely say here that "any means whereby a scene in motion, such as a football match, may be seen in intelligible detail at a point remote from the actual scene itself" is a system of Television. Of course, the inference is that the scene must be reproduced at the remote point <u>at the same time</u> as it occurs at the first place, whence it is transmitted. It is possible to take a moving picture of a cricket match, and after the film is developed, this could be shown in a picture theatre a year after it actually happened! Need we say that motion pictures are not

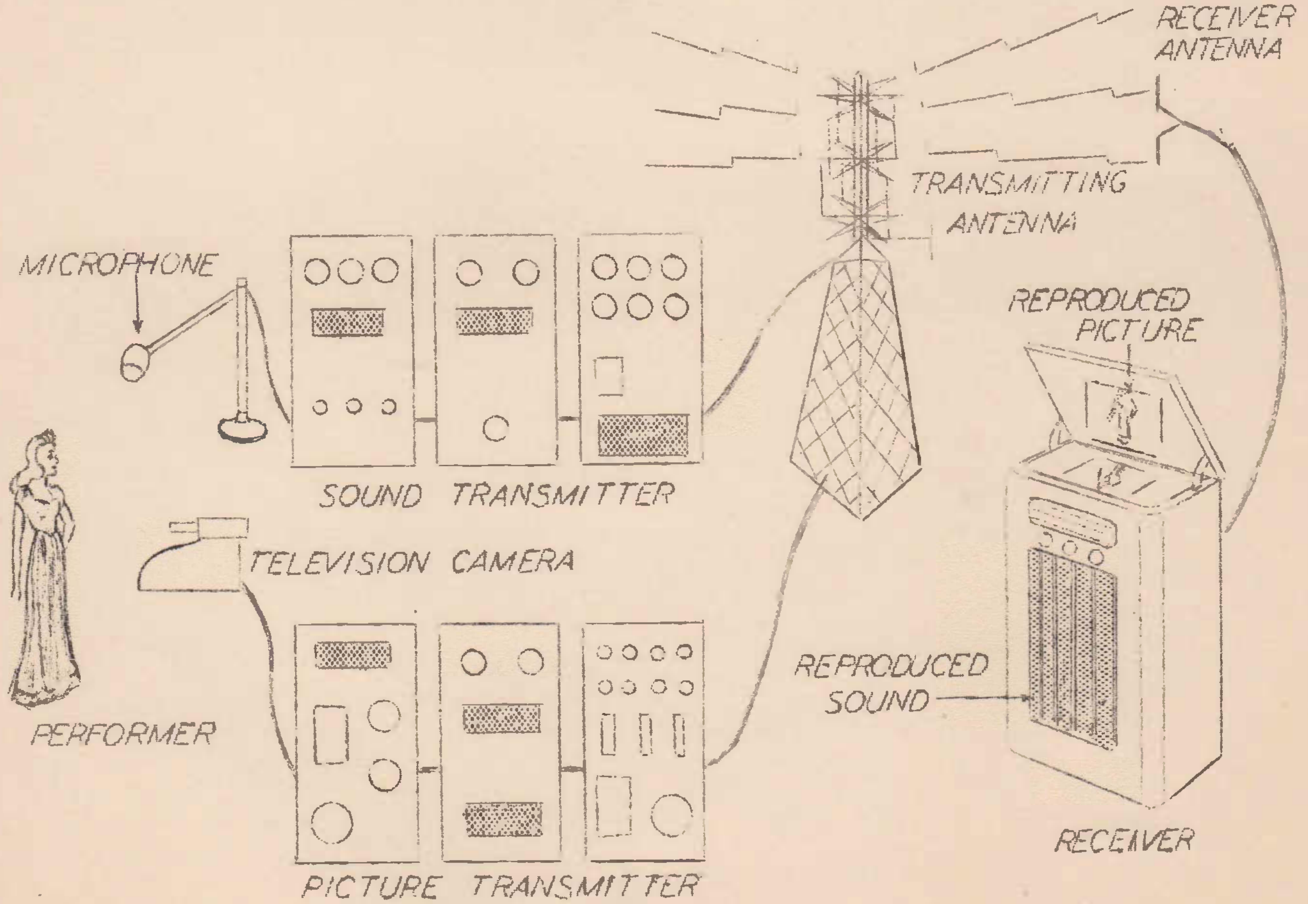


FIGURE 2.
GENERAL ARRANGEMENT OF TELEVISION SYSTEM.

Television! Just imagine sitting at home in front of a Television receiver, and seeing a surf boat riding the waves at Bondi, and you have grasped the idea.

It is quite clear that Television will open up a very pleasurable new era in home entertainment. Settled comfortably in our favourite chair, we will be enabled to watch any sporting event of sufficient importance to warrant its Televising, and it is probable that our great sportsmen will prove the most effective salesmen for Television equipment.

The motion picture industry is watching the development of Television very closely, as it has many uses in conjunction with the making of "talking pictures". For instance, it may be inconvenient to take a Television camera on a small boat, to capture the thrills of a yacht race--but, a small movie camera, the accepted thing on these occasions, could record the scenes and these items of interest may be retaken with a Television camera, and broadcast to people's homes shortly after the race. The only time delay here, would be due to developing of the film, and this, in these enlightened days, is a matter of a few short minutes. Take another example of how Television ties in with motion pictures. Perhaps you are, perhaps you are not aware that a movie is not made in one continuous film, but of countless "scenes", taken one at a time and lasting maybe two or three minutes. This enables the scenery to be suitably arranged for every "shot", and eliminates the necessity for actors and actresses to memorise an entire play. Well now, if plays and serial stories are to be successfully telecast it is logical to assume that something of the same process outlined above, will be followed. It would be very convenient to film a play in short pieces, and telecast the completed film. In this way it is readily seen that the film makers will give the progress of Television a helping hand, and also, in its turn, Television will prove of assistance to the movies. For the sake of completeness it may be useful to add, that in the normal broadcasting of a radio play or serial story, the players do not have to dress for the part, and neither have they to memorise their lines, as these may be read direct from the script. Obviously, if we are to see the actors, as in Television, the above technique is out of the question. Enough, then for the "man in the street". Let us now take in something of the history of this great new science of Television, holding, as it does, such promise for us all.

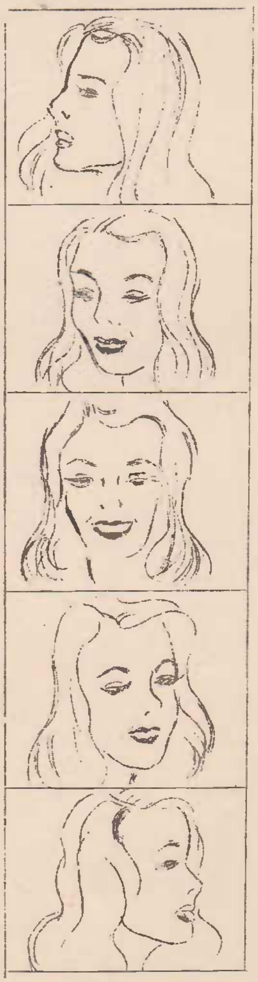
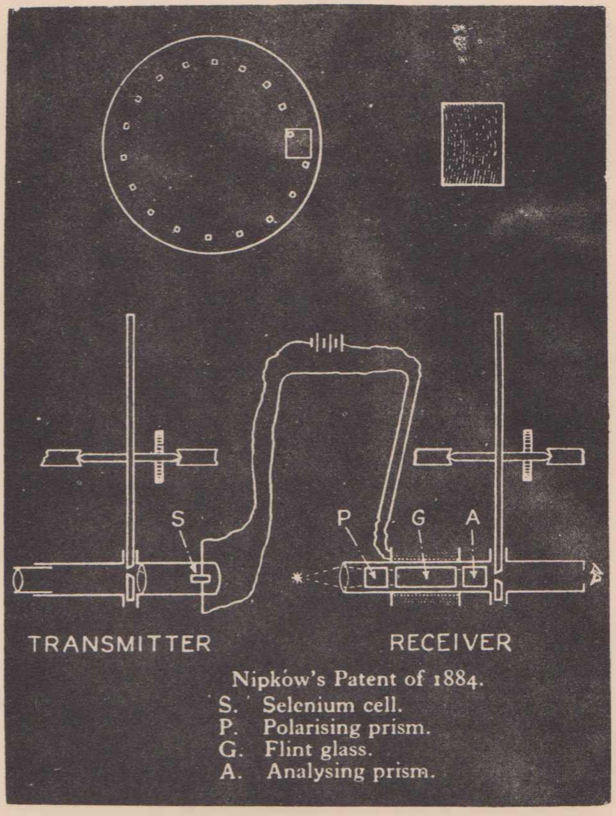


Fig. 3.
INSTANTANEOUS PICTURES OF A GIRL TURNING HER HEAD, ILLUSTRATING PRINCIPLE OF CINEMATOGRAPH.

Initially, we have to thank nature for her happy thought which makes Television, and in fact motion pictures, possible. This chance, if chance it is, of nature is called "persistence of vision", and is reasonably self-explanatory. Simply it means, that, after our eyes have seen some object, the image persists for a short space of time after we have ceased to look at it. This period of time, almost constant, irrespective of difference in age or sex in different individuals, is 1/10th second. If then, we can present a series of pictures to the eye at the rate of 10 per second, a continuity is obtained. Hence moving pictures function by the expedient of filming a moving scene in ten or more fixed pictures per second, each one differing slightly from its fellow. Actually, 10 pictures per second is not a very satisfactory rate as all persons who saw the first efforts at movies are aware, as a great degree of flicker was evident. Remember how once we talked of going to the "flicks"? The modern motion pictures are shown at the rate of 24 pictures per second, and this practice accounts for their excellence to-day.



NIPKOW'S ORIGINAL PATENT OF 1884,
RELATING TO TELEVISION.

Mr. Paul Nipkow, of whom we spoke earlier, knew about the eye's characteristic of persistence of vision, and he realised that if a moving scene could be captured in terms of 10 or more stationary pictures per second, it would appear to the observer as a moving picture; if reproduced in some manner at this rate. He also realised that it would be impossible to transmit by wire a picture as our eye sees it, that is instantaneously. To our eyes, a whole scene is encompassed or taken in at a single glance. If you look at a house on a hill, you see at once, not only the house, but the surrounding country, every detail of the trees and flowers, as well as the windows, chimney, doors and the hundred and one other items that may be in the picture. Now, Mr. Nipkow could not see any way of transmitting such a scene to a remote point, unless it was divided up in such a way as to provide some form of varying electrical current. Incidently, no-one else has thought out a way to transmit a complete scene either, right up to the present day. Now, let us imagine our house on the hill and sundry horses and dogs together with the people who inhabit the house, moving in and around the place in the course of their day's activity. It is only necessary to adopt the scheme used in the movies to take a film and when shown on a screen, all the movements are apparently reproduced. Take as a start, one of the still pictures comprising the film and let us see how it could be resolved into electrical current impulses.

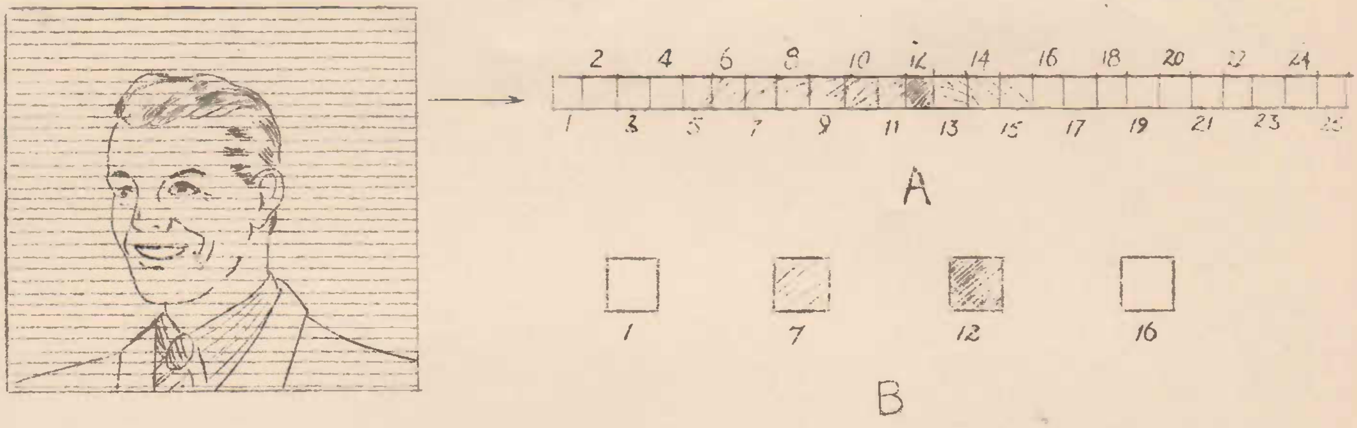


FIGURE 5.
SCANNING A SCENE.

Look carefully at the portrait on the side of Fig. 5 and notice the lines drawn across it which effectively divide it into strips, one of which is shown in an enlarged form at "A". It is at once seen that any picture can be so divided to provide a number of narrow strips, each of which present varying degrees of light and shade throughout its length, depending, of course, on the subject matter of the picture in question. Shown at "A" in Fig. 5, then, is a portion of the man's head in which the hair is clearly indicated. Going a step further, we may further dissect this strip into a number of smaller compartments, and at "A" we have shown 25 divisions, four of these being shown in greater detail at "B". The adoption of a numbering system for the strip gives a clear idea of just what has been done so far.

The next step is to focus a beam of light onto each little sub-division in turn, or, in other words, arrange for a light spot to travel the length of each strip (into which the picture is divided) and then return to travel in turn over the next strip lower down the picture, and so on until the whole has been covered by the spot. It is fairly readily apparent why this process is called "scanning" a picture, as that is precisely what our moving spot of light does.

Next we introduce a device called a photo-electric cell, which is so placed as to catch the light reflected from the picture as the spot passes over it. Varying intensities of reflected light, caused by the shadings in the strips as the light spot scans them, cause current to flow in sympathy in the electrical circuits connected to the cell. Of course, a pure white portion such as No. I in Fig. 5B will reflect the most light, and a dark portion such as No. 7 will reflect the least.

Operation of the photo-cell and its associated circuits will be detailed in following lesson work, but it is considered essential to grasp concisely, even in this early lesson, the necessity for scanning a picture in order to convert a reflected light into the form of alternating or pulsating current.

Harking back to our old friend, Mr. Nipkow, we now know just what his problem was - a means for accomplishing the scanning of a picture had to be found. His answer to the question is diagrammed, somewhat crudely, in Fig. 6, but if this is studied closely, more will be conveyed to you than several pages of the written word. As can be seen, the disc is caused to revolve in such a manner as to cause a beam through hole No. I to sweep across the top strip of the picture. Light through hole No. 2 sweeps across the second top strip and so on. Well now, it is only necessary to revolve the disc once to accomplish a complete scan of the entire picture, and were we to stand in front of the disc whilst this process was taking place, the individual spots of light would merge into a continuous blur, conveying an impression to our eyes of having seen the complete picture directly. If the man portrayed in Fig. 6 happened to be a live artist rendering the "Donkey Serenade", or some such number, we would like to see his lips and face move as he sang his song. This may be accomplished by rotating the disc more than ten times per second (remember - persistence of vision?) and we have it!

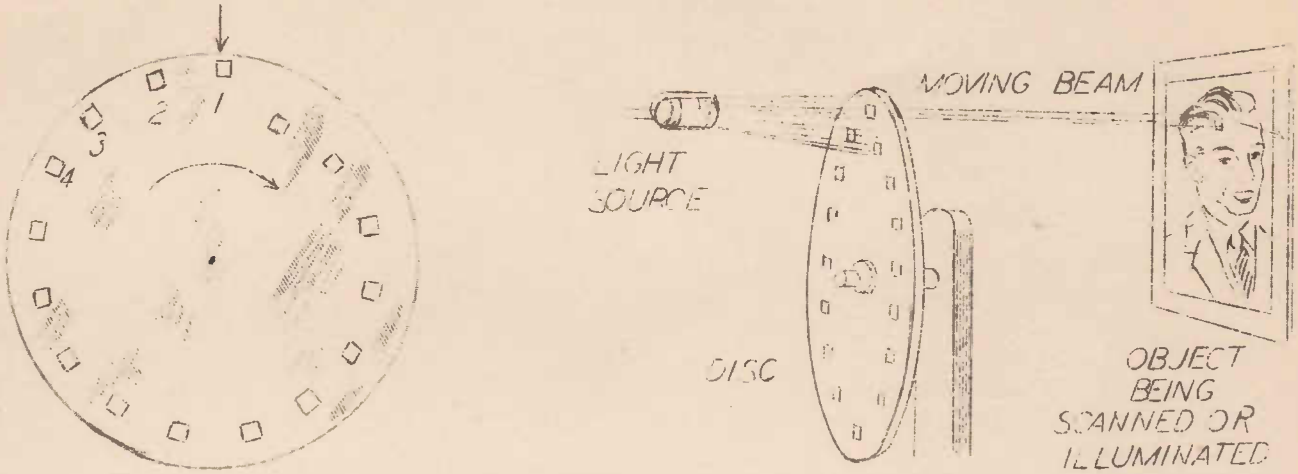


FIGURE 6.

SCANNING BY MEANS OF NIPKOW DISC.

The reasons behind the fairly lengthy exposition of the virtues of Mr. Nipkow's scanning disc, particularly at this early stage of the course, are chiefly in the cause of analogy. By this is meant that it is vitally important to have fixed firmly in your mind the necessity for, and the principle of, scanning. Nowadays, as will be told later in the course, the scanning disc is considered obsolete, as electronic means achieving the same result have been developed. But, and we labour this point, the principle remains.

Having established this process of scanning a scene in our minds, we may pass on to the most interesting subject of Television's historical progress, saying no more about Paul Nipkow, but examining the contribution made by other pioneers. About the year 1900 Weiller took out patents for a mirror drum scanning device, consisting basically of a drum with many mirrors set at different angles around

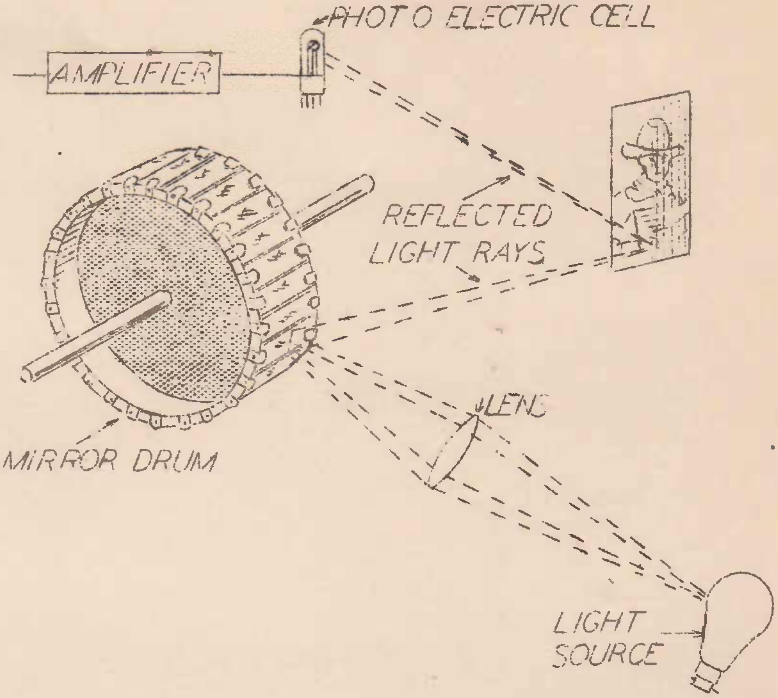


FIGURE 7.
MIRROR DRUM SCANNING DEVICE INTRODUCED ABOUT 1900.

its periphery, light from an aperture being projected from the revolving drum, through a magnifying glass or lens, onto a screen. The staggered placing of the mirrors caused the light spot to traverse the screen in a series of adjacent lines. Then in 1907 two eminent scientists conceived the idea, quite independently, of using a cathode ray tube in conjunction with the mirror drum scheme of Weiller's. These men were Boris Rosing and Campbell Swinton. Now, the examples given are some indication of the host of systems, some of them little more than suggested methods put forward by these early workers. All these schemes had a common failing - they were simply theories and suggestions, and it was impossible to present any practical results. This lack of tangible result was due, almost entirely, to the absence of some means of amplifying the minute currents caused to flow through the early, crude photo cells or selenium tubes, by the light reflected from the action of a scanning device. The difficulty was overcome when, in 1913, de Forest and Fleming produced the first radio valve which could be used for amplification. With the advent of this device, it occurred to one, John Logie Baird (often called "the father of Television") that the essentials for a successful Television system were now at hand, and in 1923 he had some success, with the simplest of apparatus, in transmitting shadows. By 1925, his apparatus had reached a stage where it was capable of sending the outlines of simple objects over a short distance by wireless, and in this year a demonstration was staged in the London emporium of Selfridges. From here on, progress became more rapid, and about the time of Baird's demonstration, C. F. Jenkins in America successfully transmitted an outline of a simple object. Then in 1926 Baird televised a crude image at a demonstration before the Royal Society. With the coming of 1930 the standard of Television had improved to such an extent that faces could successfully be recognised at the receiver, and in 1932 the B.B.C. London commenced regular transmission. However, the pictures were lacking in detail, and, moreover, had the severe drawback of flickering due to the low repetition rate of 12.5 pictures per second. In America the interest in Television became intense, and the old Telephone and Telegraph Co. gave a demonstration in 1927, causing numerous people to become interested in the new art, and to commence experimental transmission. All these early systems were mechanical in their

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operation, but improvements finally enabled the B.B.C. to increase the number of lines (strips of picture shown earlier in Fig. 5A) from the early 30, to 90, then 120, 180, and finally to 240, and this rate of scanning was used with a picture repetition rate of 25 pictures per second, making for a fairly reasonable overall definition. We come now to the trend towards electronic rather than mechanical television, with the cathode ray taking the place of the scanning arrangements as discussed so far. The tendency is to avoid cumbersome mechanical methods, as electronic systems are much more flexible and in every way more desirable. The cathode ray tube has made this electronic approach to Television possible, and the sketch of Fig. 8 indicates the essentials of the structure and gives an inkling also of how it functions.

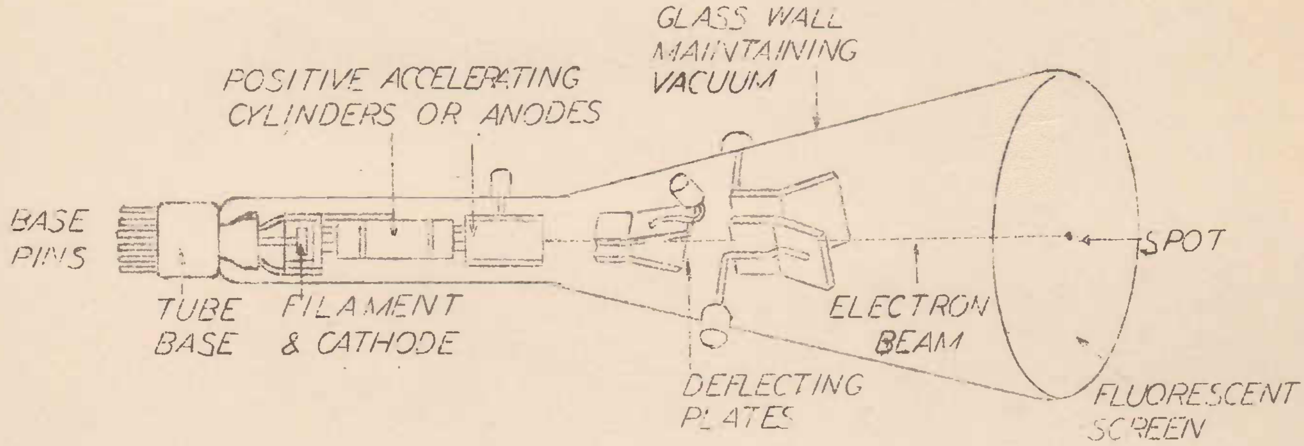


FIGURE 8.

The cathode emits electrons as in any normal radio valve, and these are formed into a beam by the focussing and intensifying effect of the accelerating cylinder or anodes. This narrow beam is then shot through a small hole in the end of the cylinder furthest from the cathode, passes through the two pairs of plates for deflection and finally impinges on the fluorescent screen at the end of the tube, causing a tiny spot of light to show. Now, if it is required to deflect this spot over the face of the screen, it is merely necessary to swing the beam in either a vertical or horizontal direction, by making one plate in each pair positive with respect to its fellow, the value of this voltage determining the degree of deflection. Here then, is the perfect solution to Television reception. We have a ready made spot of light, a means of moving it anywhere on the screen at almost any speed required, added to which its intensity may also be varied at will by suitable adjustment of the anode structure. All this, and no cumbersome mechanical parts!

The cathode ray tube principle has also been applied to the transmitting end in the guise of a television camera. So called an "Iconoscope" or "Orthocon" in America and an "Emitron" or "Super Emitron" in England, the basic principle is the same, and these names are trade designations by various manufacturers for what may be correctly styled a "picture tube". Fig. 9 gives an idea of what a modern picture tube looks like.

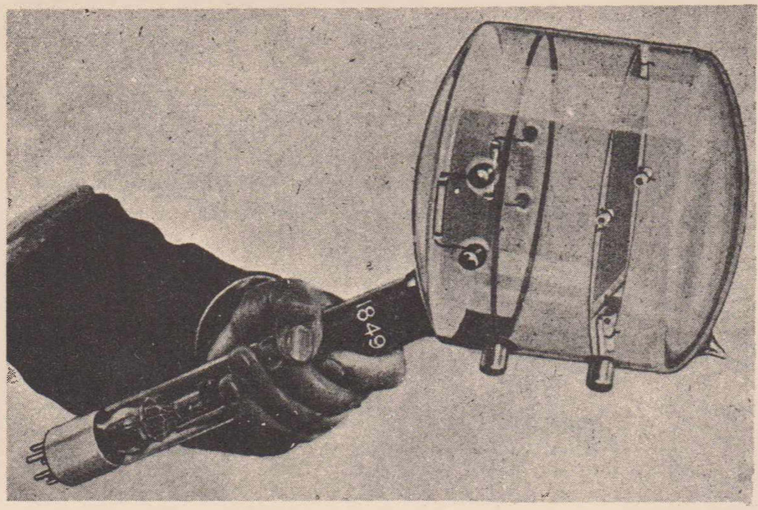


FIGURE 9.
A TYPICAL TELEVISION CAMERA TUBE.

It is not intended that the student should study the operation of this tube at the present stage, for the technical details will be dealt with at a more appropriate point later on in the course. Let it be sufficient to note here that the tube does the complete job of scanning the scene and converting the light variations to electrical impulses, which are then passed to the transmitting apparatus. The picture tube is introduced to you at this stage, however, because its development (which has taken place in both England and America) has been a most important and substantial step in the history of television. It has made possible the raising of the quality of television broadcasts to a point where the art, from an entertainment and commercial point of view, is here to stay. The tube is incorporated into a self-contained

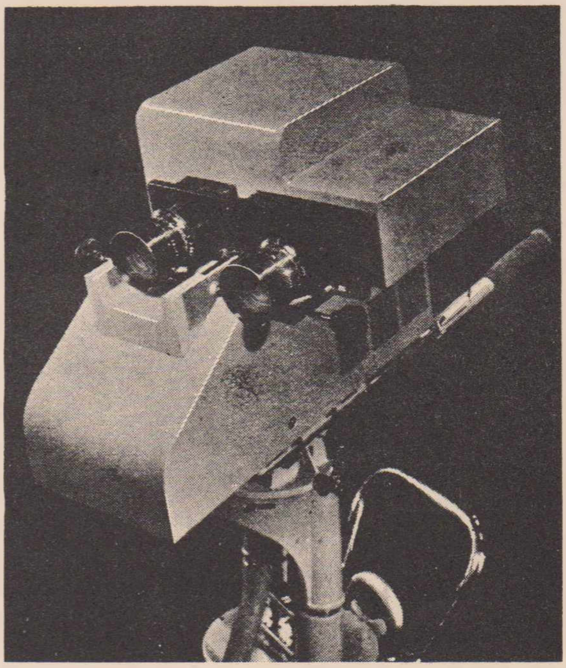


FIGURE 10.
MODERN TELEVISION CAMERA - EMPLOYING A PICTURE TUBE.

and compact unit together with lens to view the scene. In this form it is known as a television camera. Its advantages over older scanning systems lie in its sensitivity - its portability - and its ability to "scan" a scene in very great detail. Its comparatively great sensitivity has eliminated the necessity for excessively powerful lighting in studio scenes, and made possible the efficient televising of outdoor scenes, even on dull days. In this connection the camera fitted with a tele-photo lens has been specially developed as a portable unit, being connected to the main apparatus by a cable up to 1,000ft. and more in length. In this way pictures of sports events, processions, etc. having real entertainment value, as distinct from mere novelty appeal, have been transmitted. With respect to its ability to scan a scene with great detail, it is interesting to note the claim, in the case of the latest Emiscopes in use in the London Service immediately prior to the war, that these tubes had the capability of producing an electrical picture signal containing very much greater detail than could be handled by the remainder of the apparatus then in use (amplifiers, modulators, etc).

This is an important and interesting point for the reason that the chief defect of television pictures has been the lack of detail which could be reproduced, and one of the greatest, if not the greatest, factor which resulted in this state of affairs had been the limitations of the older mechanical methods of scanning the picture. But now, with the development of the electron camera type of tube, the position has been virtually reversed. Speaking of the period immediately prior to the War, the situation was one whereby the clarity and detail of the received picture was limited mainly by the inability of the circuits in both transmitter and receiver to handle, without distortion, the wide band of frequencies which (as the student will appreciate after studying later lessons) is necessary for reproduction of a high quality picture. Then came the War, causing the closing down of television services in Europe. For six or so years, very little, if any, direct research or development was carried on in connection with television. But remember the saying; "It's an ill wind that blows nobody any good". With the war came a tremendous impetus to the development, in all major countries, but mainly in England and America, of that miracle of modern science, Radar (or Radio Location). In England, secretly, research had been carried on in connection with Radio Location for several years, and the device was in practical operation around that Island's coast before the war commenced. But up till this time more or less conventional components and amplifying circuits were in use. With the immediate peril to England on the outbreak of War, the best brains in electronics and physics in England (and slightly later, in America) were mobilised, working with almost unlimited funds to develop Radar to the highest pitch possible. Now the general principle of Radar is quite different from that of Television, but the point is, that those war years have seen the development, in connection with Radar, of just those types of components (particularly amplifying, oscillating and cathode-ray tubes) and circuits for which we have been waiting for the further perfection of television. And so the future appears to hold great promise from the technical viewpoint. With the application of these new circuit techniques at both transmitting and receiving ——

ends, the full potentialities of the electron camera type of television tube (which itself will undoubtedly undergo further development) will be realised. We can look forward to the day (probably sooner than most of us might expect) when television pictures will be equal to the best ever thrown on to a cinematograph screen.

In tracing the history of television, we have kept our eye (as have most of the experimenters and scientists engaged in the science) on the development of a clear black and white picture for the home receiver. There have been, however, several other aspects of television which have claimed the attention of many of the notable pioneers, including Baird. These include large screen television (whereby the image is projected onto a large screen such as in a cinema theatre), television in natural colour, television giving pictures having a stereoscopic effect in giving the effect of depth in the image, wired television for telephones, and finally Baird's Noctovision. We shall take those developments in turn, and say a few words about each.

Large Screen Television:- The main difficulty here is to find means of projecting the image with sufficient illumination on to a screen of picture theatre dimensions. Some success however, had been achieved before the war. At least one London theatre provided television on the normal motion picture screen. The Coronation procession was televised and screened thus in London in 1937. The apparatus is very costly, and the trend will probably be to fit out one theatre in each large city in which only scenes of great national interest or importance will be screened.

Colour and Stereoscopic Television: Baird has achieved some success in obtaining pictures in more or less natural colours. As in technicolour films, three basic colours are used, those when blended in varying proportions are made to produce an almost unlimited range of shades. Stereoscopic television produces "3 dimensional" images similar to those which you may have seen on the films as a novelty (remember wearing the coloured glasses?). This development is still well within the experimental stage only.

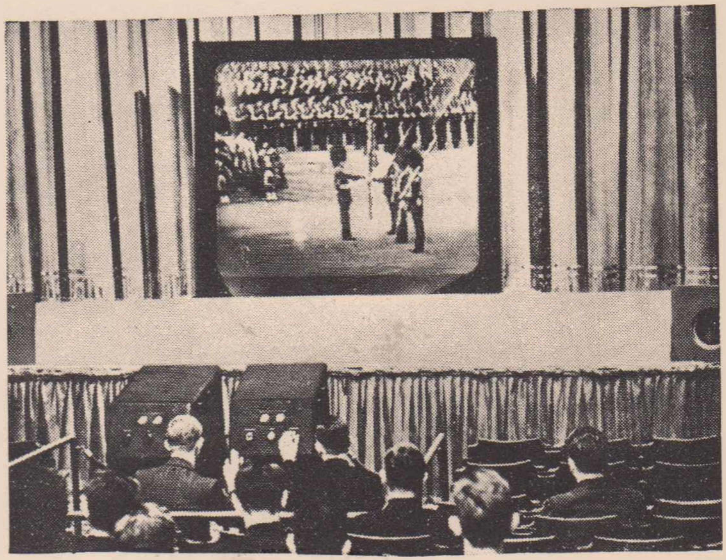


Fig. 11.
Reproduction on the screen of a London Theatre.

Television Telephone Service: This was developed in Germany before the war, and enabled persons miles apart, not only to converse with but also to see each other. Whether the utility of such a service, once the novelty appeal had worn off, would be sufficient to claim the demand of the public (an essential in all commercial propositions) is doubtful. One could visualise many objections to such a service. How much easier it is to "tell off" a person over the phone when you cannot see him (or her)! Think, too, of the delay you would be occasioned should you phone your latest lady friend when she was in the bath! Probably the greatest usefulness for the service is its ability to enable the signing of a legal document to be witnessed at a remote point.

Baird's Noctovision: About 1928, Baird succeeded in televising a subject while sitting in darkness. He made use of the fact that most photo-electric cells are affected by infra-red rays, which, however, have no effect on the eye. Of course the picture was reproduced at the receiving end in visible light rays. This idea may have possibilities from the point of view of navigation in fog. Infra-red rays will penetrate fog of sufficient density to blot out completely the visible light rays upon which ordinary sight depends.

Elements of a Simple Television System: Before temporarily leaving television to introduce you to Frequency Modulation Radio, let us attempt to give you an overall view of a simple television system. We will not attempt to explain the detailed operation of any section of the transmitter or receiver, but will simply state its purpose and what it does. Here an excellent analogy or comparison may be drawn with an ordinary radio communication system.

Where Television is like Radio Telephony.

The easiest way to get a clear insight into television is to compare its workings with the workings of sound radio. It is fortunate that there is nothing to "unlearn", that all the rules and laws applying to sound radio apply also to television or to "sight" radio.

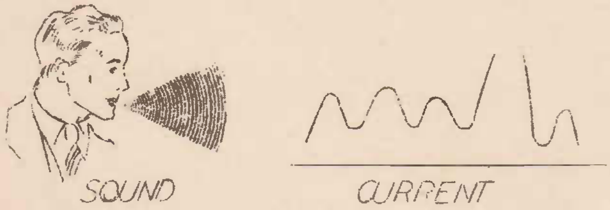


FIGURE 12.

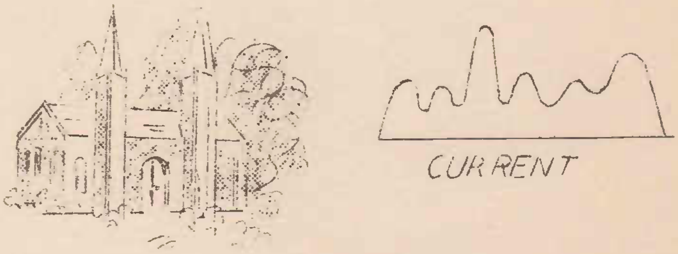


FIGURE 13.

The difference between sound radio and television is that we deal with sounds in the one case and in the other we deal with lights and shadows which make up a picture.

In radio telephony we take the sounds apart. For example, a voice consists of changes in air pressure which might be represented as at the left in Fig. 12. These changes in air pressure produce corresponding changes in electric current through the microphone and the currents are represented as at the right in Fig. I2. The sounds have been broken down into changes of electrical current.

These current changes persist throughout the whole system until they reach the loud speaker. In all parts except the microphone and the speaker we are concerned with changes in electrical current and voltage - we are not concerned directly with sounds. We don't transmit sound; we transmit nothing but electrical effect.

In television we actually take the pictures apart. If the objects or the people are in motion, this motion corresponds only to a series of rapidly changing pictures, so it is possible to consider each picture separately and take it apart separately.

Whereas the voice in Fig. I2 is made up of numerous changes in air pressure or air "density", the picture of Fig. I3 is made up of various degrees of light and shadow or of various densities of shading.

The first problem in television is to change the lights and shadows of the picture into rises and falls of electric current. Then the picture has been made to take an electrical aspect something like that in Fig. I3 at the right.

Earlier in this lesson you got an inkling of how the Nipkow disc together with a photo-electric cell created a varying electric current corresponding to the varying light and shade of different portions of the picture. The current graphed in Fig. I2 is, as you already know, called an audio current, because it is the electrical counterpart of a sound wave. The current may be called a "picture" current, but it is better known as a "video" current. It is a current produced so as to simulate or follow the variations in light as the scene is scanned. Note that in the television system, the microphone is replaced by the scanning disc and photo-electric cell (or in modern systems the television camera).

Referring to Fig. I4, the audio frequency current representing the sound is amplified, and then caused to modulate the R.F. current (set up by an oscillator) by varying the amplitude of the latter at the audio frequency. The modulated R.F. current is then amplified and passed to the aerial where it sets up corresponding radio waves which travel through space. These waves cause a modulated R.F. current to be set up in the receiver aerial. The R.F. current is amplified in the receiver and then passed to the detector, which demodulates it, producing an audio frequency current exactly similar in form to that produced by the microphone. This A.F., after amplification, then operates the speaker, which is simply a sound reproducer, reproducing a sound wave exactly similar (in theory) to the original.

If you now compare the television system (Fig. I4b) with this telephony system you will see that all sections do exactly the same type of job, except the "picture current producer" in the form of the photo-electric cell, together with scanning disc or electron camera (this taking the place of the microphone) and the "picture producer" (taking the place of the speaker) which consists of a variable light source and a scanning disc or cathode ray tube. (More of this later). The video current representing the light variations from different portions of the picture, after amplification is made to modulate the R:F. current from the oscillator.

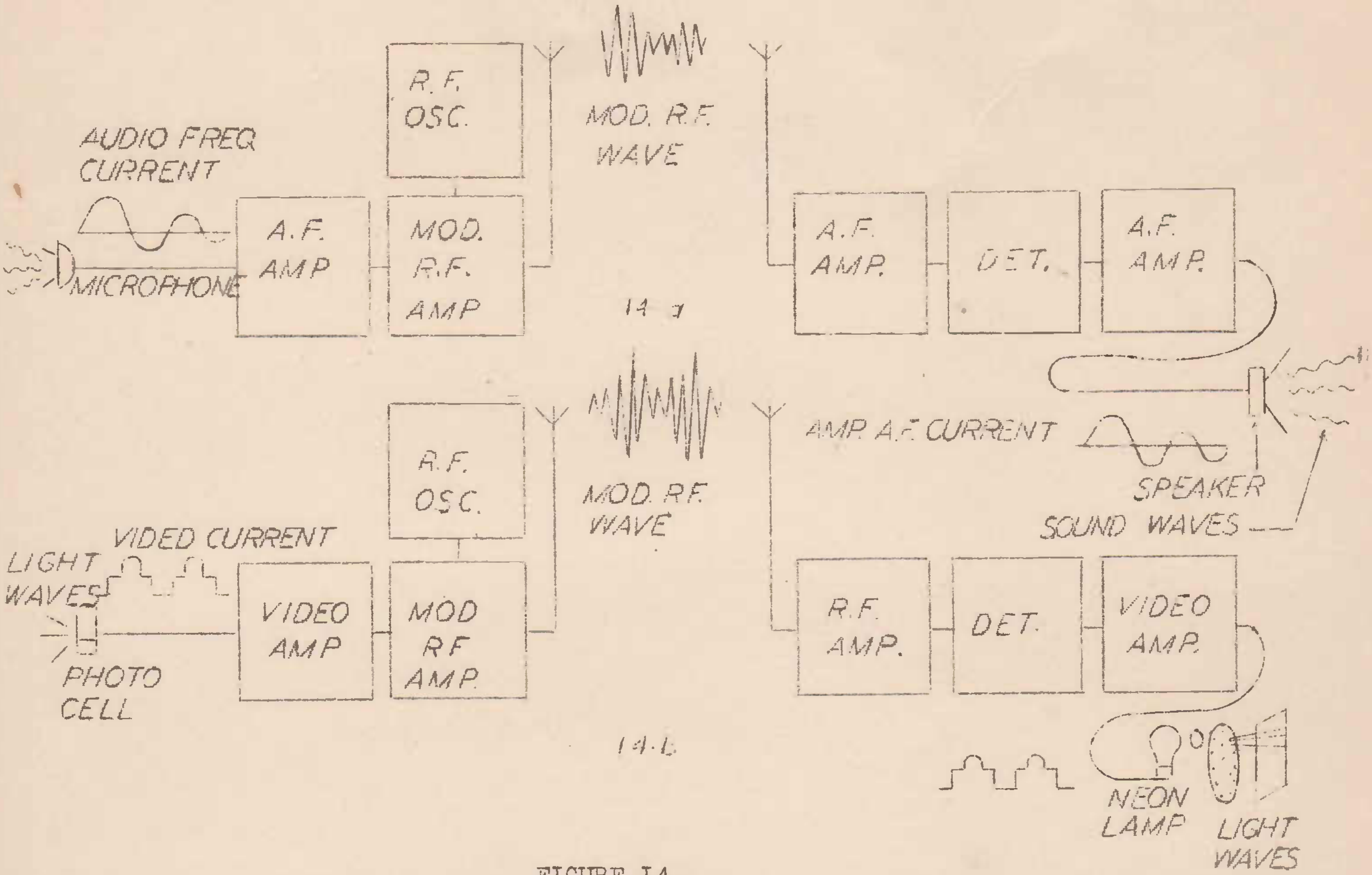


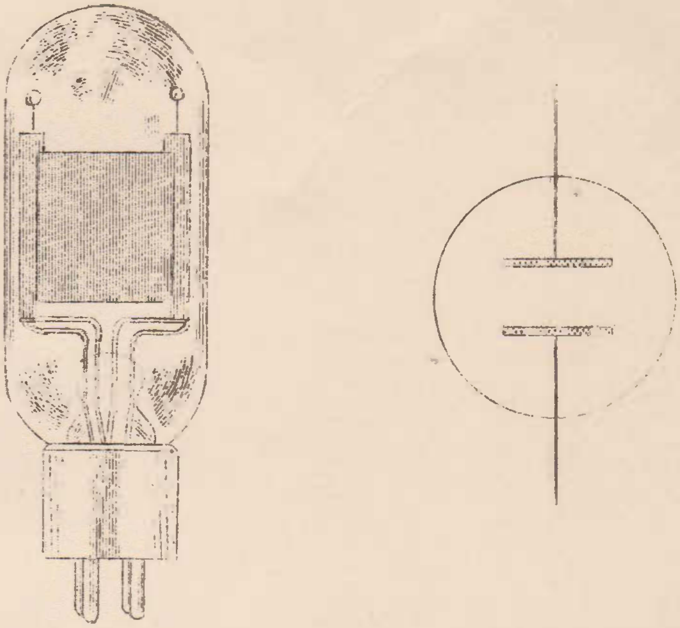
FIGURE I4.
BLOCK DIAGRAMS COMPARING SOUND AND TELEVISION BROADCASTING AND RECEPTION.

This current in the transmitting aerial sends out into space a radio wave, modulated with the video (in place of audio) signal. The television receiver also follows closely the lines of the radio telephone receiver. The detector here demodulates the modulated R.F. wave reproducing a replica of the original video frequency current in the transmitter. This video current must now be made to reproduce the original light variations and hence build up an image of the original scene being televised. This section we may here style "the picture reproducer" (corresponding to the sound reproducer - the loud speaker).

The picture reproducer in our simple crude system under discussion is a Neon Lamp together with a Nipkow scanning disc. The Neon Lamp (see Fig. I5) consists of two metal plates (electrodes) in a glass globe which has been evacuated of air, but which contains a small quantity of the gas neon. When an electrical potential is applied between the plates of the lamp, an electrical discharge takes place through the rarefied neon gas, causing the more negative plate to glow with an orange-pink light. Now the electrical picture (video) signal from the detector of the receiver is applied, after amplification, to this neon lamp in such a way that the brilliancy of the illumination varies in sympathy with the signal. In this way we have reproduced a replica of the light variations which fall on the photo-electric cell as each part of the picture or scene is scanned at the transmitter.

Assembling the Picture:

The simplest method of reconstructing the picture is by the use of our scanning disc set up somewhat as shown in Fig. I6. The television lamp is placed behind the disc in such a position that its plate completely covers the space which may be viewed by an observer looking through any one of the holes in the disc. That is, the height of the plate is such that it extends above the height of the hole which is farthest out, and so that it extends below the hole which is closest in towards the disc's centre.



NEON LAMP AS USED IN OLD TELEVISION RECEIVERS.
FIGURE I5.

A screen or "mask" is placed in front of the disc and through this screen there is an opening which is just the size of the picture to be reproduced. Therefore, the observer's line of sight cannot pass either to the right or left of the picture size or area.

The holes in the disc are sweeping across the space at the back of which is the lamp's plate. The observer will see the glow of the plate through the screen opening and through the disc holes. Therefore, his view is forced to sweep across the plate's surface. At least, his vision really does sweep across the plate surface because everything is dark except the plate surface which glows through the disc and screen.

The observer's line of vision is carried across the surface of the lamp's plate about as shown at the right of Fig. I6 where the enclosed area represents the size of the picture. One hole after another in the disc sweeps across the plate surface until the whole surface has been covered just as it was covered by the scanning beam of light at the transmitter.

If the glow from the plate does not change, the picture area will appear as a dull pink evenly distributed. The color is pink because that is the color assumed by the lamp's plate. But if the amount of light from the plate is changing, then the amount of light seen by the observer will change as the disc holes move from place to place.

If the glow of the plate is bright with a given disc hole in a certain position

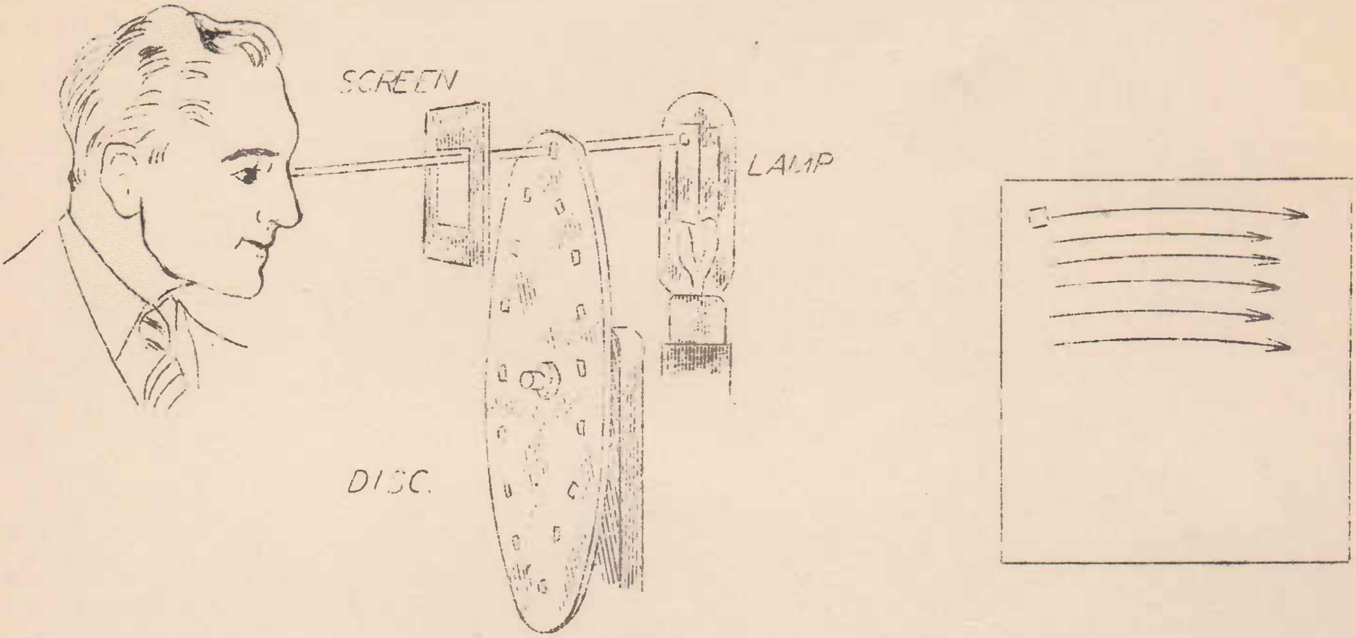


FIGURE 16.

that particular position will appear bright to the observer. Then if the glow is reduced with another hole in another place that new position will appear darker. Proper distribution of these light and dark places will make it appear that the lights and shadows are distributed over the picture area in a definite pattern, this pattern being that of the lights and shadows in the picture being transmitted. Thus we have reconstructed the scene which is being scanned at the transmitter.

By using a simple lens system the light beam passing through the Nipkow disc holes may be focussed onto a small screen, so that a spot of light scans the latter in step with the scanning light spot at the transmitter. In this way, as the light spot's brilliancy varies in sympathy with the picture signal, the scene is reproduced, and may be viewed indirectly on the screen.

WHY REPRODUCING THE PICTURE IN TELEVISION IS MORE DIFFICULT THAN REPRODUCING THE SOUND IN RADIO TELEPHONY.

In the case of sound transmission each sound, occurring at any moment, even a complex sound such as is produced by a large orchestra is represented by a single current variation (at audio frequency). In the case of transmitting a picture, however, each light variation, causing a single current variation, represents only a single part or element of each picture, a series of which constitute the whole scene. We have seen, therefore, how the picture is scanned, so that the light variations, which make up the whole picture, are dealt with in turn. In this way, the original picture was broken into "elements" which were broadcast separately, and in order. We have seen further how these separate light variations were re-created at the receiver. Now, to produce an intelligible picture, it is obvious that the picture elements be reproduced at the receiver in the same order, and at the same speed. This means that the light spot, falling at any moment, on the receiver screen should occupy the same relative position on that screen as the spot or element of the original picture being scanned at the transmitter. To achieve this state of affairs the receiver's scanning disc must rotate at the same speed exactly as, and in step, with the disc at the transmitter.

The technique of ensuring this desired state of affairs is known as "synchronization". To ensure that the receiver's disc does keep "in step" or "in synchronism" special synchronizing signals are sent out by the transmitter, at regular intervals. These synchronizing signals serve the purpose of slightly speeding up the velocity of rotation of the receiver's disc, if it tends to become too slow, and vice versa.

In modern television systems using cathode-ray tubes, the scanning of the scene is performed by beams of electrons. The necessity for synchronising the electron beam in the receiver's cathode-ray tube with that which scans the image of the scene which is focussed on the television camera's screen, still applies.

Synchronizing signals, which appear as a special regular modulation of the carrier wave are therefore still used. The methods of utilising these signals (which methods are fully dealt with in a later lesson) are, however, purely electronic, and the results achieved are much more reliable than those which could be obtained with the older mechanical methods of scanning. As a matter of interest Fig. I7 is included to show the type of trouble encountered when synchronization is faulty, resulting in pictures drifting across the screen or from top to bottom.

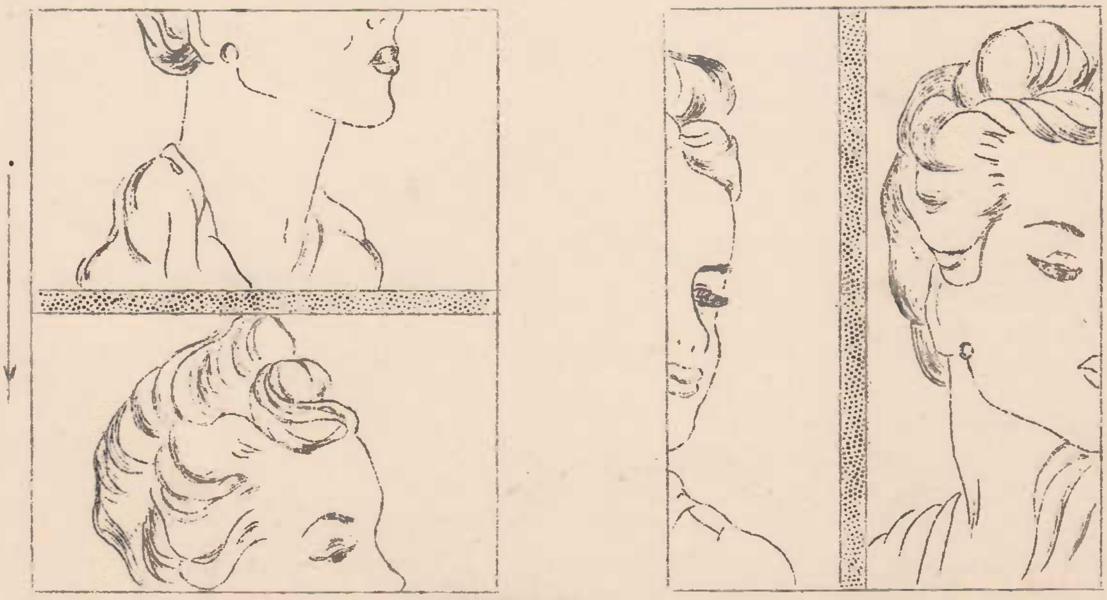
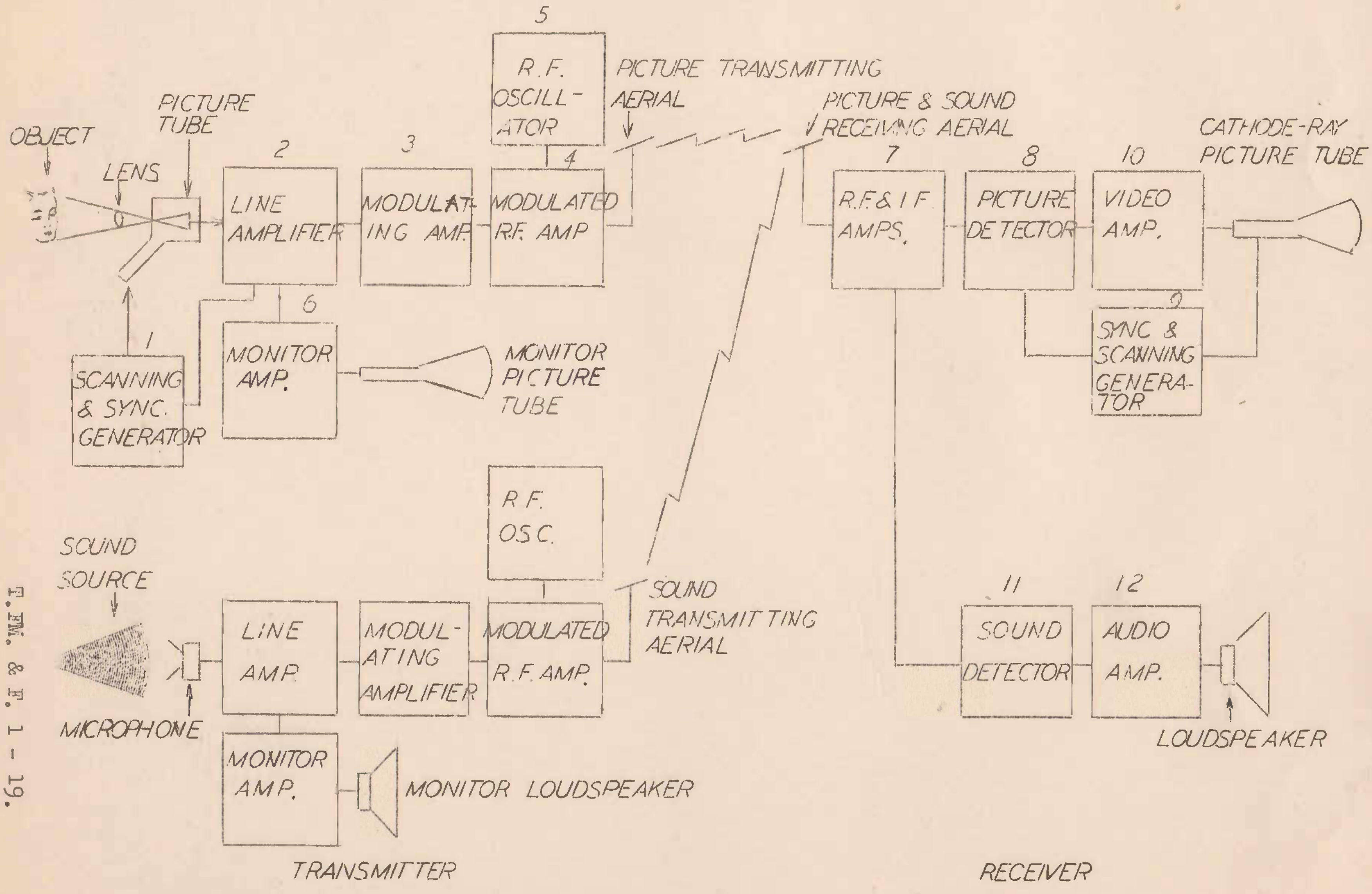


FIGURE I7.
SHOWING ONE EFFECT OF FAULTY SYNCHRONIZATION.

FIGURE 18.

ELEMENTS OF A TYPICAL TELEVISION SYSTEM.



BLOCK DIAGRAM OF A MODERN TELEVISION SYSTEM:

Fig. I8 shows in block schematic form, the overall arrangement, from televised scene to receiver screen, of a modern television system. The associated sound transmitter and receiver are also included. This diagram should be compared with that of the simple system of Fig. I4b.

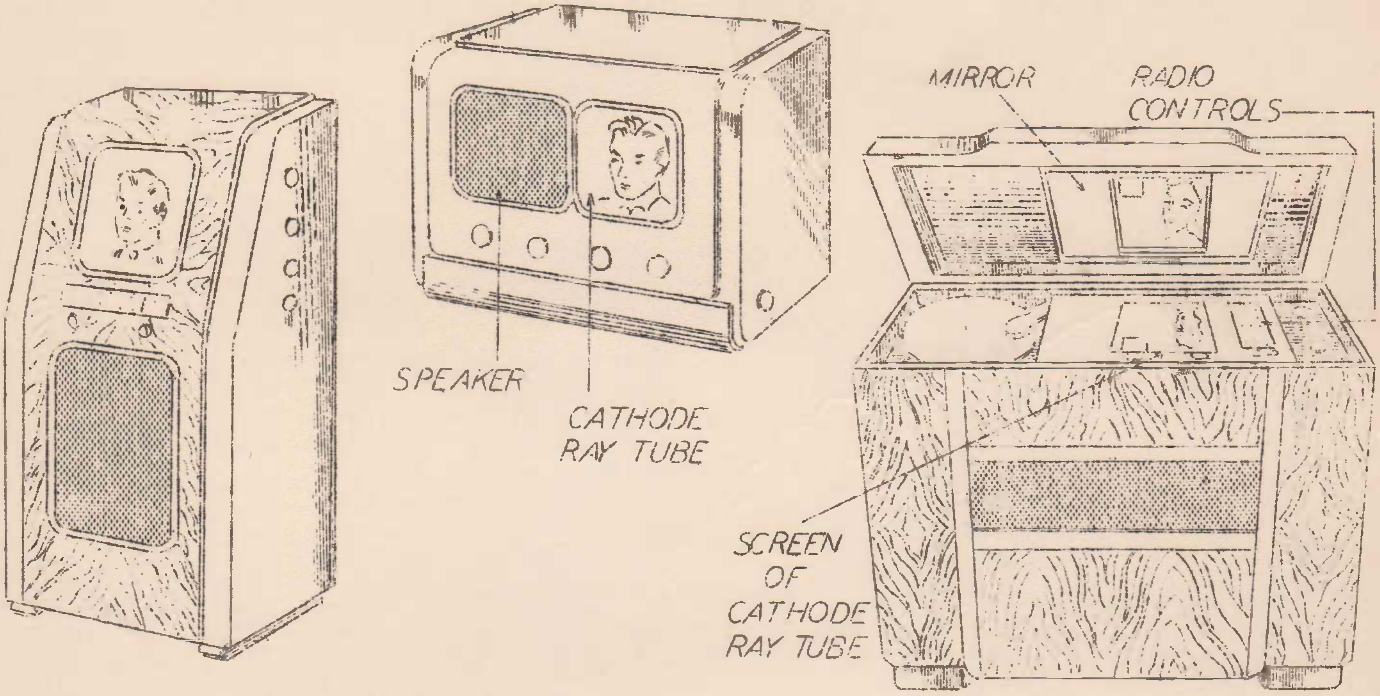
Note that the Nipkow disc and photo-electric cell have been replaced by a modern picture tube, and the neon lamp together with its disc, in the receiver, has given way to a cathode-ray tube. Block (I) is a valve-oscillator which produces alternating voltages, having a special waveform which, when applied to the picture tube, cause the electron beam to scan the image on the screen of the tube. The special synchronizating signals are also obtained from this oscillator and applied to the outgoing wave. Block (2) simply amplifies the electrical picture (video) signal from the picture tube, and may be separated from the actual transmitter by a line of considerable length. Block (3) gives further amplification, raising the level of the signal sufficiently to modulate in block (4) the R.F. carrier produced by block (5). Block (6) is a video (picture signal) amplifier which operates a cathode-ray tube of the receiver type. This gives a reproduction of the scene for monitoring purposes in the transmitter control room.

With reference to the receivers, note that both the vision and sound modulated waves are picked up by the same aerial and applied to the same R.F. amplifier. (It might be remarked here that the sound carrier and picture carrier are not identical, but usually occupy adjacent channels. The first R.F. amplifier is sufficiently broadly tuned to cover both). The picture and sound carriers are separated at Block (7) by using the heterodyne method to produce lower and distinct "intermediate" frequencies. The two signals are henceforward treated separately as shown. Block (8) is the detector which demodulated the picture carrier signal. Note also that at this stage the synchronizing signals are then used to synchronize the scanning generator (Block 9) which causes the electron beam in the cathode-ray tube to scan the screen. Returning to the picture signal proper, this is amplified by Block (I0) and the varying amplified voltage applied to the "grid" of the C.R.T. where it varies the intensity of the electron beam. In this way the varying degrees of light and shade, which constitute the different parts of the picture are reproduced on the screen. The sound carrier is detected in Block (II), the audio frequency signals are amplified in Block (I2) and reproduced by the loudspeaker.

In passing, it is opportune to remark that although some technical matter has been included in this, the first introductory lesson, such has been considered necessary. It will be found that a good basis has thus been prepared for the ready absorption of the detailed lesson work to follow.

So now, we come more or less to the present time, when Television has reached a stage where the definition is comparable with that achieved by home movies of the I6 millimetre variety. Of course, there is still a long way to go before the excellence of clarity of the modern 35 M.M. theatre projection film is achieved.

The average picture size in a typical modern Television receiver is of the order of 9" X I2" and this is adequate for most home users.



TYPICAL TELEVISION RECEIVERS.

FIG. 19.

Fig. I9 has been included to illustrate the standard and appearance of typical present-day Television receivers. It is noteworthy that in the elaborate "radio-phonograph-vision" unit the screen of the cathode-ray tube is not viewed directly, but is rather projected onto a mirror in the lid for added convenience and styling. At this point we temporarily leave the fascinating subject of Television, until future lessons, when its intricacies will be revealed, and we come now to the second section of this lesson, which is Frequency Modulation.

SECTION "B". FREQUENCY MODULATION.

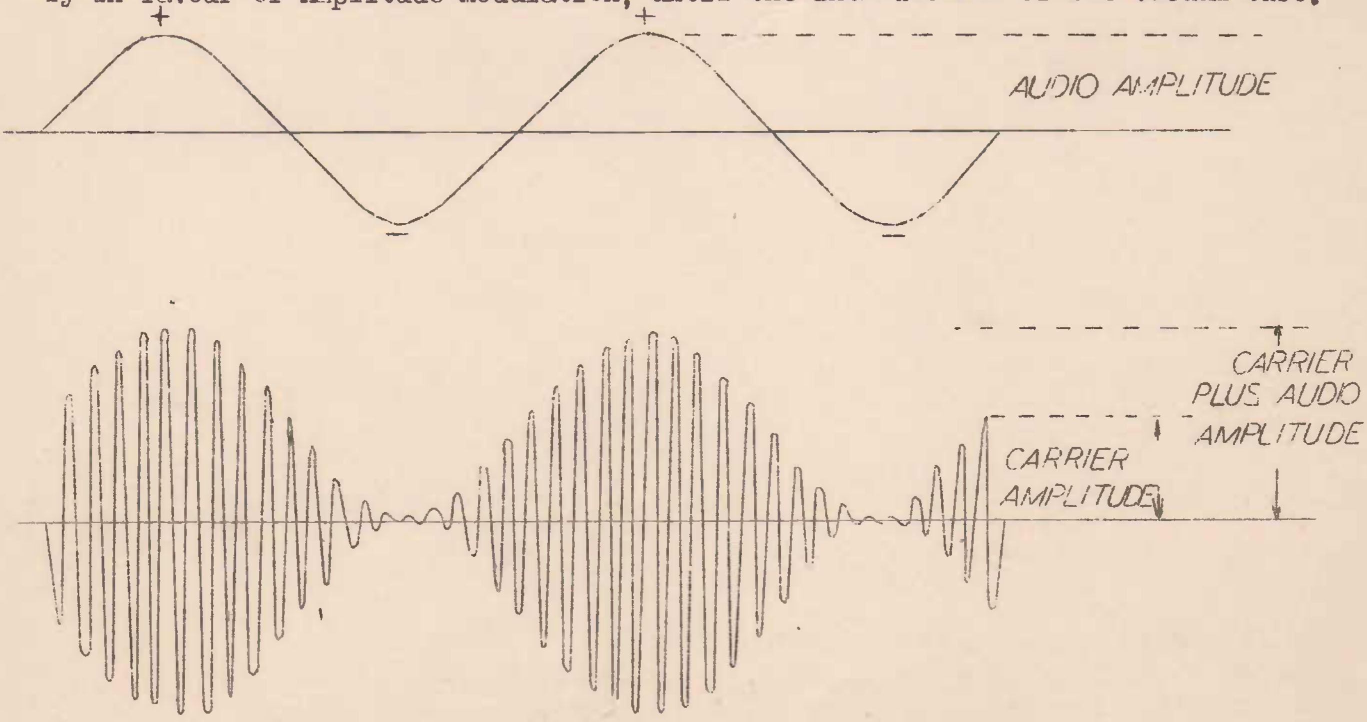
Most people who have ever owned a conventional radio receiver can recall the annoying experience of having their favourite programme marred by interference in the form of static. Additionally, through the years, a continuous striving after greater fidelity of reproduction has been exhibited by engineers engaged on the development and design of domestic radio receivers. As far as "man-made" static is concerned, the position has steadily worsened with the passing of time.

More housewives are acquiring vacuum cleaners and refrigerators to ease their domestic burdens, factories are becoming more numerous and thus interference due to their electric motors and other devices is on the increase. All this is a good sign, in as much as it denotes the diversion of scientific activities to a purpose beneficial to mankind - why, even the mere male may now have an electric razor to remove his daily growth of stubble!

Radio reception, however, is on the losing side, as far as the above advances are concerned, and it is not surprising that an effort has been made to devise some scheme whereby the reception of radio programmes is possible with even greater fidelity and with little or no static to impair the performance, even in city buildings containing moving staircases and elevators. Furthermore, in country districts, reception is oftentimes impossible due to static of natural origin. In non-technical language the results obtained by the use of a system of Frequency Modulation are reduced static and noise together with an increase of possible fidelity.

The whole matter of Frequency Modulation is an old one, as it appears to have had its origin shortly after the invention of the "Poulsen arc", when it was found impossible to 'key' the arc as in spark transmitter practice, and thus some new method of modulation was required.

The idea of varying the frequency of the carrier wave, in order to modulate it, was suggested. Various proposals to achieve this were put forward, but no practical success came of those. Frequency Modulation was, therefore, discarded entirely in favour of Amplitude Modulation, until the introduction of the vacuum tube.

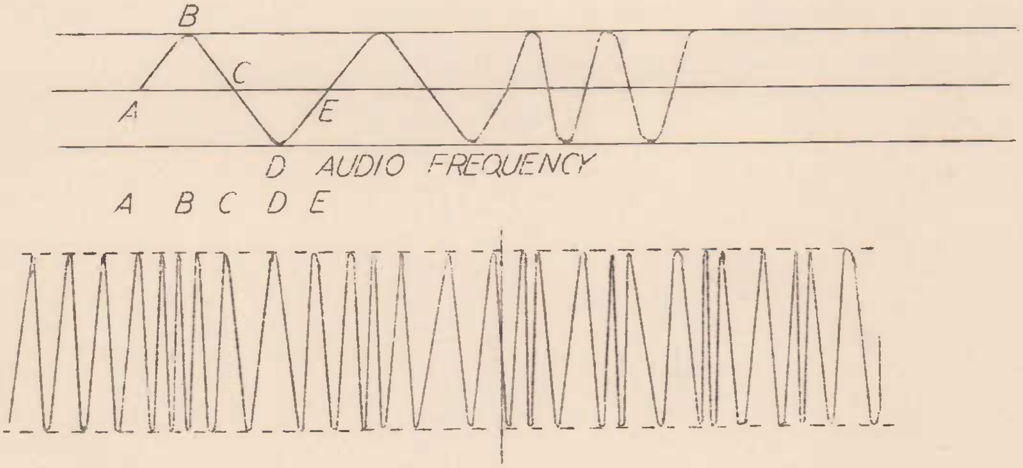


AMPLITUDE MODULATION - CONSTANT FREQUENCY - VARYING AMPLITUDE.
FIGURE 20.

It is considered opportune at this juncture to explain the basic theory lying behind the two most practical methods by which it is possible to impress intelligence at audio frequency, on a radio frequency carrier wave. Firstly, we have the means at present in universal use of Amplitude Modulation, in which the **amplitude** or magnitude of the R.F. carrier is caused to vary in sympathy with the audio frequency modulation. Fig. 20 gives us an idea of what this is all about.

This diagram should strike a familiar note as it has appeared in varying forms in most radio textbooks, and has also been featured and explained in the "A.R.C. Radio Service Course".

The following facts, however, should be kept in mind. When a wave is amplitude modulated, the carrier frequency is held constant while the amplitude only is varied in sympathy with the audio signal. The rate at which the amplitude (or strength) of the R.F. wave is varied is the frequency of the A.F. signal (or pitch of the sound note). The extent to which the Amplitude is varied (i.e. the depth of modulation) represents the amplitude of the A.F. signal (or the loudness of the original sound).
Now with frequency modulation, the amplitude or strength of the R.F. carrier



FREQUENCY MODULATED CARRIER- CONSTANT AMPLITUDE, VARYING FREQUENCY.

FIGURE 21.

wave is held constant, while its frequency is varied or "swung" around its nominal valve at a rate equal to the sound frequency (A.F.). The amplitude or strength of the audio frequency current determines the extent (i.e. the number of cycles/sec.) to which the carrier frequency is varied. Fig. 2I illustrates the nature of a frequency-modulated carrier. Note that the amplitude of the R.F. Carrier remains constant until the A.F. modulating voltage begins to modulate it at "a". Then during the positive half-cycle of the A.F. the frequency of the carrier continuously increases until the A.F. reaches its peak at "b". As the A.F. cycle decreases towards zero at "c" the frequency of the carrier is progressively decreased to its normal or average value (point "c"). During the negative half-cycle of the A.F. modulating voltage a similar action occurs, except that in this case the freq. (R.F.) of the carrier is reduced, for the duration of the half-cycle, below the average or middle value (see "cd" of Fig. 2I). Note that the strength or amplitude of the R.F. carrier remains constant the whole time. This allows the transmitter modulated and power amplifier tubes to be working at their maximum rated powers the whole time, whereas, with amplitude modulation, these tubes are worked to the limit on the occasional peaks of modulation only.

A numerical example will serve to further illustrate. Suppose the carrier has an unmodulated frequency of 40 megacycles/sec. For the loudest sound to be handled (i.e. for I00% modulation), it might be decided to swing the frequency of the carrier between 39.9 mc/sec and 40.I mc/sec, around the mean value of 40 mc/sec. This is a frequency "deviation" of .I mc/sec (or I00,KC/sec) on either side of the average frequency, or a band width of .2 mc/sec (200 KC/sec). The rate at which the frequency is "swung" between these two limits is the audio frequency of the modulating voltage. For example, if a note of 2,000 cycles/sec is being broadcast, then the carrier frequency is varied around its average value at 2,000 times per sec. For a modulating voltage of one-half the <u>Amplitude</u> (i.e. a weaker sound) of the greatest which can be handled, the carrier frequency would be varied between 39.95 mc/sec and 40.05 mc/sec., i.e. a deviation of only .05 mc/sec (50KC/sec). This would represent 50% modulation.

Again, suppose the carrier is to be modulated with a lower <u>frequency</u> sound signal, say I,000 c/sec., in this case the carrier's frequency would be "swung" around its mean value (40 mc/sec) at a rate of I/000 times per second.

Summarizing, the nature of a frequency modulated (abbreviated F.M.) carrier is such that:-

(I) The number of cycles/sec. by which the carrier frequency is deviated from its normal or mean value represents the depth of modulation (intensity of sound).

(2) The <u>rate</u> at which the carrier's frequency is deviated between the two limits on either side of its mean frequency represents the frequency of modulation (i.e. the audio frequency).

With the introduction of the vacuum tube, the idea of Frequency Modulation was revived. By this time the relationship between the band width required and the frequency of the modulating current was well understood in connection with amplitude modulation. It was realised, for example, that to modulate a carrier with audio-frequencies ranging from say 0 to 7.5 Kc/sec. a band width of I5 Kc/sec. is required (due to the generation of side-bands). Now the idea occurred that by using frequency modulation, the band width could be reduced to only a fraction of that required by the older method of modulation. The suggestion was that the frequency deviation of the carrier could be limited to, say, 2 Kc/sec., giving a total frequency variation of only 4 Kc/sec.(as compared with the IO Kc/sec. channel allowed with A.M. methods). It was thought, as the student will also probably think at this stage) that this limitation of band-width would not limit the range of audio-frequencies which could be superimposed on the carrier; for with F.M. a high audio frequency could be made to modulate the wave simply by swinging the carrier frequency over a part or the whole of the 4 Kc/sec. band at the desired rate - a rate to which there was no limit. In this way, it was hoped to obtain high fidelity transmission even though a narrow band-width was used.

In I922, however, Carson published a paper showing, mathematically, that no reduction in band width was possible without a loss in fidelity. Carson showed that a band width of at <u>least</u> twice the highest modulating frequency was required, this situation arising from the fact that frequency modulating a carrier resulted in side-band frequencies being produced in much the same way as occurred with amplitude modulation. This proved that F.M. conferred no advantages from the point of view of fidelity for a limited band width - in fact, it demonstrated that amplitude modulation was the best system from this point of view. Carson finally came to the conclusion that "Consequently this method of modulation inherently distorts without any compensating advantages whatsoever".

As a result of Carson's conclusions F.M. was again practically forgotten until I936, when Edwin Armstrong published a lengthy paper on the subject. This publication was the result of many years research carried out at Columbia University, New York, and the construction of a complete system by R.C.A. in I933-4.

Armstrong's work demonstrated that the chief merit - and this was a very substantial one - of F.M. - was that noise due to "static", man-made electrical interference, and valve "hiss", could be virtually eliminated by the correct application of this new system. This was an aspect of the question not previously considered by other workers. Strangely enough, it was further demonstrated that, although F.M. reduces noise, even when using the same band width as for A.M., the greatest benefit was obtained in this connection by utilising a band width as wide as possible. Consequently, Armstrong employed a frequency deviation as wide as 75 Kc/sec. on either side of the mean carrier frequency - a total band width of I50 Kc/sec. Simple arithmetic will show that only six stations could operate in our present broadcast band (550-I,500 Kc/sec.) if such a band width were universally employed. Moreover, the band width would form too large a proportion of the carrier frequency to allow of the efficient design of selective tuning circuits.

Armstrong's solution to these difficulties was to select a carrier frequency in the ultra-high frequency band. In the experimental system constructed 4I mc/sec. was used. Working at these high frequencies there is ample "room" for these wide band widths.

So effective did Armstrong's suggestions prove to be, that working with a transmitter of only 20 watts power on the Empire State Building in New York and a receiver sixty miles distant, results comparable with the reception of 10,000 watt stations using the conventional system were achieved. Armstrong's theoretical work (the results of which were borne out by practical laboratory tests) shows that, under favourable conditions, F.M. will reduce noise by as much as 1,000 or more to 1.

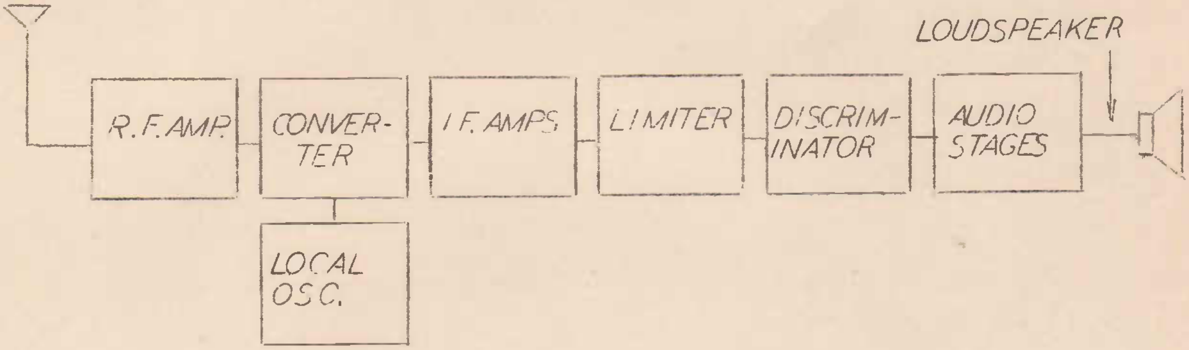
A disadvantage of the system is a characteristic of all ultra-high frequency transmissions, viz., the reception is practically limited to points which lie in a straight line from the transmitting aerial. This means that a transmitter has a line-of-sight coverage, thus limiting the reliable range to 30-50 miles, depending on the heights of transmitter and receiver aerials, and the nature of the land surface. To overcome this a system of narrow band F.M. has been proposed which may possibly find acceptance on the lower frequency bands. Fidelity would suffer here, but, on the other hand, some of the noise reduction properties would be retained to a lesser degree.

Another advantage of the F.M. system which may prove a very important one, is the almost complete immunity of a F.M. transmission from interference created by another F.M. transmission operating within the same wave-band. Provided the desired signal is more than twice as strong as the undesired one, this immunity is practically 100 per cent complete. With amplitude-modulated waves, on the other hand, the desired signal must be at least 100 times as strong as the interfering signal before the latter is effectively "swamped out".

To sum up, then, we can say that F.M. enables the reception of clearer signals less effected by noise and static than A.M. signals, and because of this property of the system small powers only are required. As far as improved tonal quality is concerned, this is incidental only and not due to any peculiar or distinct advantage of F.M. over A.M. The point is that A.M. stations are limited to a band width of 10 Kc/secs., so that the present broadcast band will contain the requisite number of stations, and if this limitation did not prevail, there is no limit to the possible frequency range of the conventional A.M. transmission. Bear in mind though, that to get a good clean signal through a bank of noise a very large radiated power would be required if the system is working on the A.M. principle, but only a small power is necessary to achieve the same thing if F.M. is used. Here then, is a great advantage, as F.M. transmitters may be cheaply constructed and will enable country folk to obtain clear and clean reception regardless of local noise and atmospheric conditions.

Fig. 22 shows in block form the basic circuit arrangement for a F.M. receiver, The similarity to A.M. systems will be obvious, except for the action of items like the limiter and discriminator in the receiver, and the reactance tube in the transmitter. Two separate transmitters have been shown in Figs. 23A and 23B, because there are two schools of thought at the present time on the subject of modulating the frequency of the carrier. The reactance-tube method of F.M. is shown at "A" in Fig. 23. together with the automatic frequency control unit necessary with the reactance tube to maintain the average carrier frequency constant.

The second scheme shown at "B" is somewhat more complicated in its action in as much as instead of a reactance tube a complex 90° phase shifting network is employed in conjunction with a crystal oscillator. This is the Armstrong system at present in commercial use in America.
Further details of these systems are contained in a later lesson.



SIMPLE BASIC RECEIVER FOR FREQUENCY MODULATED CARRIERS.
FIG. 22.

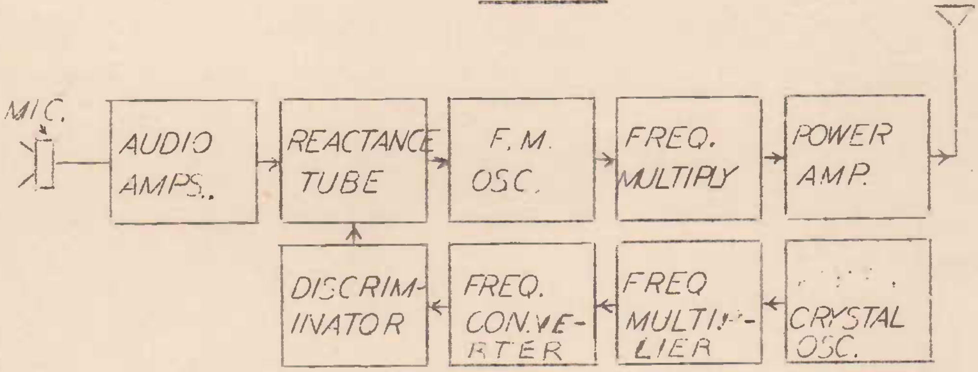


FIG. 23A.

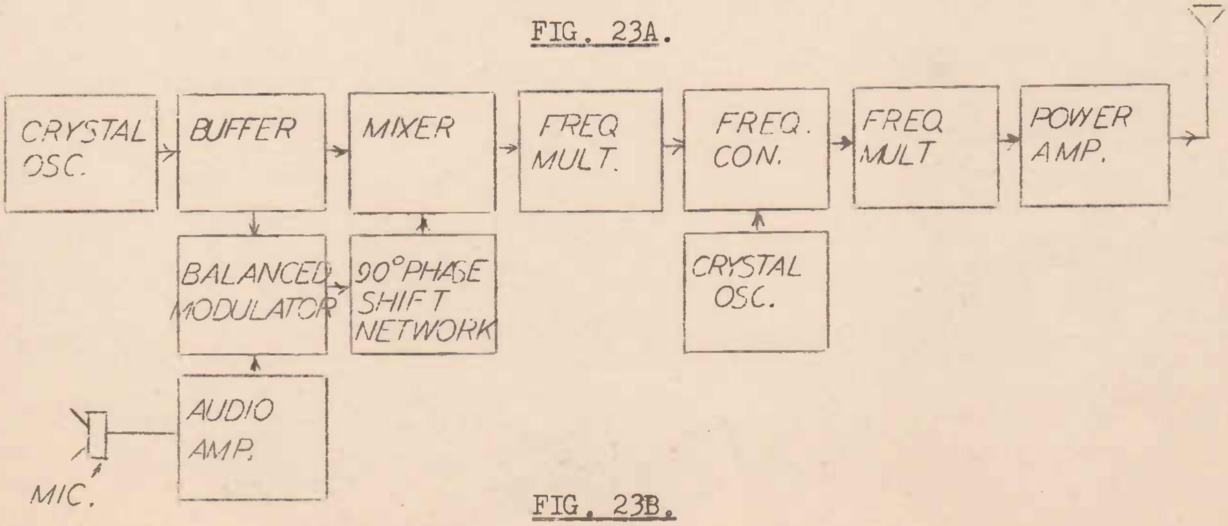


FIG. 23B.

TWO BASIC FORMS OF F. M. TRANSMITTERS.

There will always be both Amplitude, as well as Frequency Modulation, and it is merely confused thinking to assume that either one will entirely supercede the other - rather is it a matter of using the most suitable means to achieve a certain end. There are cases where A.M. has definite advantages over F.M. and vice versa, which state of affairs ensures that both services will develop to everybody's benefit.

SECTION "C". FACSIMILE TRANSMISSION.

Facsimile is a very simple thing to understand as it is almost self-explanatory, in so far as it concerns the reproduction of a newspaper, photograph, postcard, or any other similar item, in such detail that this aforesaid reproduction shall be an exact copy or facsimile of the original. Literally, any object which is a direct and detailed copy of another may be styled a facsimile of it. An Australian pound note is a facsimile of another Australian pound note, and so on.

But - and it's a big But - here we are concerned with copying something by some means in, say, Melbourne, and sending by wire or radio link related electrical impulses, which when picked up by a receiver in, perhaps, Sydney, will reproduce on a paper an exact replica of that something still down in Melbourne. This is what is meant by Facsimile. In America attachments are marketed, which, when fitted to a normal radio receiver, enable the purchaser to have reproduced in his own home, a news bulletin or paper. Mr. Suburban American just turns on the works before retiring for the night and "hey presto!" when he wakes in the morning a neat roll of printed paper is located near his radio receiver.

As mentioned briefly earlier, it is not necessary to have the link between sender and receiver a radio one; in this application wired systems are often used and prove very satisfactory. Actually we have had Facsimile services in one form in use in this country for some time, for example, the Sydney-Melbourne picturegram service, and the overseas radio-gram service operated by the P.M.G's Department and "A.W.A. Beam" service.

As in television, it is necessary to "scan" the picture or diagram in order to set up a succession of electrical impulses corresponding to the various parts or elements of the subject. Now in the case of television, remember, a whole picture must be dissected and reproduced at the receiving end in a small fraction of a second, this being necessary to create the illusion of motion. In facsimile transmission, however, we are not burdened with this time limit, as it is a still picture which is being dealt with. We may say that a facsimile picture bears the same relation to a television picture as does a magic lantern image to that of the cinematograph. In practice a facsimile picture may take anything between a few minutes to one hour to reproduce.

The picture or diagram to be reproduced is usually mounted on some sort of drum as in Fig. 24. Here the drum is mounted on a spindle having a screw thread. A stationary spot of light is focussed on the one end of the drum. As the drum is rotated the spot of light traverses the picture in a spiral fashion, so completely scanning it.

The light reflected from the picture will vary with the light and dark portions as the drum rotates. This varying reflected light produces corresponding current variations in the photo-electric cell.

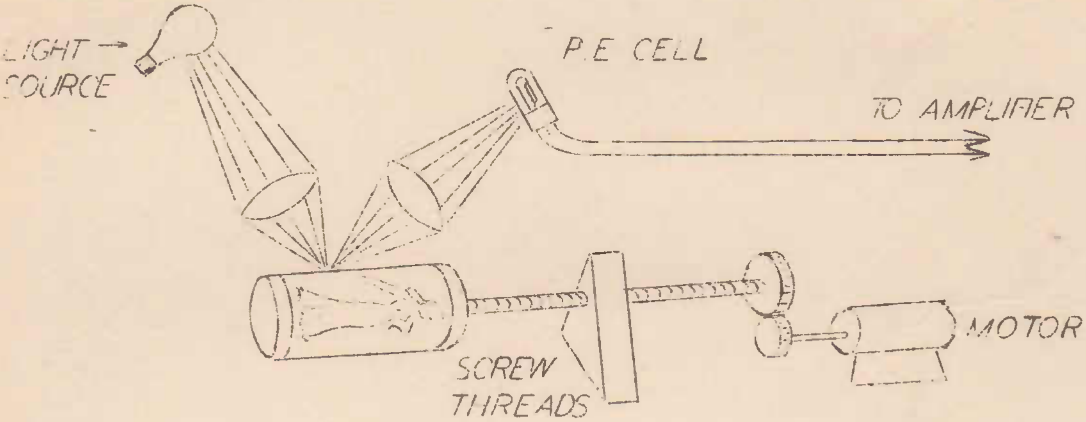


FIGURE 24.

In other arrangements the drum remains stationary, and the beam of light rotates around the picture in spiral fashion. Of course, the result is the same.

The electrical impulses are now amplified and used to modulate a high frequency carrier current which in turn may be carried over a line to the receiver (picture-gram or cable-gram) or caused to radiate a radio wave (radio-gram).

At the receiver, the carrier is detected or demodulated, the resulting current being a replica of that produced by the photo-cell.

To reproduce the picture a similar drum is used as that shown in Fig. 24 at the transmitter. The picture-signal is caused to vary the brilliancy of a light source which is focussed to a spot on a photographic film or paper around the drum. The receiver drum is rotated at the same speed, and exactly in step with the transmitter drum. In this way the light spot traverses the photographic film producing, due to the normal chemical action of such a film, varying shades of light and dark elements in sympathy with the picture current variations.

Where it is desired to send only prints or diagrams, a simplified system is used. Here it is necessary to reproduce two shades only - black and white. The transmitter sends a current for white portions of the diagram, etc., and no current for black. The current used to modulate the carrier in such a system would look something like that illustrated in Fig. 25.

At the receiver, the reproduced signal current is made to operate a stylus. When a current is being received, and for the duration of that current, the stylus

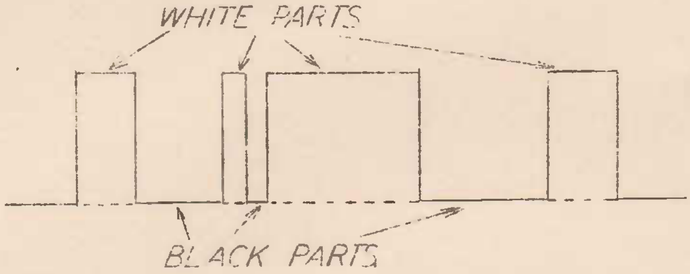


FIGURE 25.

is lifted from or does not act on the paper, leaving it white. When no current is received, the stylus is made to act upon the paper colouring it grey or black.

In this lesson we have investigated the general principles of three interesting new services. Naturally, the comparitively brief and general description of each will set you thinking and puzzling over some of the more intimate technical details. The following lesson papers will deal firstly with television equipment, and then later with frequency modulation and facsimile equipment in considerable detail, so that, as you progress, any points which at present are puzzling you, will be explained.

T.F.M. & F LESSON 1.

EXAMINATION QUESTIONS.

1. What characteristic of the eye makes television possible.

2. Although feasible systems for television were suggested as early as 1880, no practical success was achieved until 1923. Why was this so?

3. The following represent a list of components or sections in an ordinary radio telephonic system. Name the corresponding components or sections in a television system:-
(a) microphone, (b) loudspeaker, (c) audio amplifier, (d) modulator.

4. Explain briefly the meaning of "scanning". Why is scanning necessary in television transmission?

5. What have television and the cinematograph in common as regards the reproduction of moving pictures?

6. Explain briefly the difference between frequency modulation and amplitude modulation.

7. What is the chief advantage of frequency modulation over amplitude modulation?

8. Name one advantage and one disadvantage of "wide-band" F.M. compared with "narrow-band" F.M.

9. What is the main point of difference between Facsimile transmission and television?

10. Describe a simple method of scanning the picture or diagram to be transmitted by a facsimile system.

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NOTE: Write on one side of the paper only.
Always write down in full the question before you answer it.
Answer the questions as fully as you can, giving complete explanations and sketches wherever possible.
Remember that you learn by making mistakes; so give yourself an opportunity of having your mistakes found and corrected.
Don't hesitate to ask for further explanation on any point, we are always ready to help you.

AUSTRALIAN RADIO COLLEGE

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TELEVISION, FREQUENCY MODULATION & FACSIMILE COURSE

LESSON 2.

SOURCE OF SIGNALS.

WHY TELEVISION IS TECHNICALLY MORE DIFFICULT THAN SOUND TRANSMISSION:
In Lesson 1 we discussed some of the difficulties which faced the early workers in television - difficulties which were long realised by many of them before even the crudest of solutions were practically devised.

Nipkow, for example, in 1884, clearly saw that it was not possible to transmit in one piece a complete picture or scene (even though no motion was involved). It was his brain-child to deal electrically with each portion of the picture in turn, by the method known as "scanning", which was made possible by his famous disc. Thus, the general principle, which rules the operation of all modern television systems, was established, at least in a theoretical way.
Prior to this date the photo-electrical properties of selenium (made use of in the selenium photo-electric cell) had been discovered. Hence, a method was immediately available to Nipkow and others for converting the varying light impulses to corresponding electrical changes.

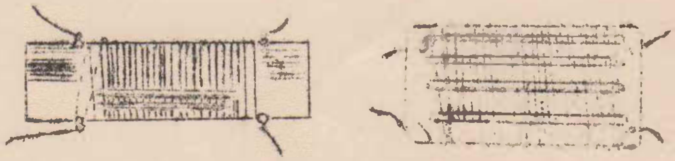
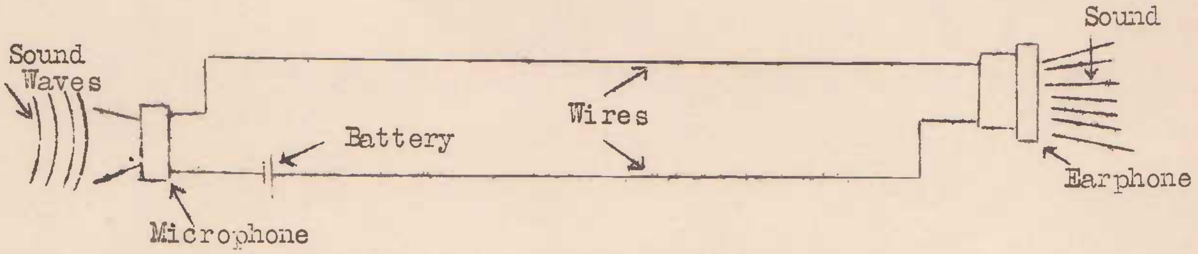


FIGURE I.
Two early types of Light Sensitive Cells. At the left, strips of selenium are placed across two spirals of wire lying in grooves in an insulating tube. At the right, the wires are wound over the strips of selenium placed on a flat card.

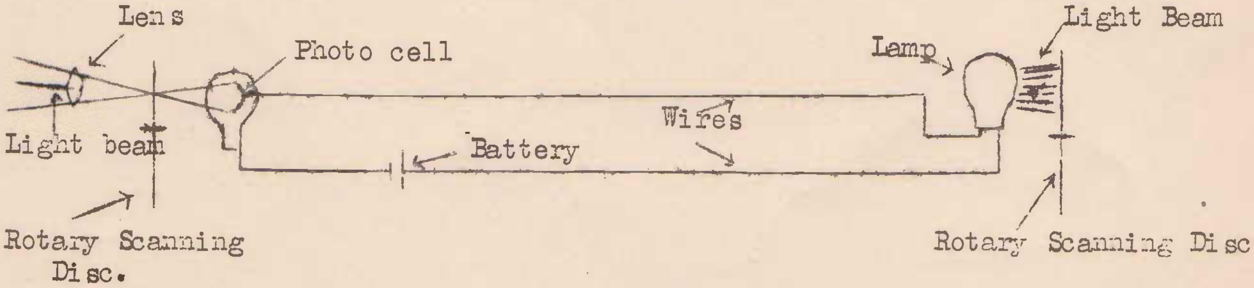
So, even at this early date, it appeared to be theoretically possible to transmit these electric current impulses at least over wires to a distant point where, if the current changes were converted back into light variations, in the correct order or pattern, the picture could be re-created, element by element.

The reason why no success was achieved was due to the fact that the "picture-signal" output from the photo-cell was too minute to serve any such useful purpose.

It was not until some years after the invention of the amplifying thermionic valve (in 1914) that practical success was achieved by Baird and others. The student should observe that the lack of means for amplifying an electrical signal was the difficulty which for many years baffled all workers in the television field. In the field of sound telephony, on the other hand, this absence of amplifying methods did not prevent the realisation of practical success. The electrical audio frequency output from the simplest of microphones is sufficient, when transmitted through wires (at least for a short distance) to



A SIMPLE PRACTICAL TELEPHONE SYSTEM.



A SIMPLE "WIRED" TELEVISION SYSTEM - NOT PRACTICABLE

FIGURE 2.

operate an ear-phone.

The problems in television, however, have deeper roots than those already discussed. These problems are bound up with the nature and characteristics of the eye itself. It is comparitively simple to "fool" the human ear (or rather the sense of hearing) by means of an artifically reproduced sound. For example, although the human ear is sensitive to sound waves lying in frequency between about 16 cycles/sec. and 15,000-20,000 cycles/sec., the sense of hearing is very well satisfied indeed if a radio loudspeaker reproduces only those frequencies lying between 50 cycles/sec. and 7,500 cycles/sec. (this representing the performance of a high-fidelity wireless set). As a further example of the lack of discrimination of the ear, it is of interest to note that ear detects no undesirable effect if the phase relationship between different sound frequencies are altered during transmission. In television, on the other hand, phase changes in transmitter or receiver produce an effect in the reproduced scene which are readily perceived by the eye.

The position may be summed up simply by saying that television apparatus (at both transmitting and receiving ends) necessary to transmit a picture which is reasonably good to the eye must be much more perfect technically than the corresponding radio telephony apparatus used to transmit a sound with which the less critical ear will find no fault.

One of the major technical difficulties in television is to devise means to produce at the transmitter an electrical picture signal of sufficient quality to represent adequately the picture or scene to be televised. It will be the object, therefore, of this lesson, to discuss and explain the principles underlying the generation of this picture signal.

Before we can intelligently study the technical aspects of this problem, however, we must fully realise the nature of the job which we are tackling. We must know what the human eye demands of an artificially reproduced picture or scene if the desired degree of realism is to be experienced.

Now we all realise that the eye allows us to "see" by utilising light waves. We are so familiar with light, or rather the effects and sensations which light produces in our minds, acting per medium of our eyes, that we rarely stop to contemplate its true nature. The first question, therefore, is

<u>"WHAT IS LIGHT?"</u>: Light is an electromagnetic form of energy which travels through space with a wave-motion. This definition will be made clearer if it is stated that light waves are of exactly the same <u>type</u> as radio-waves. What then is the difference between light and radio waves? The difference is one of frequency and wave-length only. This difference, however, is an extremely great one. Light waves bear a very much higher frequency and shorter wave length than have radio waves.

For Radio communication purposes electro-magnetic waves lying in frequency between 550,000 cycles/sec. (550 Kc/sec.) and, say, 40,000,000 cycles/sec. (40 mega-cycles/sec.) are in use. The wave lengths of these range from 550 metres down to 7.5 metres. The visible light waves, on the other hand, have frequencies lying between about 400,000,000 mega-cycles/sec. and 800,000,000 mega-cycles/sec. The wave lengths corresponding to these frequencies are .00000075 metres and .00000037 metres.

Note how vastly different these are from the corresponding values for radio waves.

It may be of further interest to note that radio and light waves are not the only examples of electro-magnetic radiations. We have, in addition: - Cosmic Rays (which have their source somewhere in space outside the earth's atmosphere); X-Rays (used for medical and industrial purposes); Ultra-Violet waves (not visible, but to which most photographic plates are sensitive); Infra-Red waves (used for special photographic and other purposes); and ordinary Heat waves. Fig. 3 will show clearly how all of these are related from the frequency point of view. It should be noted that the visible light waves form a comparitively small band of frequencies in the whole range from the lowest (Radio Waves) to the highest (Cosmic Rays). We may say that the eye can see only the light-waves because its construction is such that it is sensitive only to these particular frequencies.

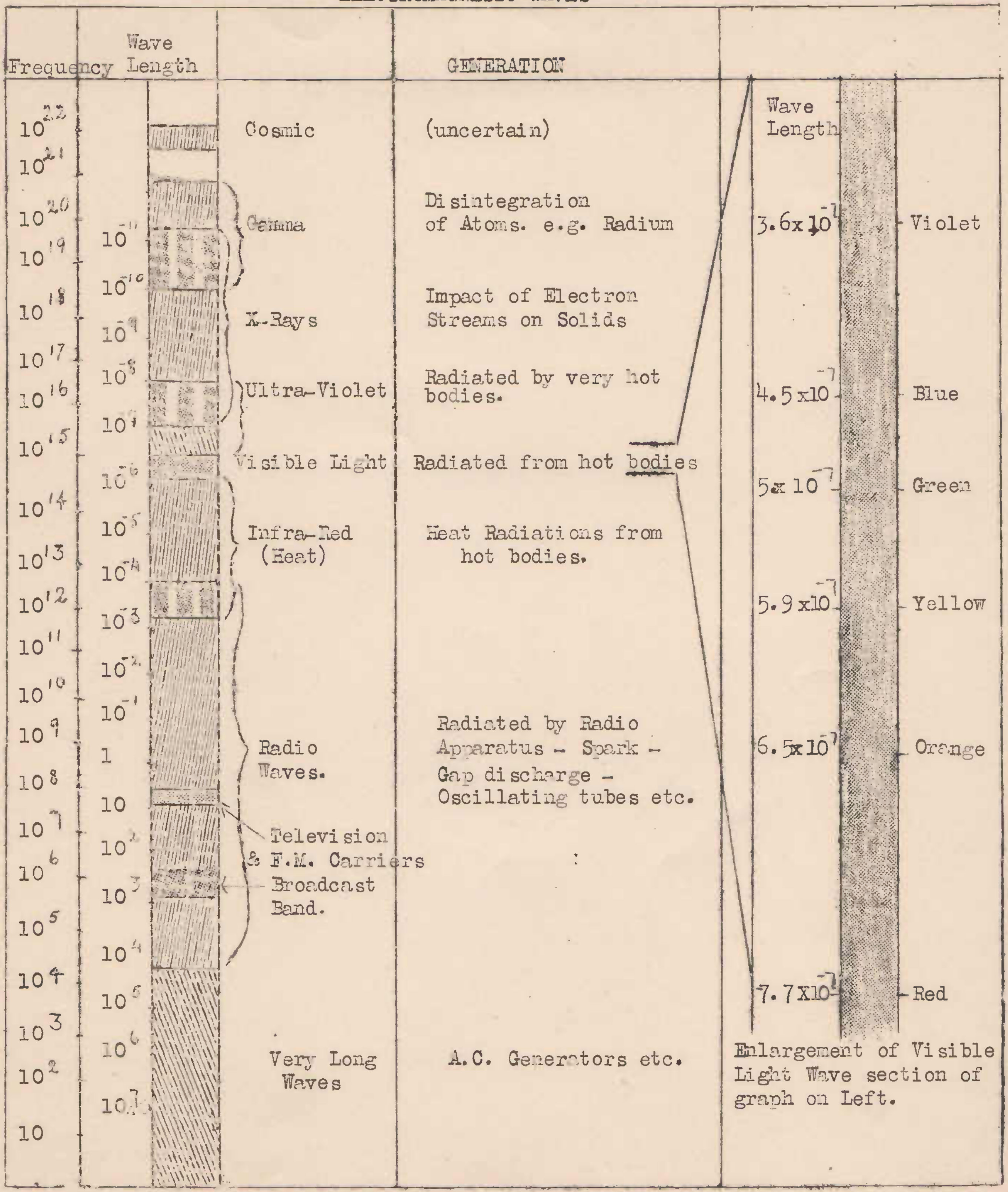
WHAT IS COLOUR? The colour of a light wave depends upon its frequency. Fig. 3 shows that the lowest frequency light-wave to which the eye can see is red. The highest frequency light-wave is violet. The other main colours; orange, yellow, green blue, have gradually increasing frequencies in that order. The strength or intensity of a light wave should not be confused with its frequency (colour). A strong light of some particular shade of red will have the same frequency as that of a weaker light of the same colour.

WHAT IS WHITE LIGHT? White light is a mixture of light waves of all colours (frequency) in the proportion they appear in natural sunlight. The incandescent filament of an electric light globe sets up light waves of all colour frequencies in approximately this proportion.

WHAT IS BLACK? Black is not really a colour at all, but the absence of all light. A black object is one which reflects to the eye no light whatsoever. Since all objects reflect some light, no object is absolutely black. The proverbial black cat in the coal-mine at midnight would probably be the nearest thing to a black object !

WHY DO DIFFERENT OBJECTS APPEAR TO HAVE DIFFERENT COLOURS? When white light (a mixture of all colour frequencies) falls on a surface, that surface might reflect equal proportions of all the colour frequencies, and we would say the object is white. Another surface might absorb all colours in the white light except red, which it reflects. Since the reflected light which strikes the

ELECTROMAGNETIC WAVES



FREQUENCY IN CYCLES/SEC — WAVELENGTH IN METRES

$10^{4} = 10{,}000$ etc — $10^{-4} = \frac{1}{10{,}000}$ etc.

FIGURE 3.

T.FM & F/ 2 - 5.

eye is red, we would say that red was the colour of the object. A blue surface would absorb all colours in the white light except blue, which it reflects to the eye, and so on.

<u>THE FUNCTIONS OF THE EYE</u>: When we look at a picture or scene light waves of different colours and intensities, which are reflected from the various elements or details of the scene, enters the front of the eye, where a lens (Fig. 4) focuses them on the retina to form an image of the actual scene. This action is similar to that of a camera (see Fig.9 later in the lesson). The retina is a sort of screen covered with minute nerve ends, each of which convey separately to the brain the sensation of light intensity and colour. Thus all the details of the scene may be taken in simultaneously. The chief functions of the eye are:-

(I) The ability to distinguish between degrees of light and shade, i.e. to evaluate different light intensities;

(2) The ability to distinguish detail in the scene, each detail being dealt with by a single, or small group, of nerve ends on the retina;

(3) The ability to distinguish colour;

(4) The ability to distinguish motion in the image;

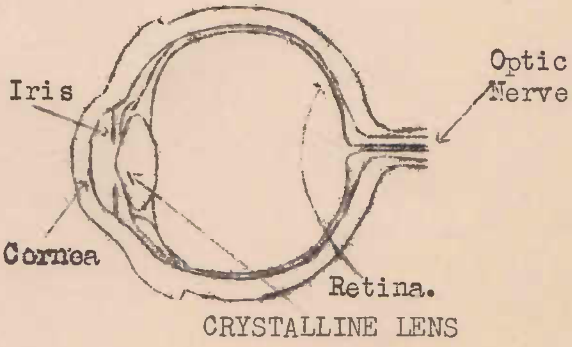
(5) The ability to distinguish "depth" in the scene.

<u>WHAT DOES THE EYE REGARD AS ESSENTIAL IN AN ARTIFICIALLY REPRODUCED PICTURE</u>? To achieve some sense of reality in reproducing a scene by artificial means, which is our problem in television and in cinematography, we must give attention to:-

(I) Reproducing considerable detail;

(2) Reproducing considerable variations in light intensities, i.e. in light and shade;

(3) Creating the illusion of motion.

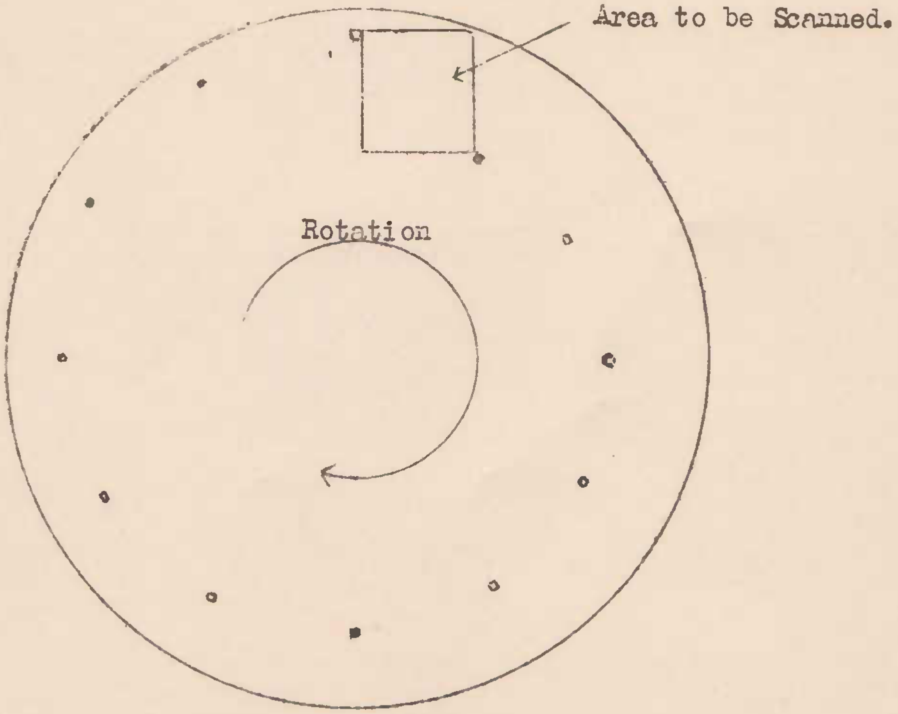


<u>THE EYE.</u>

<u>FIGURE 4.</u>

The technique of generating an electric current which can be "carried" to a distant point where it can be used to reproduce these essentials in an image of the actual scene, will form the subject matter of the remainder of this lesson.

It will be noted that colour and "depth" are not considered essential for a sense of realism. This statement is justified by experience in cinematography, where considerable realism can be obtained in ordinary "black-and-white" images. Of course, colour, if natural, adds to the realism, as does depth (as those of us who have seen the experimental "steroscopic" films will well realise). It might be remembered here that both colour and depth or stereoscopic effects have been realised in television, but the technical difficulties are considerable. Some description of the methods used to produce these effects will be given in a later lesson.



SCANNING DISC -- SHOWING POSITION OF HOLES IN RESPECT TO EACH OTHER AND TO SCANNED AREA.

FIGURE 5.

THE SCANNING DISC:

In Lesson I, we described briefly how the Nipkow Scanning Disc, in conjunction with the Photo-Electric Cell, could be used as a source of picture signal. We shall now examine in more detail the operation of this disc, in order to assess its efficiency, and to give a better understanding of the technique of breaking up the picture or scene into small sections or elements in the process of creating the electrical signal in the transmitter.

A plan of a simple scanning disc is given in Fig. 5, showing the spiral arrangement of the holes. Note that each hole is closer to the centre of the disc compared with the previous one by a distance equal to the width of the hole. This is necessary in order that the strips of the picture scanned by the spot of light from successive holes lie adjacent to each other, as shown in Fig. 6. There should be no overlapping of the scanned strips, for this will result in a distorted reproduction at the receiver. Neither should there be gaps between adjacent strips as this will result in portions of the picture being entirely missed, with consequent loss of detail.

Since the first (outermost) hole of the disc scans a roughly horizontal strip at the top of the picture and the last hole scans a strip at the bottom of the picture it is evident that the whole picture is scanned by a number of strips exactly equal to the number of holes in the disc. Futhermore, a complete scan will be achieved in one revolution of the disc. These facts will be made clear by reference to Fig. 5. As one revolution is being completed the innermost scanning hole will be just finishing its scanning strip at the bottom right hand corner of the picture. At this moment the first scanning hole will be about to commence its excursion across the top of the picture, beginning at the top left-hand corner.

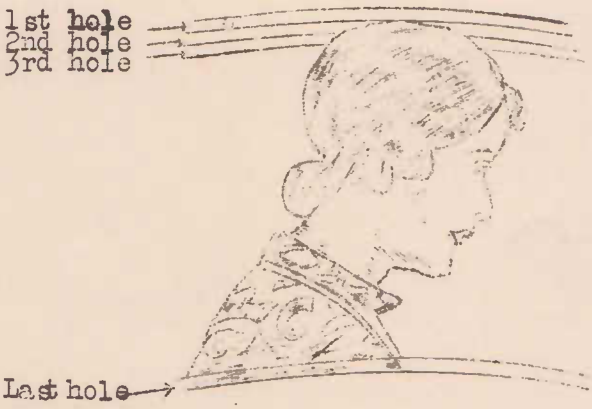


FIGURE 6.

Another important point to notice is that the distance between successive holes around

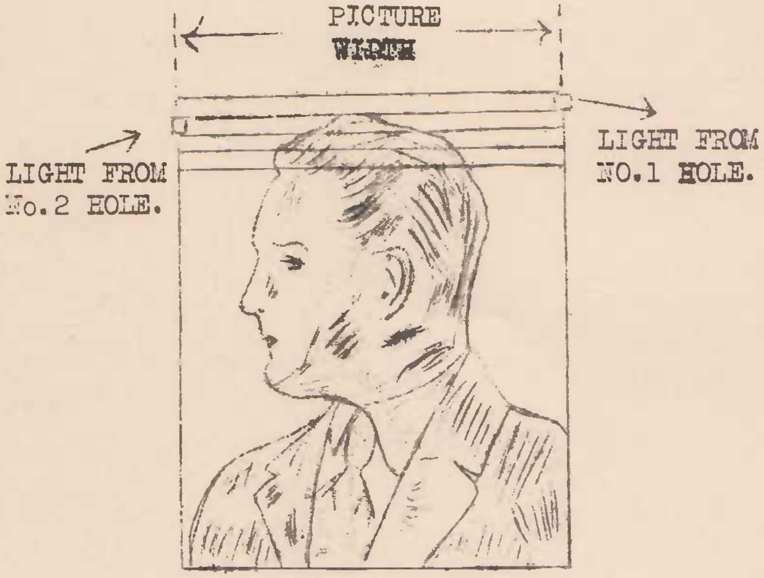


FIGURE 7.

the disc is equal to the width of the picture. Suppose we are scanning the picture of Fig. 7, the light spot from hole one has just finished its sweep across the picture and is leaving the right hand edge. At this instant the light spot from hole number two is just commencing its sweep at the left hand edge. The two spots must not be on the picture at one time, because the photo-cell must not be affected by two areas at one time. On the other hand, there must be no appreciable gap of time between the leaving of one spot and the coming of the next, for this would represent a waste of scanning time. Therefore, the separation between holes is the width of the picture or of the frame as shown in Fig. 5. There is a final fact concerning the "geometry" of the scanning disc. The difference between the distances of the first hole and the last hole from the centre of the disc is equal to the height of the picture or "frame". This is evident from Fig. 5, where a rectangle representing the frame is shown superimposed on the disc. Fig. 6 will, perhaps, make this point clearer. The first hole is at such a distance from the disc centre that it scans the top edge of the picture. The distance of the last hole is such that its light spot scans the bottom edge of the picture. So the difference between these two measurements must be the picture's height.

Summarising these points in the disc's construction, the following should be remembered as they will be referred to later in discussing the limitations and disadvantages of mechanical methods of scanning:-

(I) The number of strips or lines by which the picture is scanned is equal to the number of holes in the disc.

(2) The number of complete pictures or "frames" scanned per second is equal to the number of revolutions made in one second by the disc. For example, to transmit, say 25 pictures per second, to give the illusion of motion in the scene, the disc must rotate 25 revolutions per second, or 25 X 60 = 1,500 revolutions per mi[illegible]te.

(3) Adjacent holes must be separated by a distance equal to the width of the picture.

(4) The difference in the distances of the first and last hole from the centre of the disc is equal to the height of the picture.

METHODS OF USING THE SCANNING DISC. AT TRANSMITTER: The method used for scanning large pictures or scenes is illustrated in Fig. 8.

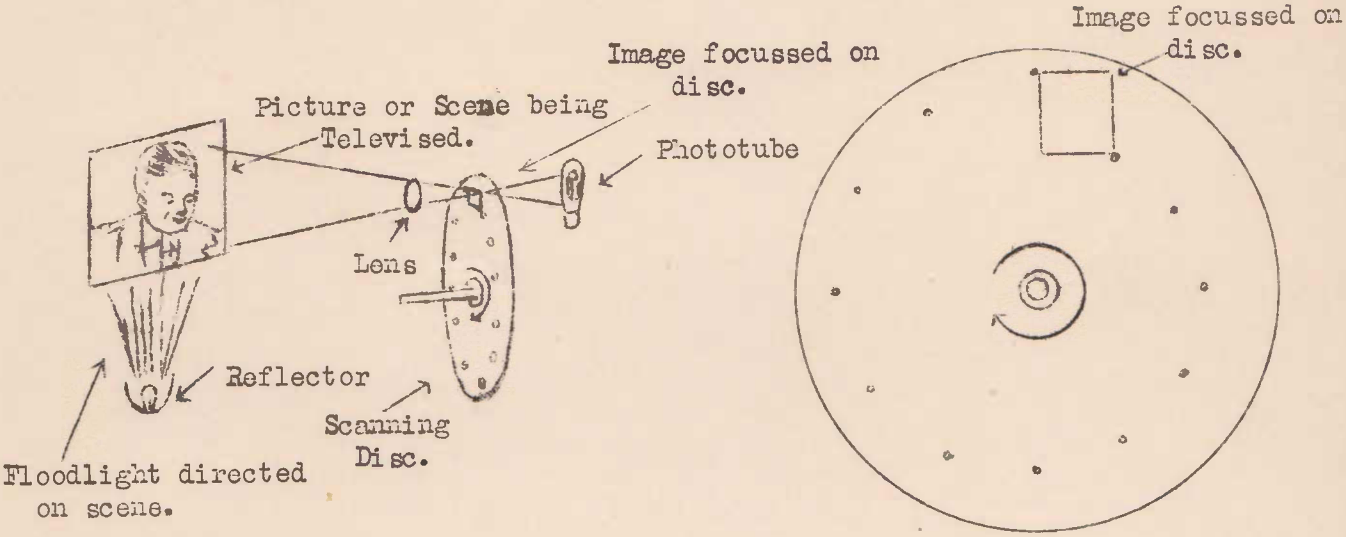


FIGURE 8.

Here the picture or scene is focussed by means of a lens to form a small image on the disc as shown. The action of the lens is similar to that of a camera, whereby an image of the scene is thrown on to the film at the back of the box, as shown in Figure 9.

The image of the tree appears inverted, this being a characteristic of the lens' focussing action.

Returning to Figure 8, note that the image on the disc must be the correct size for the positioning of the disc holes as discussed in the previous section.

The disadvantage of this system is that the whole scene being televised must be brilliantly lighted. The amount of light falling on the photo-cell at any instant is that passing through one small disc hole, and, therefore, coming from one small point of the picture or scene being televised.

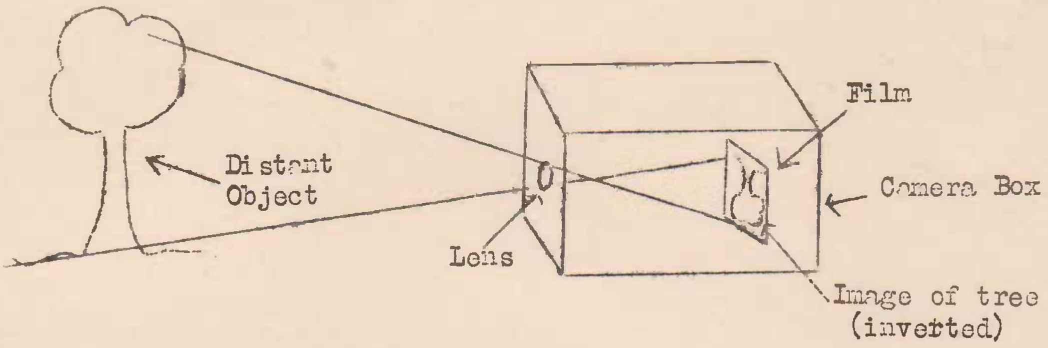


FIGURE 9.

The whole scene, consequently, must be extremely brightly illuminated if the photo-cell is to produce a sufficiently large amount. This rules out the possibility of televising outdoor scenes, except under the most favourable circumstances of strong sunlight.

In the case of studio scenes extremely powerful arc lamps must be used. These lamps give out so much light and heat that the conditions under which the announcer and other performers work are most uncomfortable. Even with ideal lighting conditions, however, the electrical output from the photo-tube is extremely minute.

The other system of using the scanning-disc is that known as the "Flying-Spot" method illustrated in Figure 10. There light from a powerful arc light is focussed, by means of lenses through each disc hole in turn on to the scene or picture being televised. With this system all the light available from a given source is concentrated on the small part of the picture or scene being scanned at a given moment.

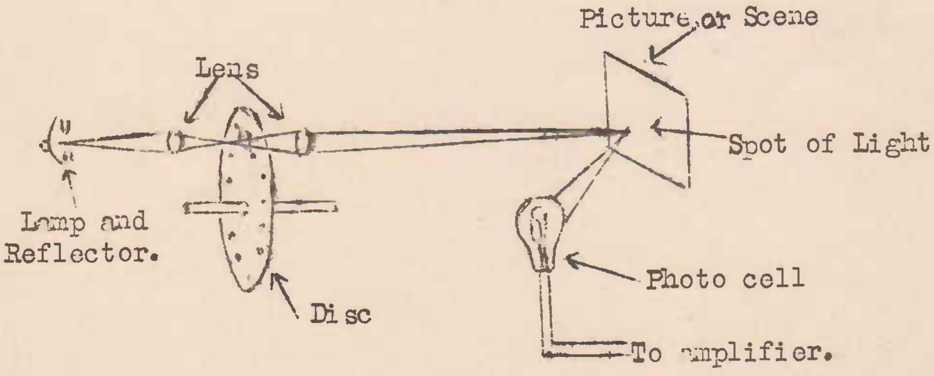


FIGURE 10.

The brilliancy of the scanned areas will, therefore, be much more intense than in the case when the whole scene is "flood-lit". In this way the flying-spot method makes much more economical use of the available light from the source.

An interesting advantage of this method, compared with the "flood-light" system, is that, although the brilliancy of the light-spot may be intense, the apparent lighting of the studio scene may be quite moderate, or even dim. The reason for this is that the spot of light traverses the whole area in, say, only one twenty-fifth of a second. Owing to the persistance of vision effect the eye is conscious only of the average light spread over the whole area in that time. This average brilliance will be much less than the actual brilliance of the spot itself.

There are several disadvantages of this method of disc-scanning, however. One is that the system is not suitable for dealing with large scenes. A second is that the scene must be in complete darkness except for the light from the scanning spot. Any external lighting covering the whole scene would cause the photo-cell to receive light continuously from all parts of the scene, and this would "mask" the effect of the flying spot. This limitation, therefore, rules out the possibility of televising outdoor scenes.

A third failing lies in the difficulty of utilising all of the reflected light from the scanned spot. Although the arrangement gives maximum illumination for the small area being scanned at any instant, the situation is not as good as it might seem. The reason for this is that a single photo-cell would "collect" only a small fraction of the scene. The reason for this may be realised by referring to Figure 11. Light reflected from an unpolished surface is "diffused". The reflected light spreads out in all directions, and only those light rays which happen to be reflected in the direction of the photo-cell will have the desired effect of setting up an electric current.

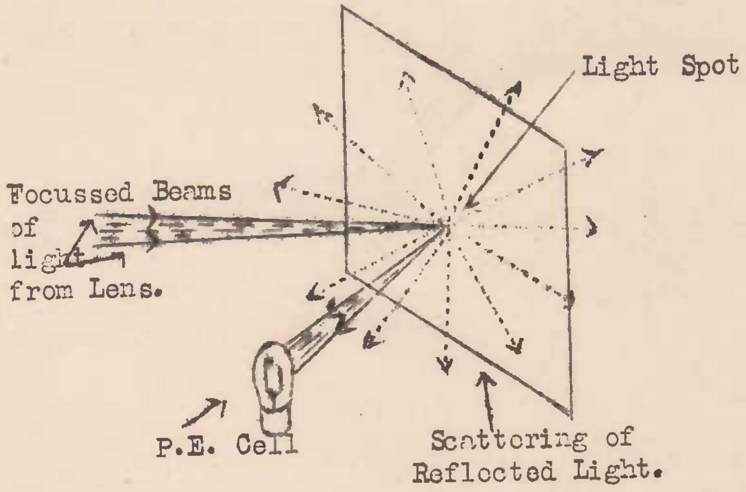


FIGURE 11.

This latter failing is minimised in practice by using a number of photo-cells clustered around the scene, and all connected electrically in parallel. Further, by using large reflectors having somewhat the same shape as those used for a car's headlights a better effect may be obtained. As shown in Fig. 12 all reflected light rays falling over the reflector's surface will be concentrated or focussed on to the photo-cell. This reflection is acting in the "reverse manner" to that of a car's headlamp.

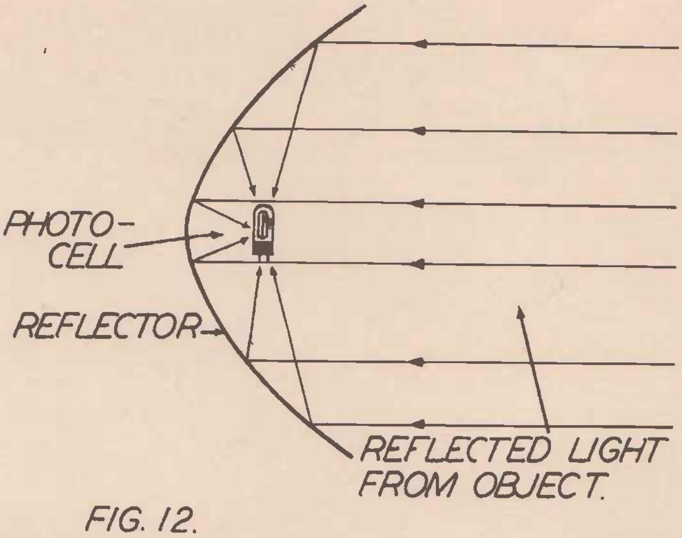


FIGURE 12.

Figure 13 is a photo of the interior of an early television studio using the flying-spot method of mechanical scanning. Note the eight reflectors used to gather the light reflected from the televised object. Of course, each reflector is fitted with a photo-tube. The scanning disc and lens system are visible at the rear of the booth.

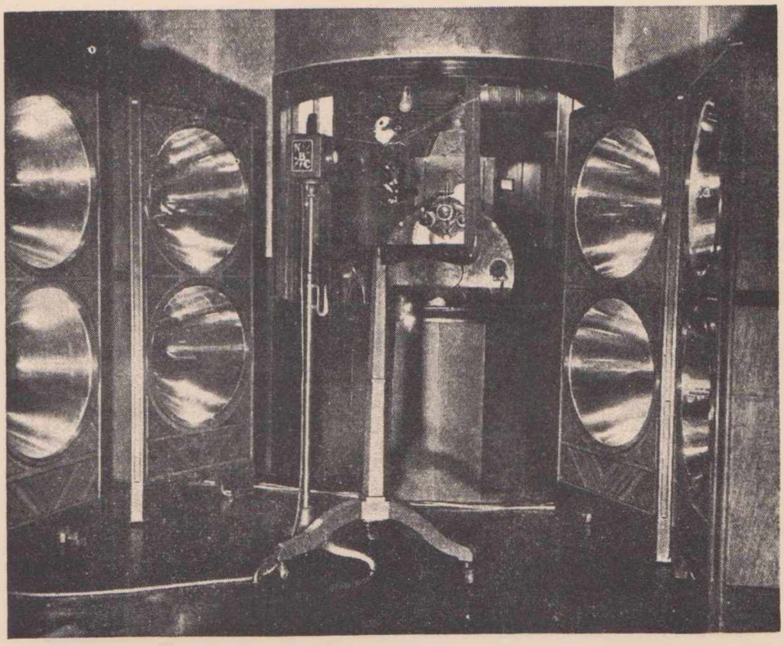


FIGURE 13.

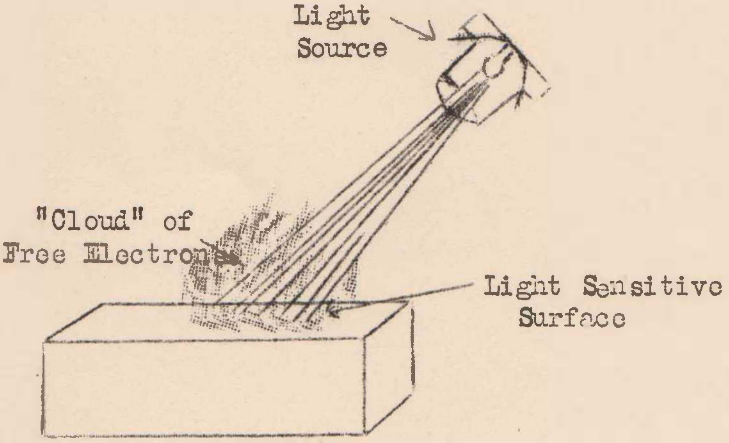
CHANGING LIGHT ENERGY TO ELECTRICAL ENERGY - THE PHOTO-ELECTRIC EFFECT: When light falls on the surface of certain substances, a strange phenomenon occurs - electrons are set free from that substance, in somewhat the same way as they are emitted by heat in a thermonic valve, and the surrounding space becomes electrically charged. This is the photo-electric effect upon which the operation of the photo-cell, and also the Iconoscope television tube, depends. Two substances which exhibit this important effect are potassium hydride (a combination of metal potassium with the gas hydrogen) and caesium, a metal. The former substance is commonly used in photo-electric cells, while the latter is found in both P.E. cells and the Iconoscope. Before describing the construction and operation of the photo-cell it will be helpful if we explain briefly the main principles of this phenomenon.

All substances consist of tiny atoms which in turn are made up of a central body or nucleus, around which move in orbits one or more tiny particles called "electrons". The nucleus containsone or more "protons", which are the smallest particles of positive electricity, while electrons are the smallest particles of negative electricity. Innumerable different substances exist having widely different characteristics (such as weight, colour, hardness, etc.) depending upon the various numbers of protons and electrons which exist in each of their atoms, and also upon the patterns or arrangements of these electrical particles. An important point to remember, however, is that all electrons are identical no matter from which substance they have been derived. When some of the electrons of a substance are "free" to move from atom to atom within a substance (as in the case of an electrical conductor) and are made to flow, we have an electric current.

Now, when light falls on a surface and is absorbed, electrons in the material are set into vibration or oscillation. In those substances, which are described as being photosensitive (i.e. light sensitive) some of these agitated electrons receive sufficient energy from the light wave to cause them to break from the solid's surface. When this occurs, the solid itself will have acquired a positive charge (due to loss of negative electrons) and hence the "free" electrons will be attracted back to it again. Thus, if a steady light is shone on the surface of such substance, electrons will be continually leaving that surface, and eventually finding their way back to it again.

At any given moment there will exist a "cloud" of "free" electrons in the space just ouside the surface, as illustrated in Fig. 14.

If now we apply a positive potential to a metal plate placed near the photo-sensitive material, the "free" electrons which have been emitted from the latter by the action of light will be attracted to this plate. The metal plate can be made positive with respect to electron-emitting body by using a small battery as in Fig. 15.



THE PHOTO-ELECTRIC EFFECT
FIGURE 14.

As the positive plate collects the electrons a corresponding electric current flows in the external circuit (i.e. in the wires connected to the battery). If now the amount of light falling on the surface were increased, a greater electron emission would occur, and a heavier current would flow in the circuit. In this way, we have a means of controlling an electric current simply by varying the intensity or amount of light.

THE PHOTO ELECTRIC CELL.

A commonly used type of photo-electric cell or photo cell is shown in Fig. 16 along with its symbol. This cell or tube consists of a glass bulb containing two elements. One element consists of a thin metal rod or ring called the anode which corresponds to the plate in the radio tubes we have been accustomed to. The other element is the active material applied to a curved metal plate and is called the cathode. The cathode active material corresponds to the cathode or filament in the ordinary tube because it emits the electrons which are drawn over to the anode or plate.

There are two general classes of photo-electric cells. In one the air has been exhausted and a vacuum remains within the bulb. This is called the vacuum type of cell. In the other a small amount of the gases argon or helium is admitted into the bulb after the air is exhausted. This is called the gas-filled cell. The gas cell is more sensitive than the vacuum type and was the one generally used in television work.

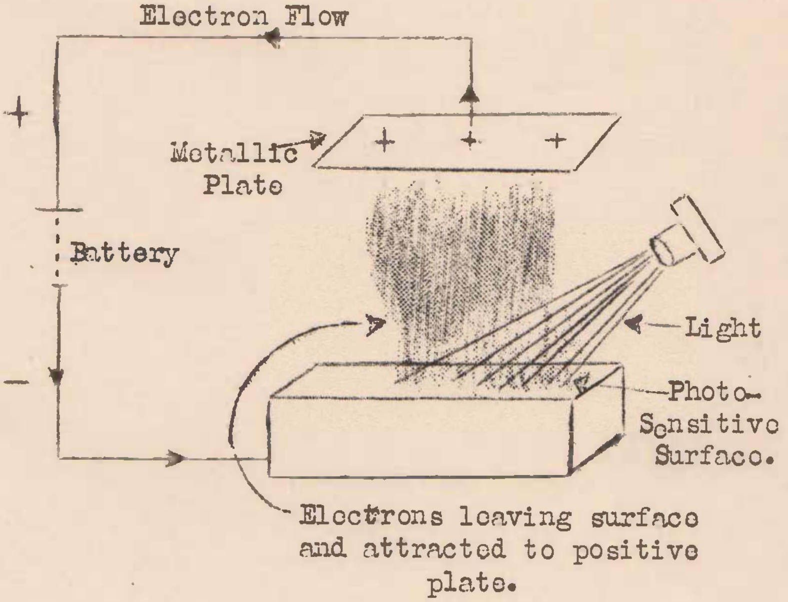


FIGURE 15.

In order to make our ordinary radio tubes do work as amplifiers or detectors we apply a positive voltage or potential to their plates. In the photo cell we likewise apply a positive voltage to the anode or rod which corresponds to the plate. We make the anode positive with reference to the cathode just as we make the plate of an amplifying tube positive with reference to its cathode.

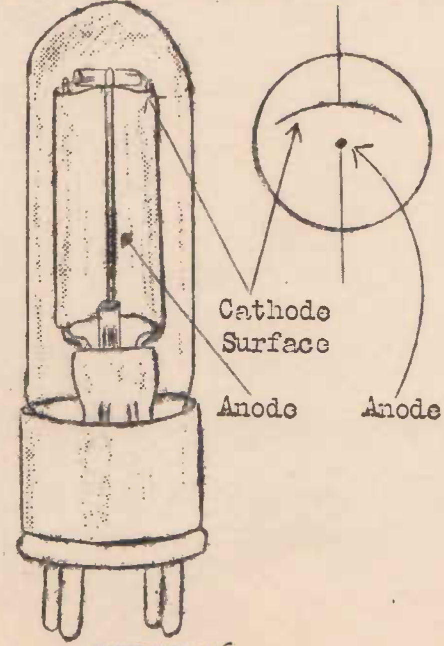


FIGURE 16.

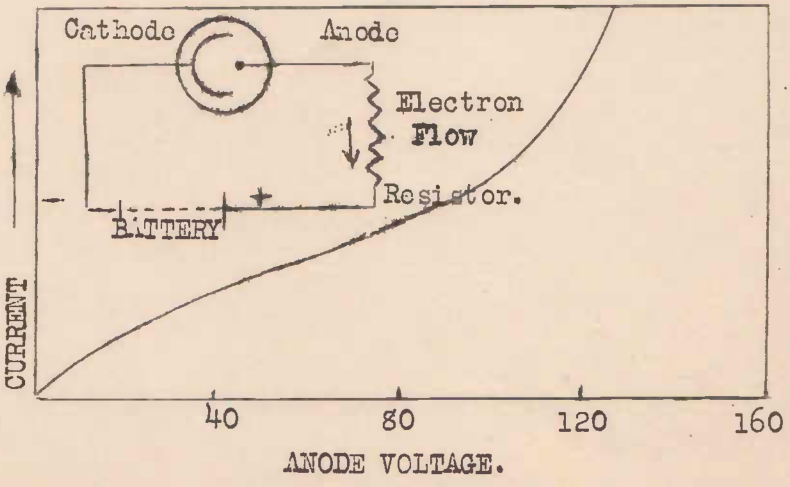


FIGURE 17.

As soon as this voltage is applied to a photo cell there is a flow of electrons from the cathode to the anode. This is exactly what takes place in the ordinary radio tubes, but in those tubes we have to have a heated cathode while in the photo cell we use the cathode in a cold condition, at ordinary room temperature.

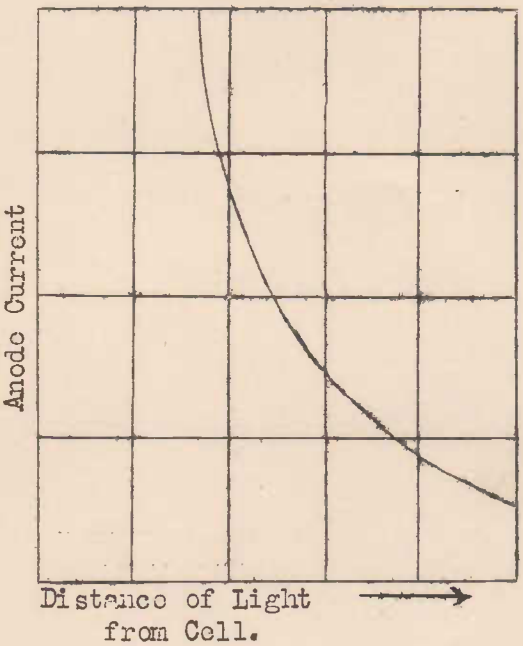
Were we to hook up a photo cell, a battery and a resister as shown in Fig. 17, there would be a flow of electrons from the cathode to the anode and this stream would pass through the resistor.

The amount of current flowing in the circuit of Fig. 17 depends on two things for a given photo cell. It depends on the voltage applied to the anode end and on the amount of light entering the window of the cell. This is not much different from the amplifying tubes where the plate current depends on the plate voltage and on the grid voltage. The anode voltage of the photo cell corresponds to the plate voltage of the radio tube, and the amount of light entering the photo cell corresponds to the grid voltage in the amplifying tube.

The rise of anode current with increase of anode voltage (the amount of light remaining constant) is about as shown in Fig. 17 for a gas cell. The current is extremely small in amount, being measured in microamperes or in millionths of an ampere. We have currents running between I and IO microamperes under ordinary conditions. The steady anode current, which corresponds to steady plate current, is fixed by the anode voltage for any given amount of light. If we apply an anode potential of 80 volts we will have some steady value of current, say 3 microamperes, until the amount of light entering the cell is either increased or decreased. Most gas filled cells cannot operate with more than 90 volts applied.

If we admit more light through the window of a photo-electric cell, all other things remaining the same, the anode current will increase. If we cut down on the amount of light entering the cell the anode current will become smaller. You might place a lamp at a certain distance from the cell and adjust the anode voltage for a certain amount of current. As you moved the light source farther and farther away from the cell, less and less light would enter the cell's window and the anode current would drop off as shown in Fig. 18. Bringing the lamp closer would put more light into the cell and the current would go up. Increasing and decreasing the amount of light entering the cell causes the cell's anode current to increase and decrease correspondingly.

The curve in Fig. 18 does not show just how the cell current behaves with change of amount of light because as a lamp or other source is moved further from the cell the amount of light drops off as the reciprocal of the square of the distance between lamp and cell, not directly as the distance. If we make the proper corrections, so that our curve shows the cell current or anode current with respect to the total amount of light passing through the window, we will have a curve like that in Fig. 19. The important thing just now is that the amount of light affects the anode current of the photo cell just as the grid voltage effects the plate current in an amplifying radio tube. If we work on a straight part of the curve in Fig. 19 we will find that equal changes of light produce equal and corresponding changes of anode current.



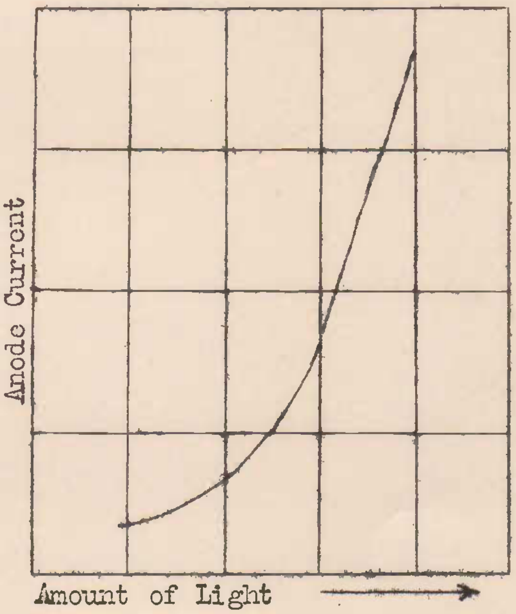


FIGURE 18.

FIGURE 19.

PRODUCTION OF THE PICTURE SIGNAL:

As has been mentioned previously, scanning disc and photo-electric cells are not used in modern methods of television transmission, but it is far easier to obtain a clear understanding of the principle of scanning from a mechanical system than from the less tangible electronic system. For this reason, we are examining in some detail the action of what might be regarded as an obsolete television system, but we are doing it deliberately so as to impress the fundamentals and to lead gently up to electronic scanning systems which will be described in following lessons.

We are now in a position to follow through exactly the manner in which a scanning beam of light divides up a picture or scene into a large number of small parts or elements, and how the photo-cell converts the varying degrees of light and shade of these elements into a pulsating electric current. This current output from the photo-cell we have called the "picture-signal", and is used to modulate the outgoing wave from the transmitter in the same way as the audio-frequency, or sound-signal current, from a microphone is used in radio telephony work.

Let us consider the system of scanning known as the flying-spot method illustrated in Fig. 8. Suppose the disc has 32 square holes, and the picture of Fig. 20 is being scanned. The whole picture will be covered by the spot in 32 horizontal sweeps from left to right.

These paths traced out by the spot will in practice be slightly curved. In Fig. 20, however, these paths, or "lines", as they are termed, have been drawn perfectly straight. This has been done partly for simplicity in the explanations which follow, and also because it represents the most desired state of affairs for efficient scanning, and, further, it more truly represents the modern electronic method of scanning.

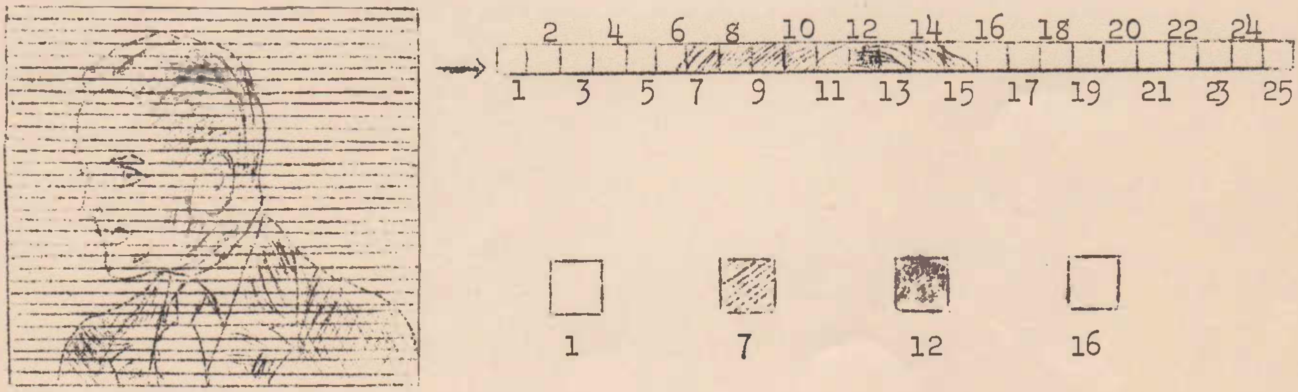


FIGURE 20.

The area enclosed in Fig. 21 might represent that of the picture in Fig. 20. We start off by directing our light beam onto the small square at the upper left hand corner. This may be considered as one of the small numbered divisions shown in Fig. 20. If the surface illuminated by the beam is light in colour we will have a great deal of reflected light, if it is very dark we shall have but little reflected light. The light beam gives us an amount of light which represents the tiny area being illuminated. In the illustrations these areas have been shown as being of quite considerable size, but as a matter of fact it takes up to 300,000 of such spots to make up the complete area of the picture in a modern system.

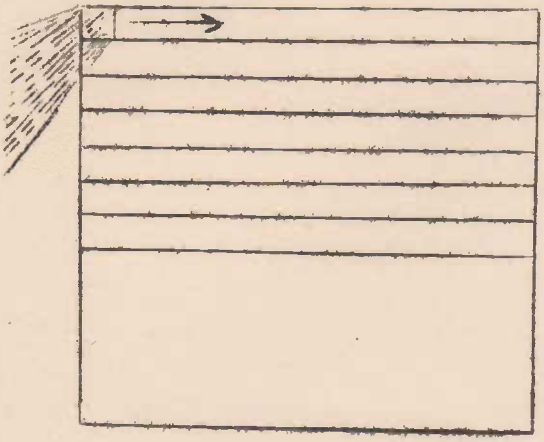


FIGURE 21.

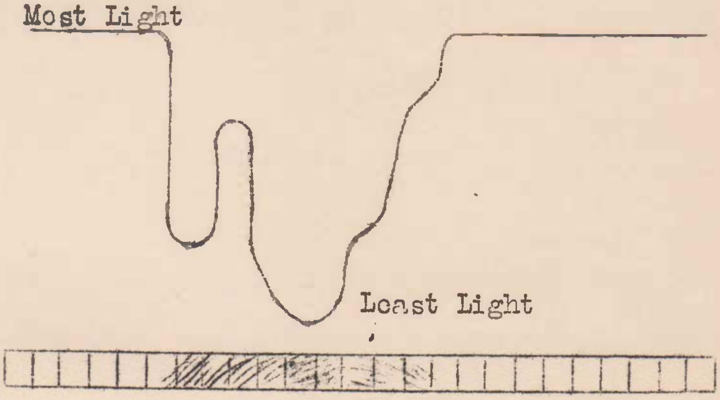


FIGURE 22.

EFFECT OF MOVING THE LIGHT BEAM:

In Fig. 21 we begin operations by directing the light beam at the upper left hand corner of the area to be covered. Now we will move the beam towards the right as shown by the arrow. That is, we shall sweep the light beam across one of the horizontal lines in Fig. 20. As the beam moves over different parts of the object or picture there is reflected back a varying amount of light, depending on the shade or color of the spot being illuminated at one instant.

Were the beam to sweep over the line drawn out by itself in Fig. 20 we would have a varying amount of reflected light as shown by the irregular curve in Fig. 22. We would have the most reflected light from the white spots, medium amounts of light from spots of somewhat darker shade and the least light from the darkest spots. The curve of Fig. 22 really represents the part of the picture which has been illuminated by one sweep of the light beam, but represents it as rising and falling amounts of reflected light.

As the beam comes to the end of the top strip in Fig. 21, it is lowered a little bit and sweeps the second strip, then it is lowered still further and sweeps the third strip. So the action goes on until the light beam has been played over each part of the whole picture or whole object being scanned. The amount of reflected light is continually varying as shown in Fig. 22.

Now we are ready to change the variations of light into variations of electric current.

This reflected light is allowed to fall on the photo-tubes' cathode. Since we have seen that the current flowing through the photo-cell is proportional to the amount of light, this current will vary in a manner exactly similar to the variations of the curve of Fig. 22. The similarity between the "light curve" and the current curve is brought out in Fig. 23. Note that maximum reflected light (i.e. when the scanning spot is directed on a white part of the picture) causes maximum reflected light (when the spot is on the darkest part of the line) results in the maximum current. Note that the photo-tube's current does not fall to zero at any point as the spot scans this line. This is because there is still some light reflected from the picture, even at the darkest part of the line shown in Fig. 22. If there were a jet black part in the picture the tube's current would fall right to zero as the light spot passed over this part.

It should be clearly understood that the current variations shown in Fig. 23 occur in the very small interval of time during which the scanning spot is traversing one line only of the picture. Each of the other thirty-one lines of Fig. 20 will result in its own series of current variations. Some lines will cause more variations, others less, depending upon the number of light changes in the picture as the spot moves horizontally across it.

The student who has followed carefully the preceding notes will probably have realised one important fact, viz. that the smaller the size of the scanning spot the greater will the number of changes in reflected light be, and, therefore, changes in current produced in the photo-cell. He will, possibly, also have guessed that the amount of fine picture detail which will be transmitted will depend upon the number of

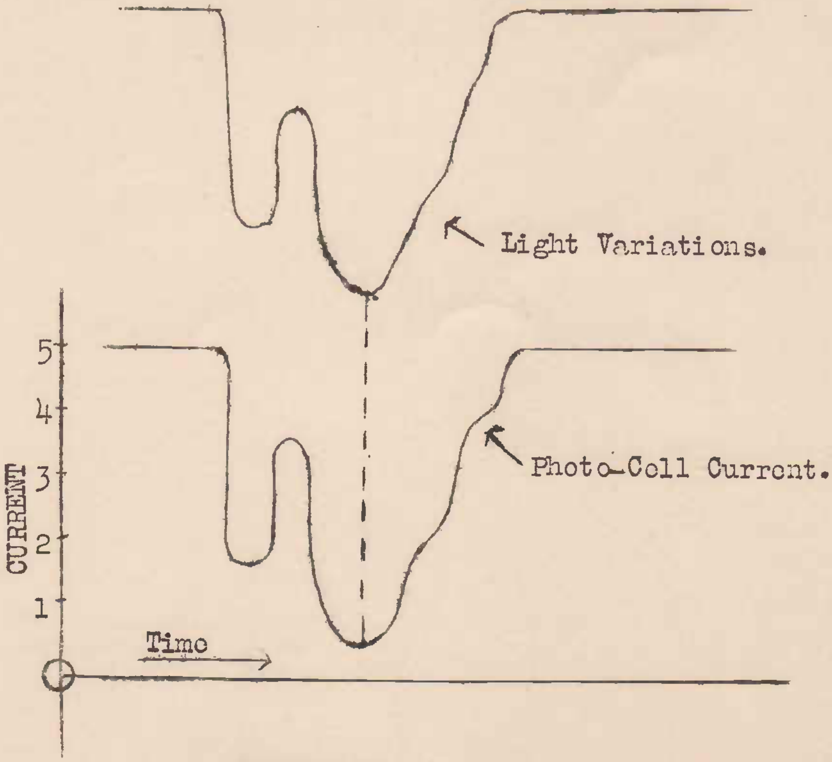


FIGURE 23

those current variations which can be generated in the photo-cell by the scanning system.

THE PICTURE ELEMENT

If we minutely examine a newspaper reproduction of a photograph, we shall see that it consists of a large number of small black dots separated one from the other by white paper. If the dots are comparatively widely separated the effect produced when viewed at ordinary reading distance is a light grey. If the dots are more closely packed a darker shade is produced. If the dots are touching each other a practically black area results. The varying lights and shades which represent the picture are thus produced by the distribution of these "elementary" dots which constitute the picture structure. Each of the dots is called the "picture element". Now it is evident that the smallest detail which will show up in the picture will be the size of a single dot. Anything smaller than this will not appear as separate and distinct detail. For example, if the picture shows a man's head the individual hairs cannot be seen, even if a magnifying glass is used. The thickness of a single hair is less than the diameter of a dot, i.e. a picture element. Such details as the individual hairs in a man's head, therefore, simply do not appear in the reproduction.

Now, if we were to procure the original photograph from which the newspaper picture was reproduced, and we examined it under a microscope we would see that it was also made of many minute dots, these actually being grains of metallic silver which appear black. These dots, however, would be very much smaller than those of the newspaper picture. Hence we could say that the picture-elements of the photograph were much smaller than those of the newspaper print. The photograph would, of course, show very much greater detail - we might even be able to distinguish the separate hairs on the man's head. The important point to note is that the amount of detail which appears in any artificial reproduction of a scene, i.e. in a picture, depends on the smallness of the picture-elements, and, therefore, upon the number of them used in the structure of that picture.

PICTURE ELEMENTS REPRODUCED IN A TELEVISION SCANNING SYSTEM:

Returning to the question of picture scanning with a disc system, the tiny spot of light illuminates one fraction of the whole picture at any one moment. We would expect that the area of this spot would represent the smallest portion of the picture, which would cause a current variation in the photo-cell - i.e. it would represent a picture-element.

In order to understand more clearly the above statement, it should be remembered that the current flowing through the photo-cell is proportional to the total light falling on its cathode at any moment.

To illustrate, consider Fig. 24, where the light spot has an area equal to the square ABCD, and is moving along the line from left to right.

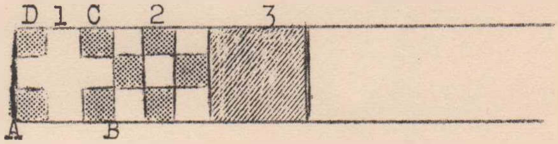


FIGURE 24.

In position 1 the light spot is covering an area of the picture which includes four black squares, representing details of the picture. The light reflected to the photo-cell would come mainly from the white parts of the area ABCD, and the phototubes current would assume a certain value. When the spot had moved to position 2 the tube's current would be exactly the same as for position 1; for the total light reflected from the area covered by the spot would be unchanged. In position 3, light is reflected from the whole area, but the total light received by the photo-cell for this portion of the picture might be the same as before. Hence as the beam scans the picture from left to right no change in picture-current occurs. At the receiver, all three areas, 1, 2 and 3, would appear alike - i.e., a uniform grey. The picture details represented by the eight black dots in positions 1 and 2 would be completely missed out - because they are smaller than the picture-element determined by the size of the light beam ABCD.

In order to observe how this all-important question of area of light spot affects the amount of detail reproduced, consider the scanning of the picture in Fig. 25, using sixteen lines.

Say we have a light beam of the size indicated by the small square in the upper left hand corner of the picture. This beam will sweep across the first or top line without change in light, since everything is white. On the second line we have the subject's hair which is dark and which makes an abrupt change. The corresponding rise and fall of light might produce passable results and indicate the top of the man's head.

But supposing we continued on until the beam rested on the subject's right eye. The beam would be illuminating the part of the picture shown enlarged over towards the right. Here we have part of an eyebrow, part of the skin around the eye, part of the eye's "white", also the iris and the pupil - quite a collection of lights and shadows. But, coming from this spot, which is illuminated, would be a single beam of light for the window of the photo cell. The cell's anode current could assume only one value at this instant; it could not assume a whole collection of values all at once. This one value of anode current would represent the average shading of the area shown at the right in Fig. 5. In place of the various parts making up this eye, we would have the same average current which would result if this spot did not contain an eye at all, but contained only a part of the subject's coat,

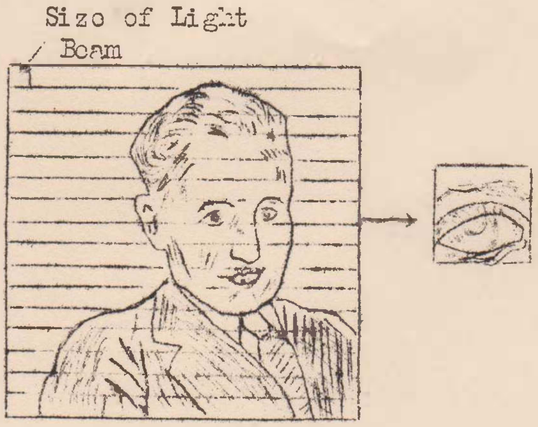


FIG. 25.

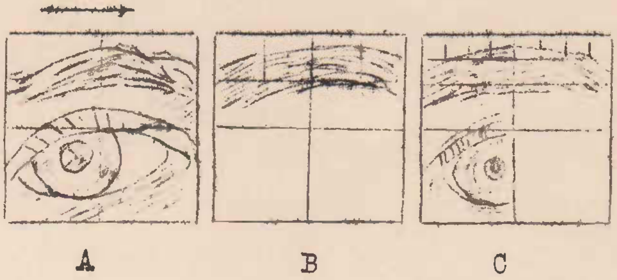


FIG. 26.

which is an even grey.

It is evident that our light spot is too large. Say we make it one quarter the size so that we have the division shown at "A" in Fig. 26. As the beam sweeps across in the direction of the arrow it is covering not only the eyebrow but also parts of the skin on both sides. Once more the reflected light would be of a value representing the average of the dark eyebrow and the lighter skin. Even though we were able to recognise that a face was being transmitted, the subject would have no eyebrow - only a darker place on his face. When this smaller beam came along to the eyeball on the next line below the results would be even worse because there is a greater detail to be transmitted.

Again cutting the size of the beam as at "B" in Fig. 26, we would actually begin to get some changes of shade as the beam travelled across the eyebrow and would have corresponding changes for the eyeball below. But to show the eye's expression as denoted by the position of the iris and pupil with reference to other parts we would have to use a beam so small it would give us the areas shown at "C" in Fig. 26. Then there would be a real change between the white of the eye and the darker coloured iris and pupil.

In Fig. 25 we started with a light beam of such size that it would illuminate the whole picture in 256 squares. At "A" in Fig. 26, we have divided these original squares into four parts each, making a total of 1024 areas. This was not small enough, so at "B" we made a similar division and would have 4096 such parts in the original picture. To get any real detail we made a third division at "C", which would give us a beam dividing the whole picture into 16,384 small elementary areas.

From this analysis of the picture in Fig. 26, you can see that the detail of the picture or the amount of information conveyed in the changing electric currents depends on the number of parts into which we divide the picture. The greater the number of parts the greater will be the amount of detail brought out. The fewer the parts the less detail will show and the more all the different features will run together into even shades. With modern systems a scene may be represented by as many as 300,000 individual areas.

HOW NUMBER OF LINES AND NUMBER OF PICTURE-ELEMENTS ARE RELATED:

It should now be evident that the all-important factor in producing a picture-signal containing a great amount of detail (i.e., a large number of current changes) is the number of lines used in scanning the scene.

In order to obtain a large amount of these picture-elements and current changes, we have found it necessary to work with a light spot of small size, now the smaller the size of the light spot the greater the number of times it will have to traverse the picture, i.e., the larger the number of lines.

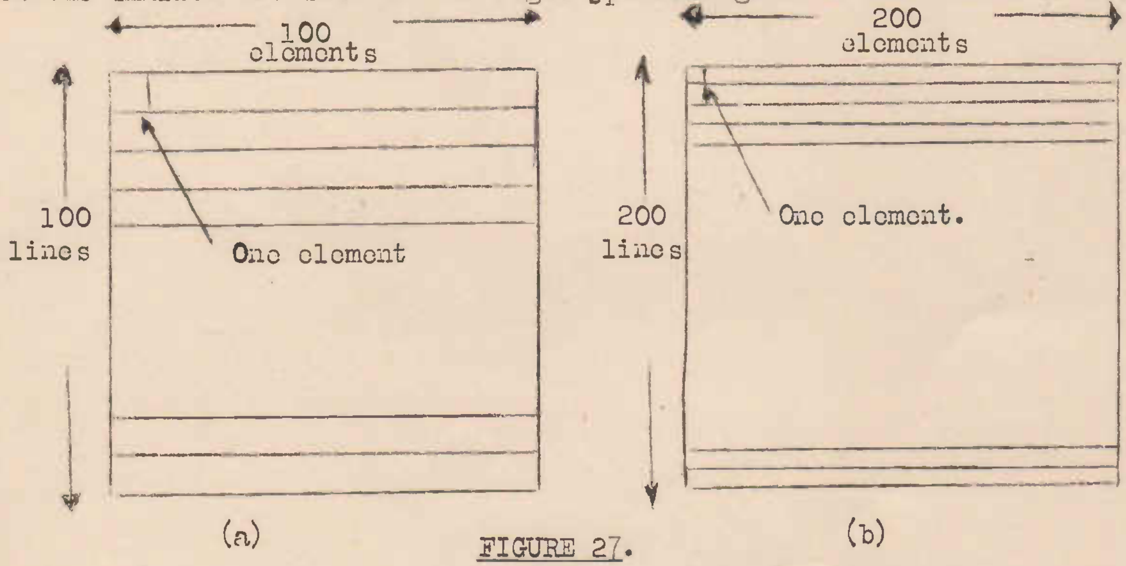
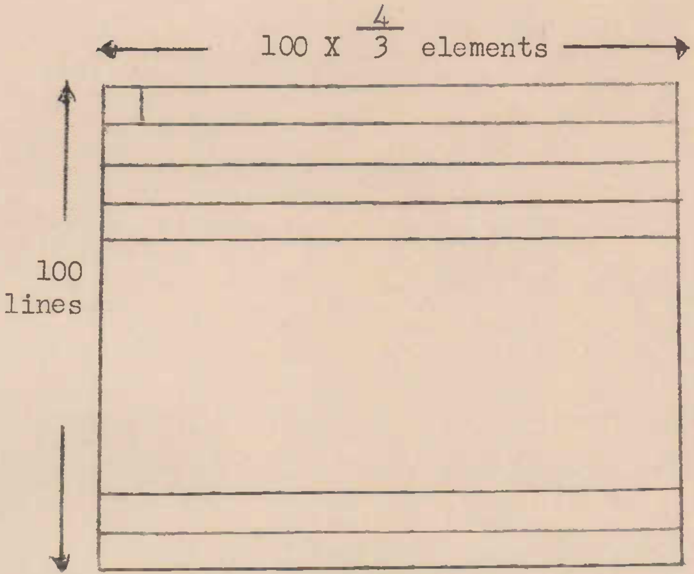


FIGURE 27.

Considering a square picture in Fig. 27 suppose at (a) we have 100 lines. The number of elements in each line will also be 100. The total amount of areas equal to the area of the light-spot, i.e. the number of elements in the picture will be 100 X 100 = $(100)^2$ = 10,000 = (number of lines)^2. Now suppose in Fig. 27 (b) we have increased the number of lines to 200. The number of picture elements will now be $(200)^2$ = 40,000. This is four times the number of elements when using 100 lines, and will result in four times the detail.

In present day television practice the picture is not square, but the width is usually either four-thirds or five-fourths the height. Referring to



Aspect Ratio = $\frac{4}{3}$.
FIGURE 28.

Fig. 28 and comparing with the 100 line square picture of Fig. 27 (a), we see that the number of elements in each line is one and one third times as great. Here the total number of elements in the picture will also be increased in the ratio of 4/3 compared with the square picture. The number of elements will be

$$(\text{number of lines})^2 \times \frac{\text{Picture Width}}{\text{Picture Height}}$$

The ratio $\frac{\text{Picture Width}}{\text{Picture Height}}$ is frequently referred to as the Aspect Ratio. Hence we may write:-

$$\text{Number of Picture Elements} = (\text{Number of Lines})^2 \times \text{Aspect Ratio.}$$

NUMBER OF PICTURE ELEMENTS PER SECOND.

In order to utilise the persistence of vision effect, and to produce the illusion of motion, it is necessary, as explained previously, to scan the picture at least ten times per second. The number of complete scannings per second is called the "Picture Frequency". The number of picture elements converted to current changes by the photo-cell in every second will, therefore, be the number of picture-elements in the picture multiplied by the picture frequency, i.e. -

$$\text{No. of Picture Elements per sec.} = (\text{No. of lines})^2 \times (\text{Aspect Ratio}) \times (\text{Picture Frequency}).$$

For example, in the case of 400 line scanning, 25 pictures per second, the number of picture elements converted to picture-signal current changes in each second is:

$$(400)^2 \times 4/3 \times 25 = 5{,}333{,}333 \text{ per sec.} - \text{an enormous number.}$$

HOW MANY LINES?

When we speak of a "high-definition" picture we refer to a picture which is clear-cut and contains a great number of sharp details. A low-definition picture is one which is indistinct and blurred due to lack of the necessary detail. Considering the formula given above the number of picture--

elements contained in the signal, it is seen that the number of lines used in the scanning system is all-important in producing a high-definition picture at the receiver.

In the early days of television, when revolving discs and other similar mechanical devices were the only means of scanning the picture, a number as low as 30 lines was used. This gave a very poor picture - much too poor to give any real entertainment value. A reproduction of a 30-line picture is shown in Fig. 29. Note the extreme lack of detail, and also the marring of the picture by the scanning lines (vertical scanning), which are clearly visible. (An original photograph is also shown for comparison).

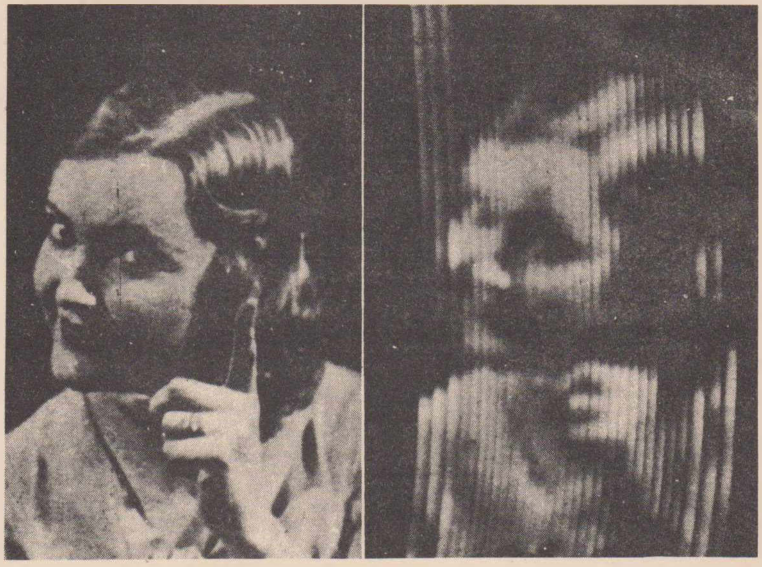


FIGURE 29 - 30-LINE TELEVISION
The photograph at the right is of the screen of a 1932 model television receiver employing 30 line scanning in a vertical direction.

The British Broadcasting Commission's first transmissions in 1932 were of 30-lines. As time went on, the number of lines was increased to 90, then to 180, and, finally, to 240, using mechanical methods of scanning.

With the development of electronic methods of scanning, the ambition immediately was born to reproduce pictures equal in quality to the home cinematograph of the 16 m.m. variety.

Now the number of picture-elements contained in each picture of a 16 m.m. film was known to be in the vicinity of 120,000-150,000. If we consider a 400 line television picture of the same shape as a cinematograph picture, i.e. **Aspect ratio** 4 to 3, the number of picture-elements from our formula above is:-

$$(400)^2 \times 4/3 = 213,000 \text{ elements.}$$

This would appear to give considerably more detail than the 16 m.m. film. However, in deriving the formula above from the simple theory explained a number of factors were not considered. For example, it is found that, on the average, 400 lines will not produce 400 details or elements in a vertical direction.

The latter point can be understood by referring to Fig. 30. Here the object being scanned is a vertical bar containing a number of alternate black and white segments, the heights of which are equal to the width of the scanning lines.

As in Case A (Fig.30) the bar is so positioned that a scanning line passes directly over a black segment or element and the corresponding current in-

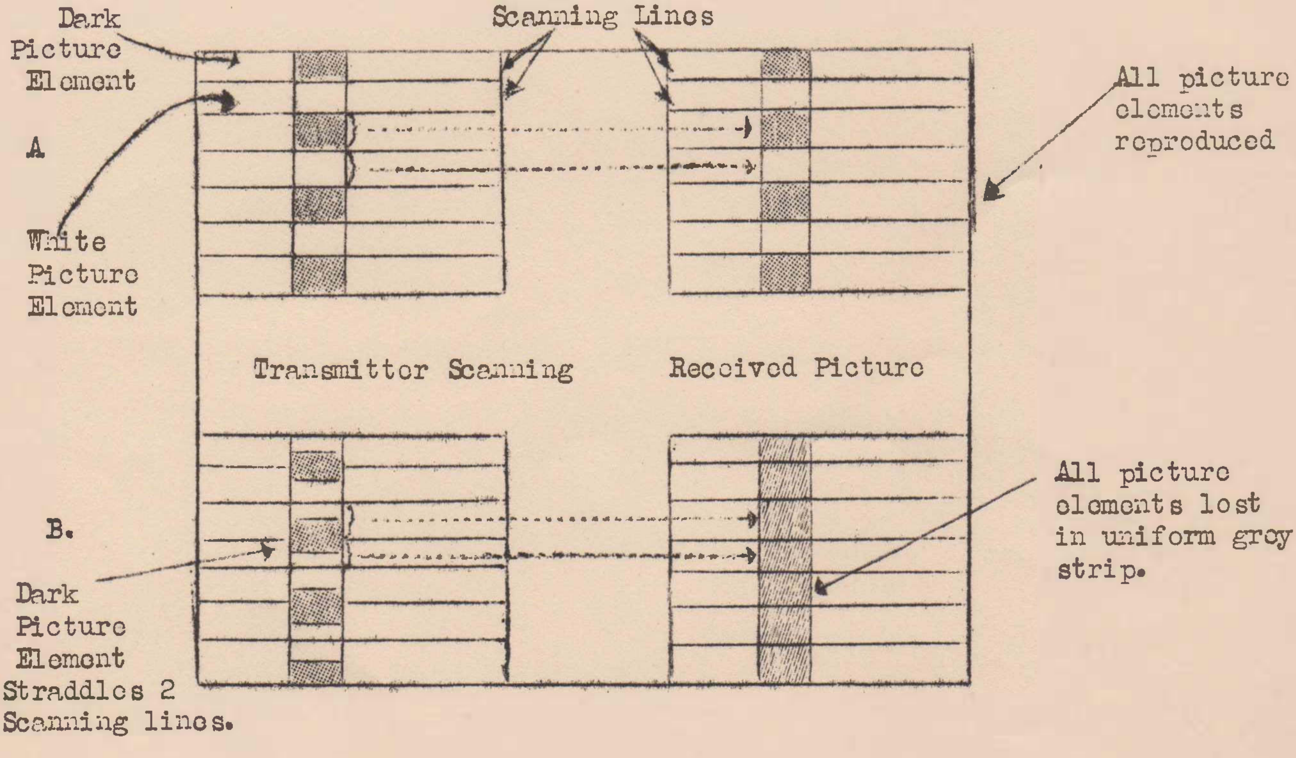


FIGURE 30.

pulse reproduces a black element at the receiver. The next scanning line passes directly over a white element, and a white element is reproduced in the receiver.

In Case B, however, the bar is so positioned that each element straddles two scanning lines. In this case, as the scanning spot passes across the bar, the area illuminated will be half black and half white, and the amount of light producing the picture-signal will be the same as if the whole area were a uniform grey, intermediate between black and white. The bar reproduced at the receiver will therefore be a uniform grey, and it will be impossible to distinguish between the black and white spots, i.e., the detail is entirely lost.

In the one case (Case A, Fig. 30) where the picture-elements are passed directly over by the scanning lines, all of these elements show up in the reproduced picture, i.e., the number of picture elements on a vertical line contained in the signal will be exactly equal to the number of scanning lines used, as assumed in our simple theory earlier.

In Case B, however, where each element "straddles" two scanning lines, it is possible that the signal will contain no current changes whatever, and the number of elements reproduced on a vertical line is zero.

In practice, of course, the subjects transmitted are not segmented vertical lines, but whole pictures, containing a scattered, non-uniform, arrangement of picture-elements, some of which fall directly on a scanning line, others of which straddle two lines. Theoretical investigations, and practical tests, have shown that, <u>on the average</u>, on a vertical line the number of picture-elements which will show up is slightly more than 75% or 3/4 of the number of scanning lines. In other words, when using 400 lines, about 400 X $\frac{3}{4}$, = 300 or more details will be reproduced in a vertical direction in the picture.

Taking, then, our previously calculated number of 213,000 picture elements in the whole picture for 400 line scanning, we should modify this figure by multiplying by 3/4, giving an actual number of 213,000 X $\frac{3}{4}$, or a little over 150,000 picture-elements. Thus it is seen that 400 line scanning should give a picture which compares very favourably with the best 16 m.m. cinematograph image.

For the reasons discussed above it was decided, before the War, to choose a number of lines in the vicinity of 400. In England the B.B.C. chose 405 lines, and the number used in America was 441. Later, in 1941, the standard in the latter country was raised to 525 lines. When treating electronic scanning methods in a later lesson, it will be seen that not all the lines actually scan the picture area. Hence, assuming that 500 of the lines are "active" in scanning we have - No. of Picture-Elements = $(500)^2$ X 4/3 X $\frac{3}{4}$ =

250,000. This is better than the 16 m.m. cinematograph (150,000 elements) but not up to the standard of the full size (35 m.m.) cinema picture, which contains about 500,000 picture elements.

INTER-LACED SCANNING:

As pointed out previously it is found, in order to produce the illusion of motion, that it is adequate to transmit between 20 and 30 complete pictures per second. In cinematography 24 separate photographs, showing moving objects and persons in slightly different positions, are used per second. This rate, however, is not sufficient to eliminate entirely flicker. This problem is solved in cinematograph projection by projecting each image twice in rapid succession. As each picture or frame on the film strip appears before the projector a shutter interrupts the light, thus showing on the screen two images for each frame. This produces 48 separate impulses of light to the eye, and flicker completely disappears, leaving the effect of continuous and steady illumination of the screen.

In a previous calculation we found that scanning at the rate of 25 pictures per second (using 400 lines) the picture signal would contain roughly 5,330,000 current changes per second. If we were to increase the scanning rate to 50 pictures per second in order to eliminate flicker, this number of current changes would double, i.e. increase to 10,660,000. Now, we would find it impossible, using our circuits at present available, to handle this enormous number of rapid current changes in each second.

Each pair of current changes, that is, an increase or decrease in current followed by a decrease or increase respectively, would correspond to one cycle of current at the output of the camera. Consequently, our picture signal containing 5,330,000 current changes would correspond in a way to an alternating current of 2,665,000 cycles per second. The amplifiers handling the video frequency signals should be capable of amplifying all frequencies up to 2,665,000 cycles per second with absolute uniformity and this is a tremendous task compared with audio frequency amplifiers, which only are required to operate at frequencies up to about 10,000 cycles per second.

A signal containing more than 10 million elements would involve frequencies of about five million cycles per second, and the uniform amplification of frequencies up to this value, while not altogether impossible, is too difficult to be considered practicable.

An ingenious scanning system has been devised, however, which allows us to produce the flicker-free effect of 50 pictures/sec., without increasing the frequency of picture-signal current changes. This system is known as "Inter-laced Scanning", and is now in universal use.

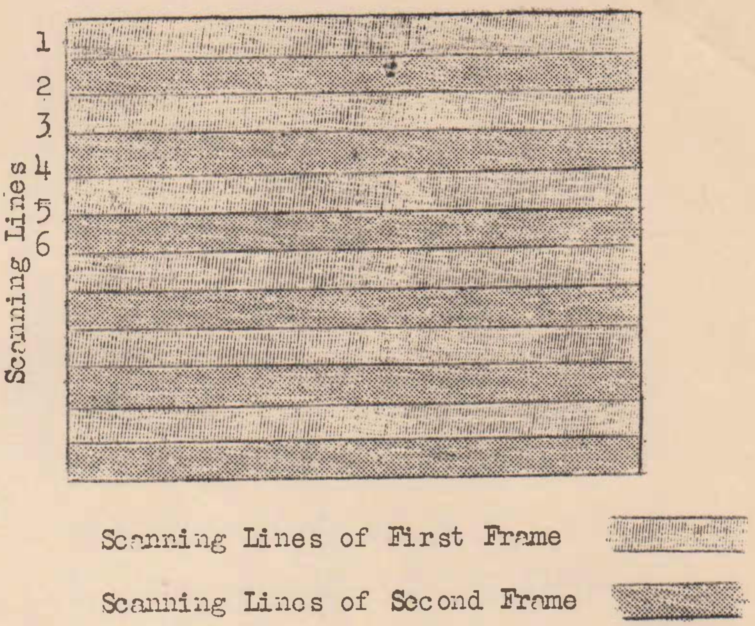


FIGURE 31. INTERLACED SCANNING.

Scanning is described as interlaced when the picture area is completely scanned in two successive steps as illustrated in a simple way in Fig. 31. Here the scanning beam covers the picture in alternate lines, 1,3,5,7, etc., leaving strips equal in width to one line between each line of the scan. When the beam has reached the bottom right-hand corner of the frame, it shifts back to the beginning and commences to cover the strips omitted in the first scan, i.e., it covers alternate lines, 2,4,6, etc. Thus all details in the picture will be covered in two operations - each operation using one-half of the total number of lines of the scanning system. If, for example, 400 lines in all are used, the picture area will be completely covered, in alternate strips, in 200 lines. This, in England, is called one frame: in America it is called one field. The second frame or field is formed by the remaining 200 lines filling in the gaps missed during the first field.

It should be noted that a single field, consisting of only half the scanning lines, will reproduce the effect of a complete picture, although such picture does not contain all the detail. The missing detail will, of course, be supplied by the succeeding field, consisting of the other half of the scanning lines. This second field will also create to the eye, at the receiver, the effect of a complete picture lacking full detail. In this way, during the time taken for a complete scanning, the eye receives the impression of two complete pictures, as against one, if the scanning were done by adjacent lines. In other words the picture repetition rate would appear to be doubled, and the flicker would be greatly reduced.

The student should take care to understand clearly how interlacing reduces flicker, and should any doubt remain in the mind the following numerical illustration should be studied where the question is tackled from a slightly different angle. Suppose 400 line, interlaced, scanning is used, the complete scanning process taking 1/25th of a second, i.e., a complete picture frequency of 25 pictures/sec. After 1/50 second, 200 of the lines would have covered the picture along alternate lines (1, 3, 5, etc.). At this instant the spot would leave the bottom right hand corner of the picture area and return to the top left hand corner commencing on line 2. Now the point to which the spot has returned is only the thickness of one line away from the position it occupied when commencing the first scan. If the receiver screen is viewed from normal distance this small displacement of the scanning spot will not be distinguished by the eye, and it appears that the spot has returned to its original position, and the second scanning is being repeated over the same lines. The apparent frequency (each picture consisting of the full 400 lines) is kept at 25 per second. As far as flicker is concerned we have achieved an effect at least as good as the 48 pictures/sec. of the cinematograph.

LIMITATIONS OF MECHANICAL SCANNING.

Mechanical methods of scanning represent great difficulties, and have many faults when high-definition pictures are required! Many of these could be listed, but we will content ourselves with considering the structure of a simple Nipkow disc designed for 400 line scanning, and, in considering the speed at which the scanning spot moves for a picture frequency of 25 per second.

Such a disc would require, of course, 400 holes arranged in an accurate spiral. If the picture is 8" high, the width of each line, and, therefore, the diameter of each disc hole, would be 8/400" = .02" (one fiftieth part of an inch). For a picture 10" X 8" an extremely large disc about 106 feet in diameter would be required as will be evident by referring again to Fig. 4, where the relationship between picture and disc dimensions is shown. The technical difficulties of constructing a disc with accurate positioning of the holes to produce adjacent lines are considerable.

Consider now the speed at which the light spot would move - this being also the speed of the outer parts of the disc. If a picture is completely scanned in 1/25 sec., each line will take 1/25 ÷ 400 = 1/10,000 sec. If the picture is 10" wide, this is the length of each line, and the speed of the spot will be 10" ÷ 1/10,000 = 100,000 inches per second. This is a speed of nearly 1 2/3rd miles per second.

It will be evident that working with these high scanning speeds, mechanical methods become almost out of the question, and we resort to electronic methods, where we use beams of electrons which can be moved about with the required agility.

SUMMARY OF DEFINITIONS AND STANDARDS:

Picture Frequency: The number of complete pictures transmitted per second. 25/sec. in England, 30/sec. in America.

Line Frequency: The number of lines scanned in one second. Line frequency = picture frequency multiplied by the number of lines in the picture.

Frame (England) or Field (America): In the case of interlaced scanning, a coverage of the complete picture area by one-half of the scanning lines along alternate strips. There are thus two or more frames or fields per complete picture. (N.B. in America the term "frame" is used to mean the same thing as "picture").

Picture Element: The smallest area of the picture which can be transmitted as a complete picture. The picture element is approximately the area of the scanning spot. (The number of picture elements is given approximately by $(\text{No. of lines})^2 \times$ Aspect Ratio).

Dot Frequency: The number of picture elements transmitted per second, divided by 2.

Aspect Ratio: The ratio of the length of the picture to its height. In England the Aspect Ratio is now 5:4; in America 4:3.

T. FM & F. LESSON 2.

EXAMINATION QUESTIONS.

1. What do you consider the three most essential requirements which must be fulfilled by a television system in order to produce a picture having real entertainment value? Give brief reasons for your choice.

2. Explain why a certain object, illuminated by "white light" appears to have a characteristic colour, say blue.

3. The scanning light spot at the transmitter passes in turn over a black area, a green area, and a white area of the picture. Explain why the photo-tube's current would rise from zero (or approximately zero) to an intermediate value, and then to a maximum value.

4. Explain the meaning of "Interlaced Scanning".

5. What is the advantage gained by interlaced scanning?

6. With the aid of a diagram, describe and explain the operation of a photo-electric cell.

7. A simple Nipkow disc containing 30 holes, is rotating at 900 revolutions per minute. What is (a) the picture frequency (b) the line frequency? (c) Give two reasons for the poor quality or the reproduced picture.

8. What is the purpose of the synchronising signals which are found in the modulation of a television transmitter's wave?

9. A television transmitter scans the scene with 180 lines at a picture frequency of 20 per sec. How many picture elements are dealt with per second if the aspect ratio is 5:4?

10. <u>Interlaced</u> scanning is carried out with a total of 405 lines and a picture frequency of 25 pictures per second. What is (a) the frame frequency (b) the line frequency?

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TELEVISION, FREQUENCY MODULATION & FACSIMILE COURSE

LESSON NO. 3.

CATHODE RAY TUBES.

The Cathode Ray tube is perhaps the most versatile and useful of all electronic devices. As has been pointed out in our first two lessons, its functions in the television field are: (1) as the picture "reproducer" in the receiver and (2) in the advanced and modified form, known as the "Electron Camera", as the source of the picture signal at the transmitter. Its advantages over other devices, used to serve these purposes, lie mainly in the fact that scanning may be performed at very rapid rates, since no mechanical movement is necessary, and also in that all control (such as synchronising the scanning of the screen at the receiver with that of the scene at the transmitter) may be achieved by purely electrical methods.

In addition, however, to these functions, the cathode ray tube may be used to serve many other purposes. For example, it may be used as an "electrostatic " voltmeter, which enables us to measure voltages (D.C. or A.C.) when other types of voltmeters may be useless due to the fact that they interfere with the normal operation of the circuit under examination. Again, the tube is incorporated into the service instrument known as the cathode ray oscilloscope or oscillograph. This device allows us actually to see a graphical representation of an A.C. voltage at any point in a radio or television receiver. The oscilloscope is practically an essential in carrying out service work on a television receiver, and the time has come when engineers and servicemen are realising just how useful this

FIGURE 1.
12" CATHODE RAY TUBE

device can be as an aid in testing and checking ordinary receivers of sound programmes. For these reasons we shall deal, in due course, with the details of circuits and operation of the cathode ray oscilloscope.

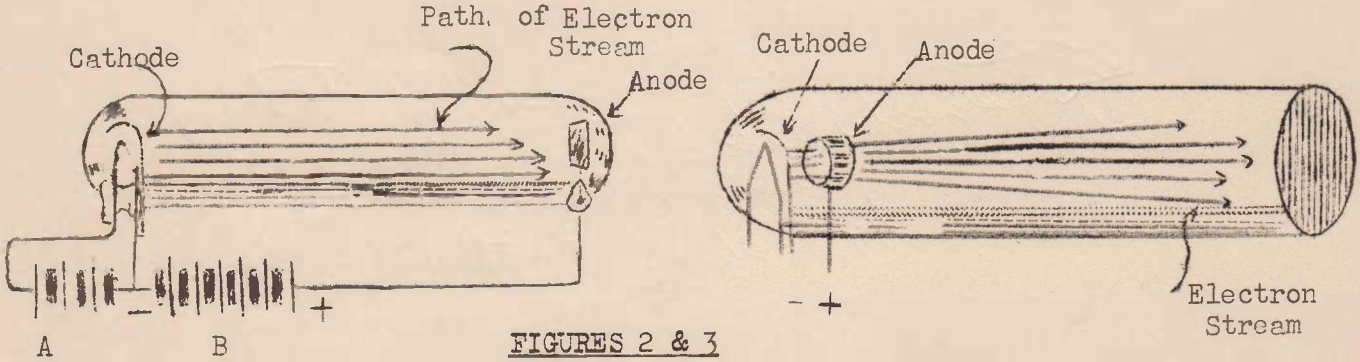
THE NATURE OF A CATHODE RAY.

The cathode ray tube is really a very special type of thermionic vacuum tube. As is usual when approaching anything new in the field of electronics (which includes television), we can always go back to the things we learned about radio in general. We almost invariably find that we have only a different adaptation of the same old principles. Here we are going back to the elementary principles of the vacuum tube.

When you first studied the behaviour of vacuum tubes used in radio, you learned that electrons, which are minute negatively charged particles, are emitted from the heated cathode and are attracted towards the positively charged plate.

Now a "cathode ray" is essentially the same as the electron stream in the ordinary tube, except that the electrons are not allowed to spread out in all directions, but travel in a beam, more or less narrow, towards the positively charged plate.

In Figure 2 we have represented an experimental type of "cathode ray" tube. Note the cathode, which is heated to a high temperature in order to cause it to throw off a "cloud" of electrons. Note also the anode or plate, to which a high positive potential has been applied, which causes it to attract the electrons from the cathode. These electrons move at extremely high velocity, in a pencil-like stream or beam. This is the "cathode ray".



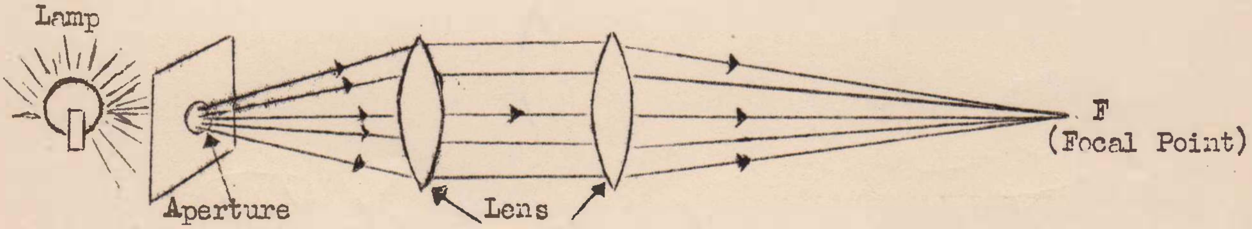
FIGURES 2 & 3

In Figure 3 we have made a slight alteration in the construction of the anode. The anode or plate has been made in the form of a ring or a short cylinder and has been brought close to the cathode or filament. The electrons are still drawn from the cathode to the anode but they are travelling so very, very fast that many of them fail to stop there and keep right on going through the anode opening and continue on towards the far end of the tube.

The greater the anode voltage, that is the greater the potential difference between the anode and cathode, the faster the electrons travel, and the more of them that get up to such a speed that they pass right through the opening in the anode. Also, the more nearly perfect is the vacuum in the tube, the faster the electrons travel, and the farther they go beyond the anode. Under certain conditions the speed of the electrons in the beam approaches the speed of light which is 186,000 miles per second.

FOCUSING THE BEAM.

The simple tube of Figure 3 produces a beam of electrons, but this beam is not "focused". To focus the beam we must "squeeze" all the electrons together so that they do not spread out. We want these electrons gradually to converge, so that they all strike the far end of the tube at practically the same point. The idea of focusing may be illustrated by reference to the action of a lens system on light rays. In Figure 4 the rays from the source are diverging, or spreading out. The first lens bends these rays, to some extent, towards each other, that is, it produces a partial focusing effect. The second lens completes the action by further bending of the rays until they all converge towards a point "f", called the focal point.



FOCUSING LIGHT RAYS BY MEANS OF A LENS SYSTEM.

FIGURE 4.

Although two lens are shown in Figure 4, light rays may be focused by means of a single lens, although the effect is usually less perfect. Further, a lens system consisting of more than two is sometimes used, this producing still more perfect results.

In the case of the electron beam in a cathode ray tube, a method of focusing is necessary, because, no matter how narrow the beam is as it leaves the cathode, it will always tend to spead out. This is due to the fact that the electrons are all negatively charged, and will therefore tend to repel each other outwards. Three methods may be used for focusing:

(a) By the use of a trace of gas in the tube
(b) By the use of electrostatic fields.
(c) By the use of magnetic fields.

(a) The method of gas-focusing, as it is called, used to be very popular for laboratory work on account of its simplicity. A small quantity of inert (i.e. inactive, chemically) gas, such as argon or helium, is introduced into the tube before it is sealed off. This means that the space in the tube will be filled with gas molecules, or particles, which will be in the way of the electrons as they shoot up the tube. The electrons will collide with the gas molecules and "ionise" them by collision. This means that when a collision occurs the moving electron of the beam knocks off, or forces out, one or more electrons belonging to the gas molecule. The molecule, being electrically neutral in its normal state, is thus left with a positive charge, and is now called a position ion. After the electron beam has passed up the tube we can therefore imagine its path strewn with positive ions. These will act as a kind of core to the beam, and, being positive, they will therefore neutralise the repulsion existing between the electrons. As a result the beam will cease to fan out and will eventually become narrower, i.e. it will be focused on the screen.

The principal advantage of gas-focusing is the low anode voltage required, and some tubes will operate on 300 volts. On the other hand the beam is only sharply focused for one particular value of beam intensity. In television receiver work it is necessary to vary the beam intensity to correspond with the varying degrees of light and shade of the picture elements. We therefore require some different focusing method, one which will maintain a good focus of the beam as its intensity, or strength is varied. Again, when gas-focusing is used, the focus is lost, and distortion occurs, when the beam is deflected or moved about at high frequencies over the screen. Hence the method is unsuitable for television scanning purposes, where it is required to move the beam at the line-frequency, which in the case of a 400 line, 25 pictures per second, system is 400 X 25 = 10,000 cycles per second. For these reasons gas-focused tubes are not used in television, but are included here in order that the student will have a picture, as complete as possible, of the most important device, the cathode ray tube.

<u>ELECTROSTATIC FOCUSING</u>. The electrode assembly for producing a focused electron beam in an electrostatic type tube is shown in Figure 5. Note, by the way, that the glass envelope shape has been altered to allow of a longer screen.

As will be seen, there are now, in addition to the cathode, three electrodes within the tube. These include two anodes, and a control electrode occasionally called the grid. The latter, to which a negative potential is applied in relation to the cathode, performs the same function as in an ordinary amplifying tube, i.e. it controls the value of the electron stream which flows from the cathode towards the anodes. Note, however, that this control electrode has a very different structure from the grid of the tubes you are familiar with.

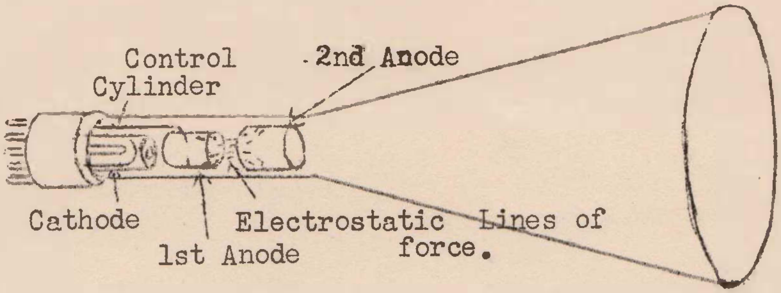


FIGURE 5.

It consists of a hollow cylinder which almost completely surrounds the cathode except for a small hole in its end. Being negative, the walls of the cylinder will turn back any electrons which happen to be thrown out towards them by the heated cathode. If the anodes are sufficiently positive, however, a thin stream of electrons will be drawn through the control cylinder's aperture. In this way, the control cylinder serves the additional function of aiding in the beam focusing action.

The two anodes are in the form of hollow cylinders (Fig. 5). The one nearer the cathode is called the "first", or the "focusing" or the "accelerating" anode. The other is called the "second" or "main" anode. Both are given a high positive potential with respect to the cathode, but the voltage on the second is usually about three to five times as great as that on the first. For example, if the first anode is at a potential of, say 600V, the second would be in the vicinity of 3,000 volts. In the case of tubes used in television receivers for picture reproduction the final anode is worked at voltages ranging from 2,000 to 10,000. These very high values are necessary to produce on the screen a picture of satisfactory brilliance. Oscilloscope tubes usually work at lower voltages than these, although the potential of the second anode is rarely below about 1,000 volts.

The anode assembly, in addition to performing the functions of forming the electron beam (the "cathode ray"), also serves the purpose of focusing it to a fine spot on the screen at the large end of the tube. To assist in explaining how the focusing effect is brought about the student should refer to Figure 6, which shows in diagrammatic form the electrode assembly.

The first anode, by virtue of its positive potential, attracts electrons from the cathode through the control electrode's aperture, so forming a fairly narrow beam. By the time these electrons have reached the vicinity of the first anode they are travelling at high speed and tend to shoot straight through this hollow electrode. They then come under the influence of the more positive second anode which accelerates them to an even greater speed, with the result that they pass right on, finally striking the screen at the far end of the tube.

Note that, after the electrons leave the grid aperture, they fan out, as explained earlier. On entering the electrostatic field existing between the

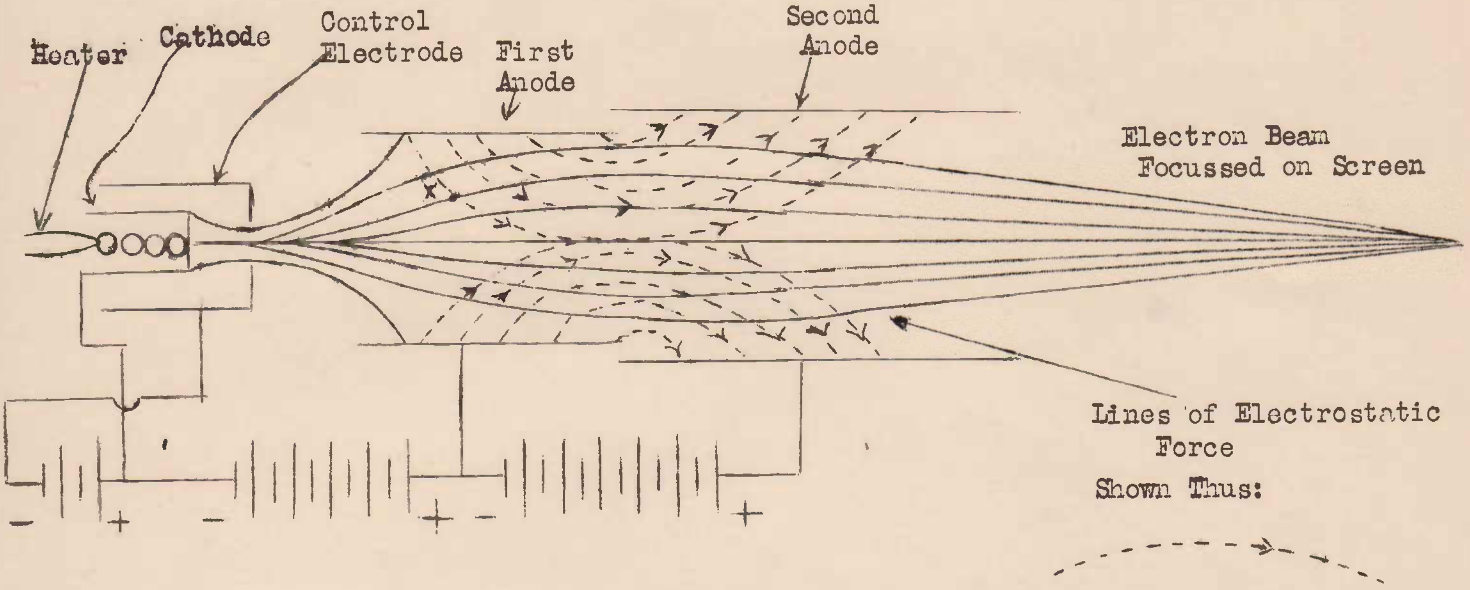


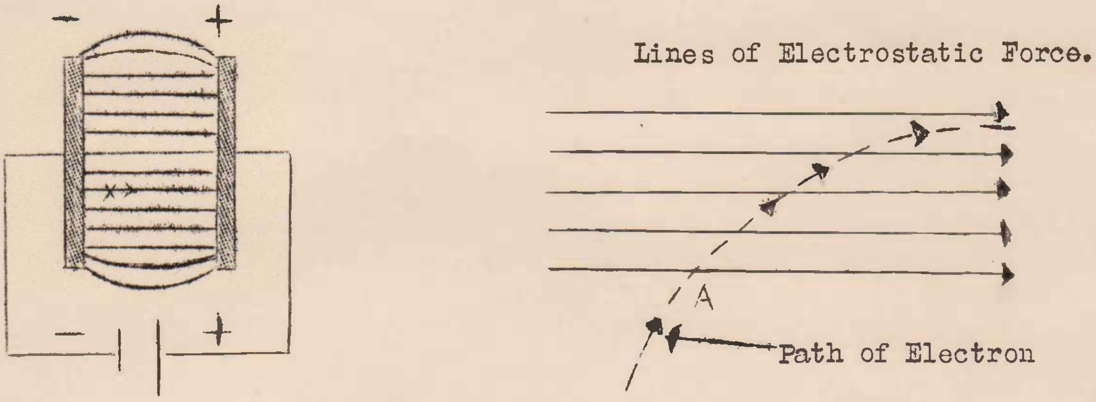
FIGURE 6.

two anodes, however, their paths are shown bent inwards towards the central axis of the tube. The net effect is that, no matter in what direction the individual electrons were travelling when they entered the field of the anode assembly, they are all travelling in converging lines after leaving it. These paths are such that all the electrons in the beam will meet over a very small area on the screen's surface, provided that the voltages are correctly adjusted.

In order to understand how the electron paths are "bent" to bring about this focusing action, it will first be necessary to recall a few points about electrostatic fields.

An electrostatic field is the type of field set up between the plates of a simple two-plate condenser when a potential difference is created between them, as in Figure 7 (a). The battery forces a negative charge on the left hand plate, and positive charge on the opposite plate. The lines drawn between the plates are called "lines of electrostatic force" and simply represent the lines along which forces will act upon any charged particles placed in the field. For example a negative electron at X will be impelled along the line in the direction of the arrow, for it will be attracted by the positive plate and simultaneously repelled by the negative.

The heavy lines in Figure 7 (b) represent an electrostatic field, the arrows representing the direction of the force which would act upon a negatively charged particle. Suppose an electron travelling in a straight line at high velocity enters the field at A. Immediately the field is entered a force



"A" "B"

FIGURE 7.

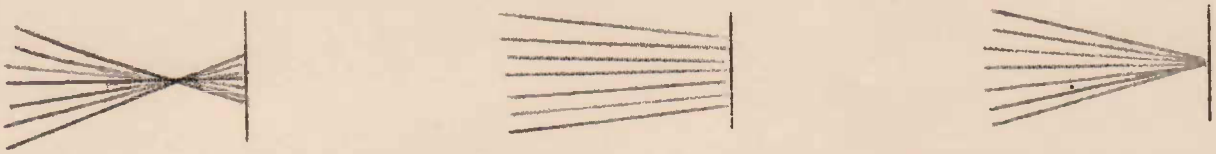
will act upon the electron in the direction of the lines of force, viz., horizontally to the right. The result is that the electron's path will be curved to the right, i.e. in the direction of the field.

Referring again to Figure 6, an electrostatic field exists between the first and second anodes, since they are at different potentials. The dotted lines with the arrows represent the direction of the forces which will act upon electrons in the field. An electron which travels straight along the central line or axis of the tube will not be deflected to right or left, because it is travelling parallel to the lines of force.

In the event, however, of an electron diverging from the central path after leaving the central cylinder, the case is different. Suppose such an electron enters the field between the two anodes at X, so that it is moving partially across the lines of force. In this case the electrostatic field will exert a force, acting in the direction of thedotted lines, with the result that the electron's path is bent so that it is turned back towards the central line as shown. The greater the extent to which the electrons have diverged, or spread out, before entering the anodes' field the greater will be the amount of bending of their paths. The net result is that, providing this field is of the correct strength, all electrons will converge in such a way that they strike the distant screen at practically the same point, i.e. the beam is focused.

In practice the job of bringing the beam to a sharp focus on the screen at the end of the tube is achieved by using a potentiometer to vary the voltage on the first anode. Since the second anode is usually worked at a fixed potential, any change to that of the first will alter the potential

<u>difference</u> between the two, and hence the strength of the electrostatic field. If this field is not exactly the correct value the beam will tend to focus at a point in front of the screen, or beyond it. In the former case the electrons will converge to a point, and then diverge or spread out again as at (a) in Figure 8. In the latter case the screen will intercept the moving electrons before they reach their point of focus, as at (b) in Figure 8. The result will be the same in both cases - instead of seeing a small, sharp spot of light on the screen, there will appear a large area of light with ragged edges. Correct **focussing** is shown at (c) Figure 8.



Incorrect Focussing

"A"

Incorrect Focussing

"B"

Correct Focussing

"C"

<u>FIGURE 8.</u>

Although we have assumed two anodes in discussing the focusing action, modern electrostatic tubes for television purposes usually employ three anodes. This allows of a more nearly perfect focusing of the beam for all degrees of beam intensity. When two anodes only are used, alterations to the control cylinder potential tend slightly to de-focus the beam. This, of course, is undesirable. A three-anode assembly may be compared with a three-lens optical focusing system used for cinematograph or other purposes when a sharply focused light beam is required. In the case of these tubes, focusing adjustments are usually made by potentiometer control of the potential on the <u>second</u> anode, the potentials on the first and third being maintained at fixed values.

The electrode assembly of a modern three anode television tube is shown in Figure 9. This picture also shows the "deflecting" plates, which have yet to be discussed.

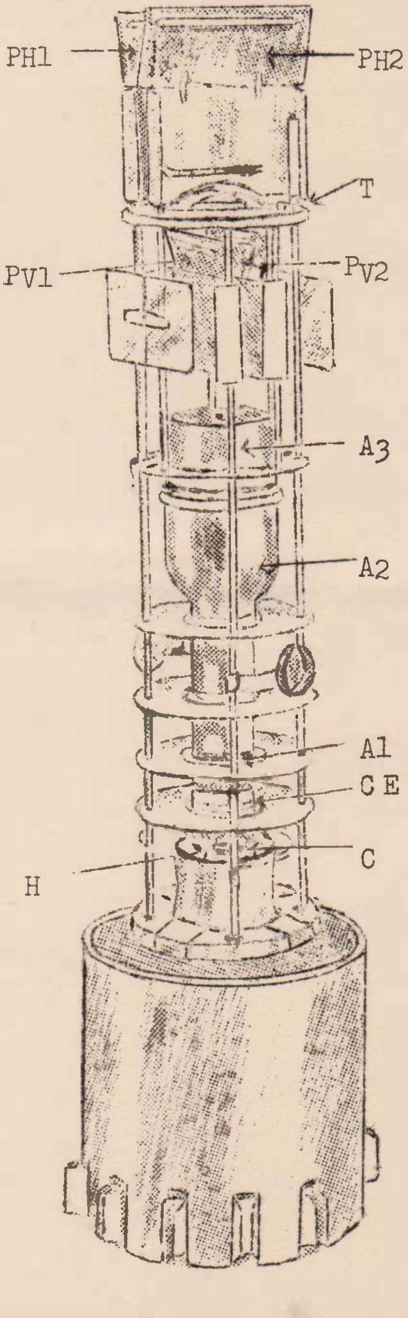
Although, in our explanations of focusing - action above, the anodes were described as consisting of short hollow metal cylinders, their structure may vary from this in the case of a tube as illustrated in Figure 9. One or more of the anodes may consist of a simple circular disc of metal having a central hole or aperture. (see Figure 10 (b)) Another common structure consists of a cylinder fitted with one or two apertured discs as in Figure 10 (c). In all cases the theory of the focusing action is similar to that explained for simply hollow-cylinder construction. It should be noted that in the case of a multiple-anode tube, each anode, or rather the electrostatic field existing between any two anodes, forms an "electron lens" (analogous with a light lens) and helps in the focusing action. The complete job of focusing is a function of the whole assembly, as in a multiple-lens light beam system.

MAGNETIC AND ELECTRO-MAGNETIC FOCUSING.

It has long been known that moving electrons may be deflected in their paths by means of a magnetic field, and experimenters hit upon this method of cathode-ray focusing quite early in the history of cathode-ray tubes. As a matter of fact magnetic focusing was used before electrostatic and hence the order in which we have dealt with the subject here is not identical with that of its historical development.

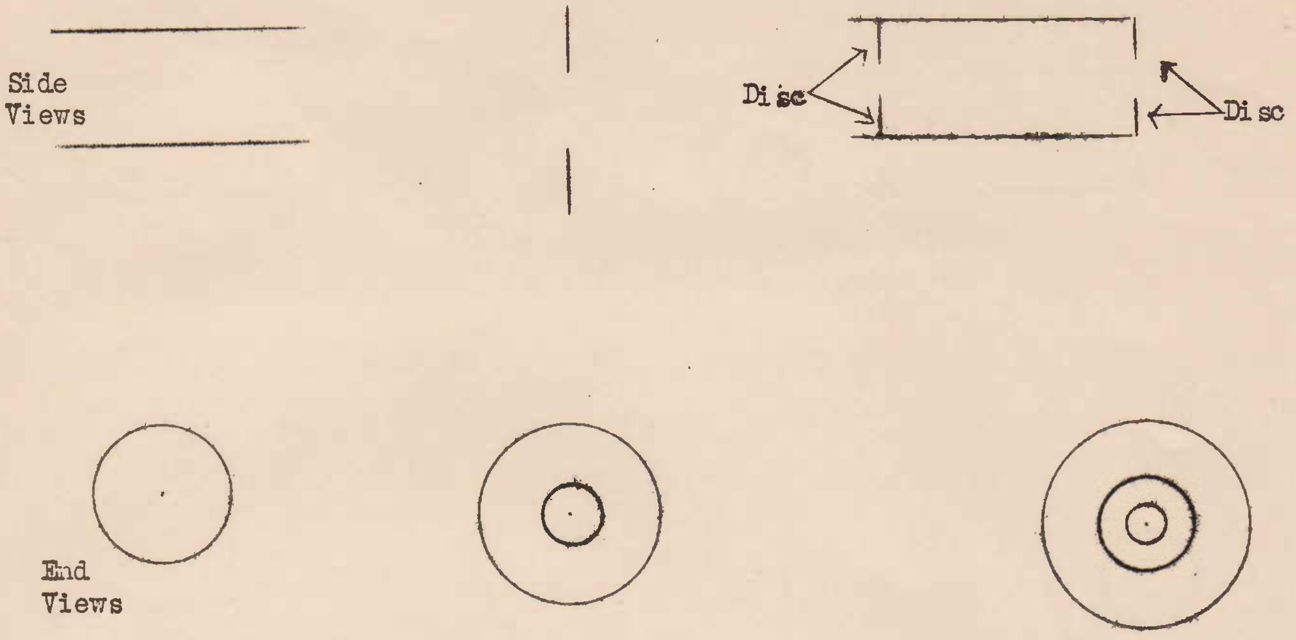
Let us summarise the important facts in relation to the action of a magnet field upon moving electrons. Firstly a magnetic field is the field of force set up by either a permanent magnet, or a coil of wire carrying a current. Figure 11 shows the nature of the fields of a straight bar permanent magnet and of a "solenoid" type of coil.

The "lines of magnetic force" are usually regarded as running, outside the magnet, from North Pole to South Pole. Note that the field outside the coil at (b) Figure 11 is exactly similar to that of the bar magnet at (a). Hence the right-hand end of the coil will act as a North Pole, and the left-hand end as a South. Inside the coil, however, the lines are parallel and concentrated and run in the opposite



INTERNAL STRUCTURE OF CATHODE RAY TUBE.

FIGURE 9.



Cylinder
(a)

Disc
(b)

Cylinder with Discs
(c)

Three types of Anodes -Longtitudinal Sections above, end sections below.

FIGURE 10.

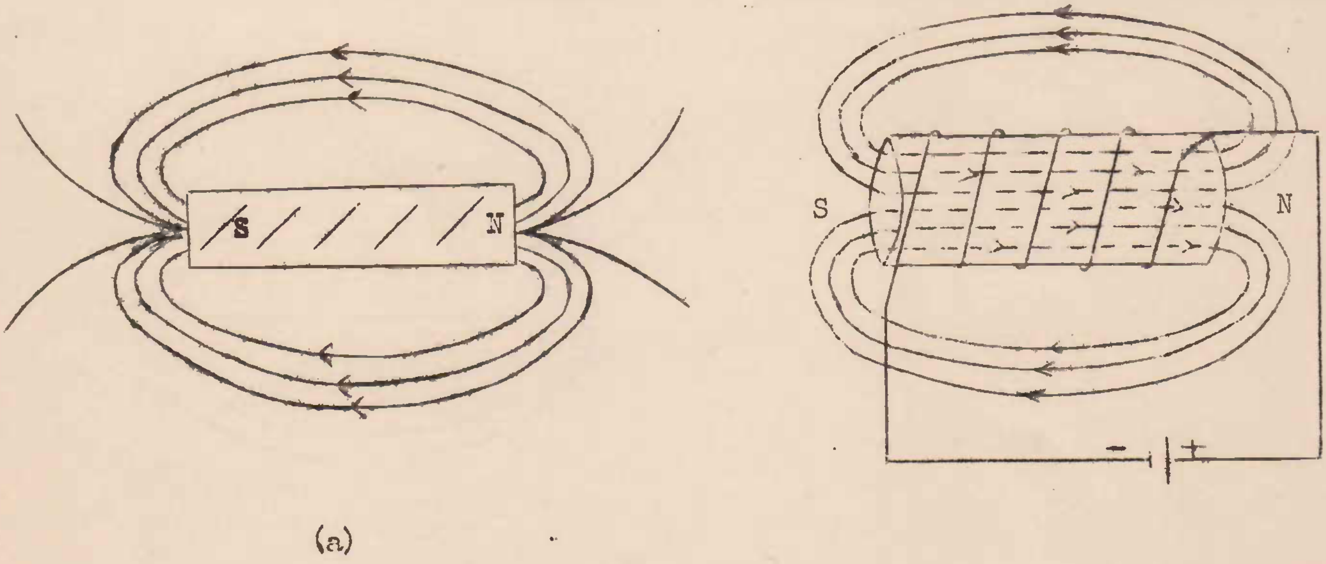
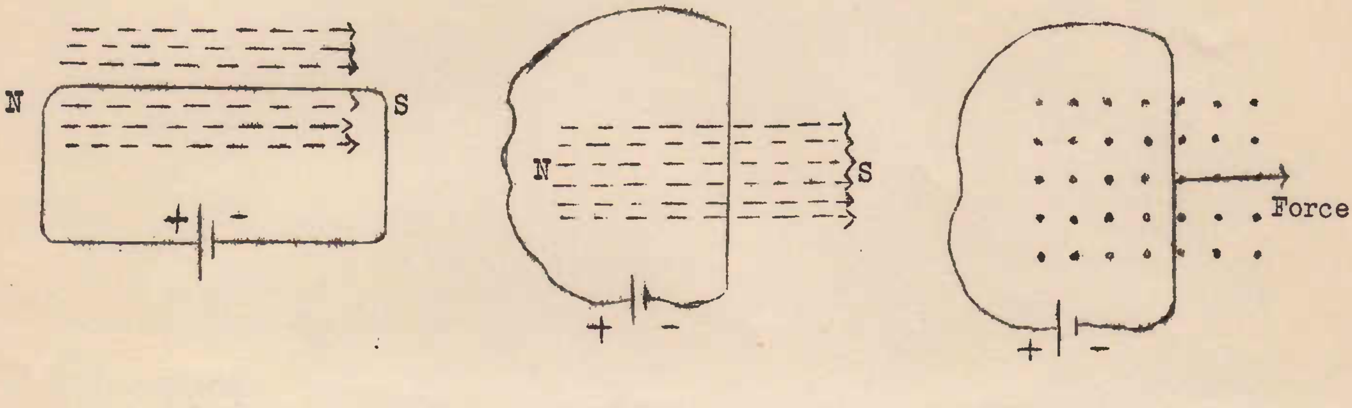


FIGURE 11.

direction. It is this part of the field in which we are interested when dealing with electro-magnetic focusing.

Consider, now, the well-known action of a magnetic field on a conductor, such as a straight piece of wire carrying an electric current in a magnet field. This is the underlying principle of the electric-motor. At (a) in Figure 12 the current-carrying conductor is lying parallel to the field - i.e. the current is flowing parallel to the field. In this case there is no force whatever acting on the conductor. At (b) the current is flowing across the field, i.e. at right-angles to it.



(a) (b) (c)

FIGURE 12

We now find that a force will act on the conductor, impelling it <u>out from the paper</u>. At (c) we have depicted the situation at (b), but now viewed "end-on" to the lines of magnet force, which are therefore shown as dots. The force on the conductor is to the <u>right</u> as shown. Note, then, that when a current carrying conductor lies across a magnet field, a force acts upon it in a <u>direction at right-angles to both the lines of force of the field and to the conductor itself</u>.

If we now remember that a current in a solid conductor is simply a flow, or drift, of electrons through that conductor, we may deduce the action of a magnetic field upon a stream of electrons, such as constitute the beam in a cathode ray tube. Such a beam may be regarded as an electric current <u>in space</u>, and the forces acting upon it when it enters a magnetic field will be exactly similar to those which act upon a current in a solid conductor.

Referring to Figure 13, suppose we are viewing a magnetic field "end-on" (as was done at (c) in Figure 12). The dotted line represents a stream of electrons, travelling at high velocity, and entering the field from the direction as shown. These moving electrons, representing a "current" will, when they enter the field, experience a force acting always at right-angles to their direction of motion. The result will be that each electron's path will be turned, or deflected, continually to the right. The path of an electron beam will therefore be a <u>spiral</u> as shown.

The principle construction of magnetically focused cathode ray tube is shown in Figure 14.

The cathode and grid structure are as previously described. The anode here consists of a simple disc with a central aperture. The focusing coil is wound around and outside the tube. The magnetic field produced inside the tube is as shown. A steady direct current is passed through the coil. After the electron beam passes through the hole of the anode, some of the electron path's begin to fan out. Electrons which pass directly down the central axis of the tube move parallel to the lines of magnetic force, and are therefore not affected by the latter. An electron which has "fanned-out" however, will enter the field at an angle. Cutting across the lines of force it will experience a force at right-angles to the lines of magnetic force and at right-angles to its direction of motion.

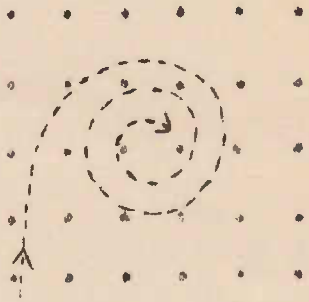


FIGURE 13.

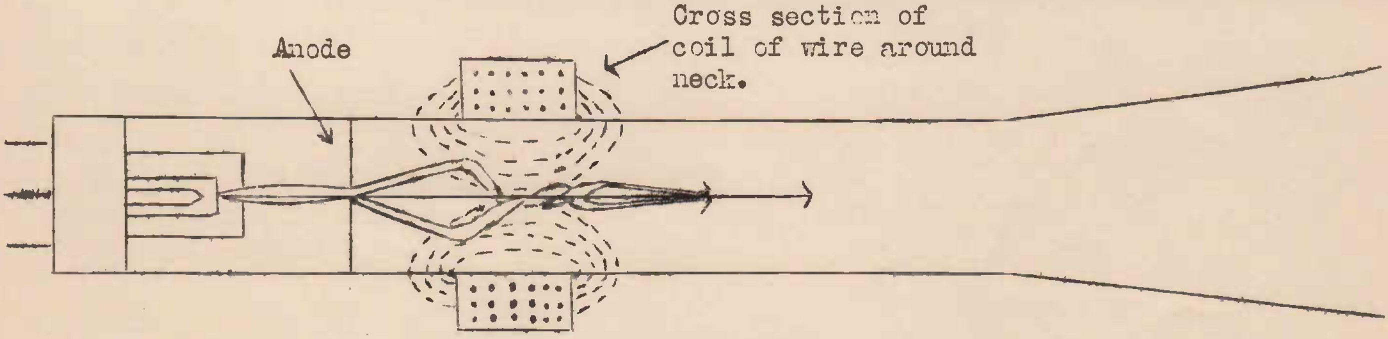


FIGURE 14

It will therefore, while in the field, move in a spiral path. At the same time it also possesses a general movement down the length of the tube. To visualise the net path taken by the electron, imagine a coil of wire wound on a tapered point of wood as in Figure 15, a battery being connected so that an electron-stream flows in the direction shown.

In this way all electrons, which enter the coils field (Figure 14) at an angle, will commence to rotate around the central axis of the tube as they continue their motion towards the screen. Moreover, the whole time, as a result of the spiral motion they will be getting closer and closer to this central axis. Of course, as soon as the electrons leave the magnetic field the spiral rotation will cease, but they all will possess an inwards motion, which is carrying them closer and closer towards the central axis. At some distant point, which should be on the screen, all electron paths will converge together, and we will have a sharply focused beam.

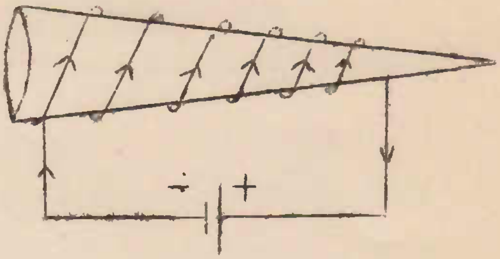


FIGURE 15

The focusing coil is often enclosed in a soft iron hollow ring-like case, in which has been left an air-gap. (Figure 16) This confines the magnetic field within the coil, except for those lines which "escape" through the gap. In this way a more concentrated field within the glass tube is obtained, and "stray" fields, which upset the focus, are avoided.

The factors which affect the focus are the position of the coil in relation to the anode, and the magnitude of the current. In practice, provision is made to adjust both of these. A rough focus is obtained by moving the coil on the neck of the tube, and a final adjustment, to sharpen the focus is carried out by adjusting the value of the coil's current.

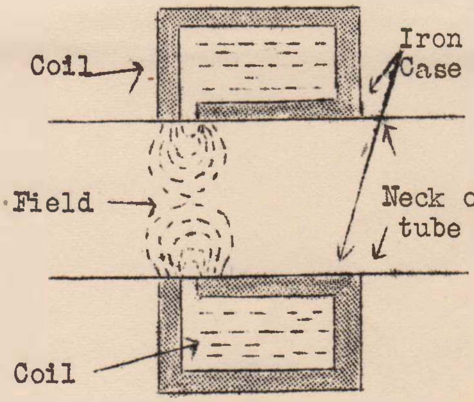


FIGURE 16.

MAKING THE ELECTRON BEAM VISIBLE.

We have so far seen how it is possible to produce a high-velocity stream of electrons which strike the large end of the tube at its central point. We have discussed the methods by which this beam may be narrowed down until its dimensions, at the point of impact on the screen are almost as small as we choose to make them. If the "cathode-ray" is to replace the light beam of mechanical systems for television scanning purposes, it remains to render the beam visible by causing it to give out light waves as it strikes the screen.

FLUORESCENCE.

As you look at an amplifying tube in action, you see no visible evidence of the flow of electrons within the tube -- at least you see no evidence when the tube is being operated properly. In the cathode ray tube, having a high degree of vacuum, you likewise see nothing of the ray as it travels through the length of the tube.

The end of the ray is made visible by a property of certain substances which is called "fluorescence". When a film of such a substance is struck by the cathode ray there is produced a bright glow where the substance is caused to fluoresce. There are a number of such substances, among them being zinc orthosilicate, called "willemite", also calcium sulphide and calcium tungstate. Instead of describing these substances by their chemical names, we generally refer to them by number, such as "Phosphor No. 1" and so on. Phosphor No. 1 produces a green light, Phosphor No. 2 produces a bluish white light, Phosphor No. 3 produces a yellow light, Phosphor No. 4 gives a white light and Phosphor No. 5 gives a blue light. Phosphors 1, 2, 3, and 5 are used mainly in cathode ray tubes intended for use as electrical test instruments, while Phosphor No. 4 has been specially developed for television purposes as it produces a black and white picture similar to ordinary moving pictures.

In the cathode ray tube we now apply one of these fluorescent substances, preferably Phosphor No. 4, to the far end of the tube. Then as the cathode ray strikes this surface of prepared glass there is produced a bright spot of light having a size proportional to the size of the ray and a brilliancy proportional to the strength of the ray.

Just like the grid in a radio valve, the control electrode is given a negative bias with respect to the cathode. The amount of bias determines the amount of electrons which it allows to pass through to the rest of the tube and consequently determines the brilliancy of the picture. Making the control electrode more negative, reduces the number of electrons and dims the spot of light, while making the control electrode less negative increases the electron flow and makes the spot more brilliant.

Just as the signal voltages are applied to the grid of an amplifying valve and produce changes in plate current, so the signal voltages, from our television receiver, are applied to the control electrode of the cathode ray tube and produce corresponding changes in the brilliancy of the spot of light.

POWER SUPPLY FOR CATHODE RAY TUBES.

We shall first consider the question of supplying the various electrode potentials and the heater current for a typical three-anode electrostatic type tube.

The majority of these tubes require 2,000 - 6,000 V on the final anode, and for television purposes the latter figure is the most common. The potentials gradually increase from the small negative potential (say 50 V max.) for the control electrode to the high positive potential on the final anode. These voltages are invariably obtained by a chain of resistances across an H.T. supply from a rectifier. These resistances form a voltage divider which allows us to tap off the required voltage for each electrode. A typical power supply is shown in Figure 17.

It will be noted that the final anode is at earth potential, while the cathode is at a high (5000 V <u>negative</u>) potential with respect to ground. This is common practice in electrostatic type tubes, and the reason will be fully understood after reading the section on "deflection" later in the lesson. If should be fully realised now, however, that the third anode, although at zero potential with respect to earth, is at a positive potential of 5,000 V with respect to the <u>cathode</u>.

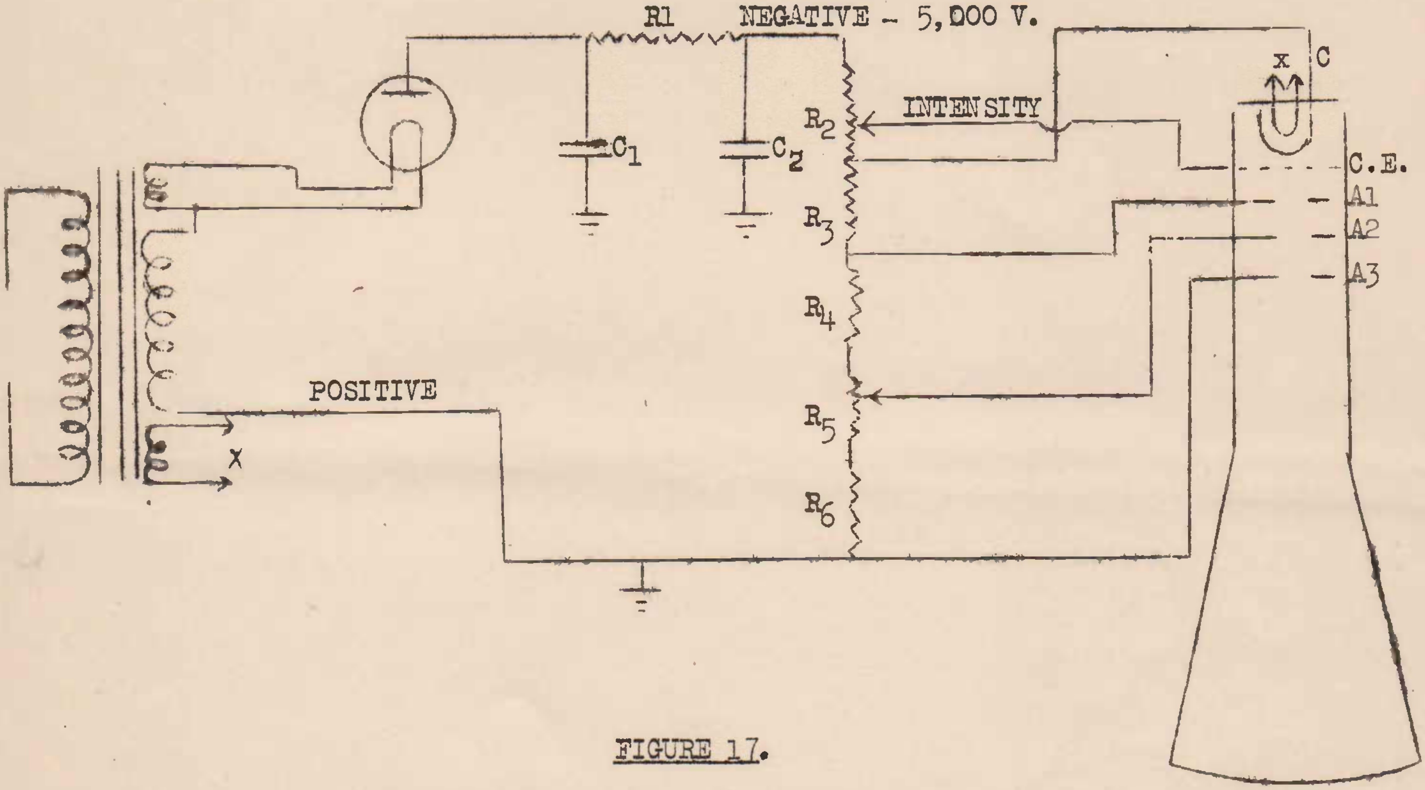


FIGURE 17.

The current taken by the electrodes is very small, and the only drain on the H.T. supply apart from the resistance load is the current which flows in the beam itself. This seldom exceeds 100 micro amperes (0.1 m.a.). As a consequence the design of the power supply is greatly simplified. For example resistance capacity filtering or smoothing may be used. Condensers C_1 and C_2, a Resistor R_1 and the other resistors in the chain form the filter circuit. In practice R_1 and C_2 may be omited, C_1 being simply a small capacity (.5 or .25mfd) of high voltage rating. The total resistance in the chain may be as high as 10 Megohms.

The Intensity Control is a potentiometer which allows the negative potential on the control electrode, with respect to the cathode, to be adjusted. This, as has been explained varies the beam's intensity, and therefore the brightness of the spot on the screen. In a television receiver, the video signals are also applied to the control electrode.

The Focus control allows of adjustment to the second anode's (A2) potential. Correct setting of this control produces a sharply defined spot on the screen. In a two-anode tube the focus would be controlled by adjustment to the potential of the first anode.

Note that the cathode, and the heater, which is connected electrically to it, are at a high negative potential with respect to the metal chassis. The transformer heater winding for the cathode ray tube must therefore be insulated for high voltages.

In the case of magnetically focused tubes there are usually only two voltages to supply -- that for the control electrode and for the single anode. The cathode is usually at ground potential, while the anode is at a high potential (positive) above ground. The focusing coil is supplied with a low voltage direct current from a separate supply.

DEFLECTION OF THE BEAM.

The cathode ray tubes so far described are capable of producing a sharply focused electron beam which will result in an intense spot of light which remains stationary at the centre of the circular screen. In order that the tube might be a useful instrument either as a television picture reproducer or as an oscilloscope, it will be necessary to provide means whereby the spot of light may be moved to any point of the screen.

This is accomplished by bending, or deflecting the electron beam, within the tube, sideways, or upwards, or in both directions simultaneously. Deflection of an electron beam may be brought about, as we have seen in principle when dealing with focusing by means of (a) an electrostatic field, or (b) a magnetic field. Both methods are in use in modern tubes.

ELECTROSTATIC DEFLECTION.

Consider first the moving of the beam vertically across the screen. This may be done by two more or less flat and parallel metal plates, called "deflector" plates, within the neck of the tube, and on the screen side of the final anode. (Figure 18.)

These plates are placed horizontally, and have connections which pass through the glass walls of the tube. Sometimes one plate is connected internally to the final anode, and is therefore at ground potential.

If both plates are connected to ground the beam will pass straight through them, without deflection, and will strike the centre of the screen. Suppose now we apply a potential difference between the two plates by means of a battery as in Figure 19. The electrons in the beam will be attracted towards the positive plate and repelled from the negative as the beam passes between them. This will cause a bending of the beam upwards as shown. The spot will now be found

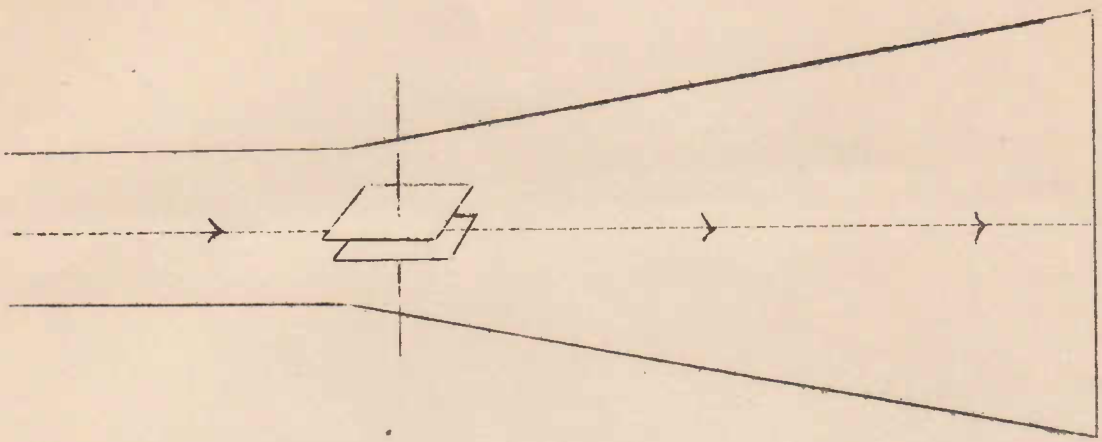


FIGURE 18.

at the point X on the screen directly above its central point.

The amount of bending of the beam, and therefore the amount of movement of the spot away from the centre of the screen will depend on several factors:-

(a) The potential difference between the deflector plates. (b) The length of the deflector plates.
(c) The anode voltage used in the tube.

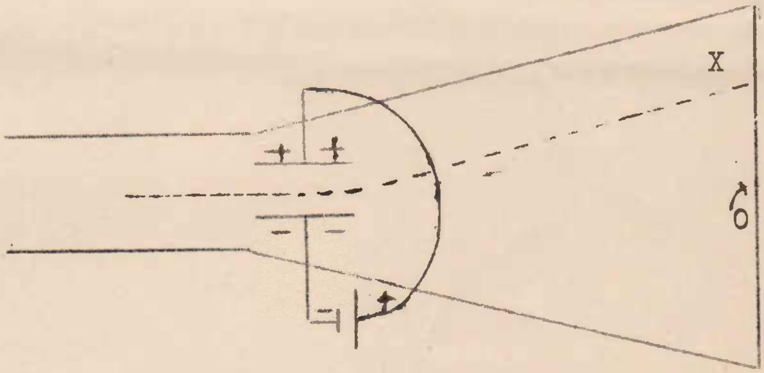


FIGURE 19.

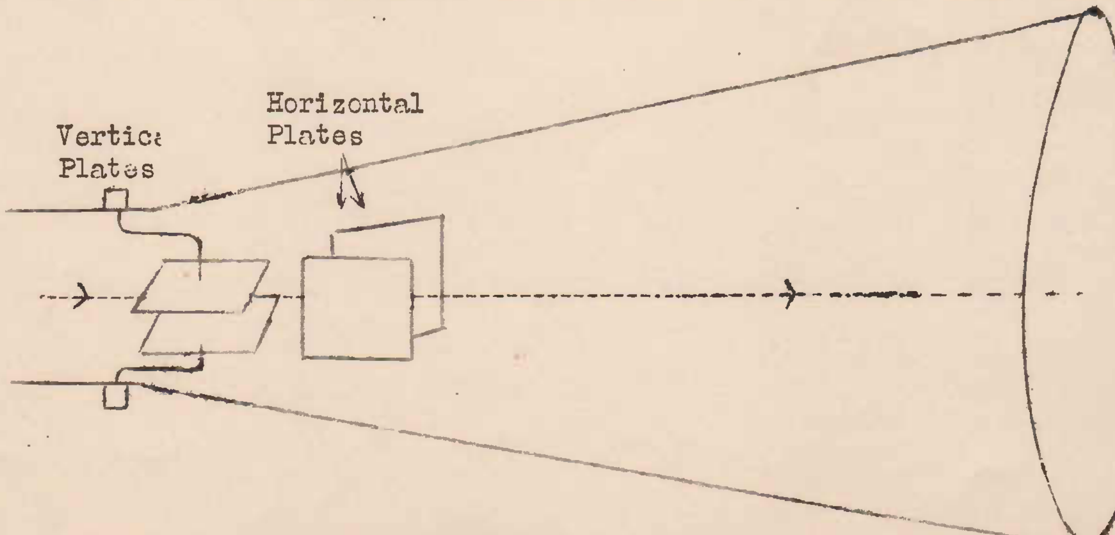
Concerning (a), the deflection will be found to be almost exactly proportional to the applied P.D. between the plates. For example if the voltage is doubled, the movement of the spot away from the centre of the screen is doubled, and so on. It is this fact which allows the cathode ray tube to be used as an electrostatic voltmeter. If the number of volts required to produce say 1 cm deflection of the spot is known for a given tube (operated under given conditions of anode voltages), an unknown voltage may be measured by applying it between a pair of deflector plates, and measuring the actual deflection of the spot.

With reference to point (b) above, the longer the plates, then the greater the length of time during which each electron is passing between them. If the electrons remain a longer time under the influence of the plates the greater will be amount of the bending of their paths. The plates cannot, in practice, be made too long, however, for this would limit the amount of deflection which could be obtained. A large deflection might possibly result in the electron stream actually striking the plates before emerging from between them. To avoid this the plates are often flanged out as may be seen by reference to Figure 9.

The final point (c) is of importance. If the anodes' voltages are increased the electrons in the beam will be given an increased velocity. For a given deflecting force produced by the deflector plates, the actual amount of bending of the beam will now be decreased (and vice versa). This effect may be understood if one imagines a ball thrown <u>across</u> wind. The faster the ball is thrown, the less will be the deflection, or curving of its path.

<u>Deflection Sensitivity</u>. This term is used in order to compare the ease with which the spot may be deflected from the central point of the screen, of different types of tubes, or for the one tube working under different <u>anode</u> ratings. The deflection sensitivity is defined as the amount of deflection, measured in millimetres, produced by a potential difference of one volt applied between a pair of deflector plates. This value, in the case of high voltage tubes, works out usually as a fraction of a millimetre. Since 1 mm equals about 1/25 of an inch it will be seen that quite a large voltage will be required to move the spot right to the edge of the screen. For example, suppose that the deflection sensitivity for a pair of plates of a tube is given as 0.25 mm/volt. If the tube's screen is 12 inches in diameter, the spot must be moved 6 inches to move it from the centre to the outer edge. This deflection is 6 X 25 = 150 m.m., taking 1 inch = 25 mm. The potential difference required between the deflector plates will be $150 \div 25$. volts = $150 \div \frac{1}{4} = 600$ volts. To move the spot right across the screen from one side to the other, a distance of 12 inches, a total potential difference <u>change</u> of 1200 volts will be required.

It should be noted that the deflector plates of Figure 19, which are mounted horizontally will produce only a <u>vertical</u> movement of the spot. If it is desired to move the spot horizontally across the screen as well, a second pair of plates is required. These will be mounted vertically, but are called <u>horizontal</u>



<u>FIGURE 20.</u>

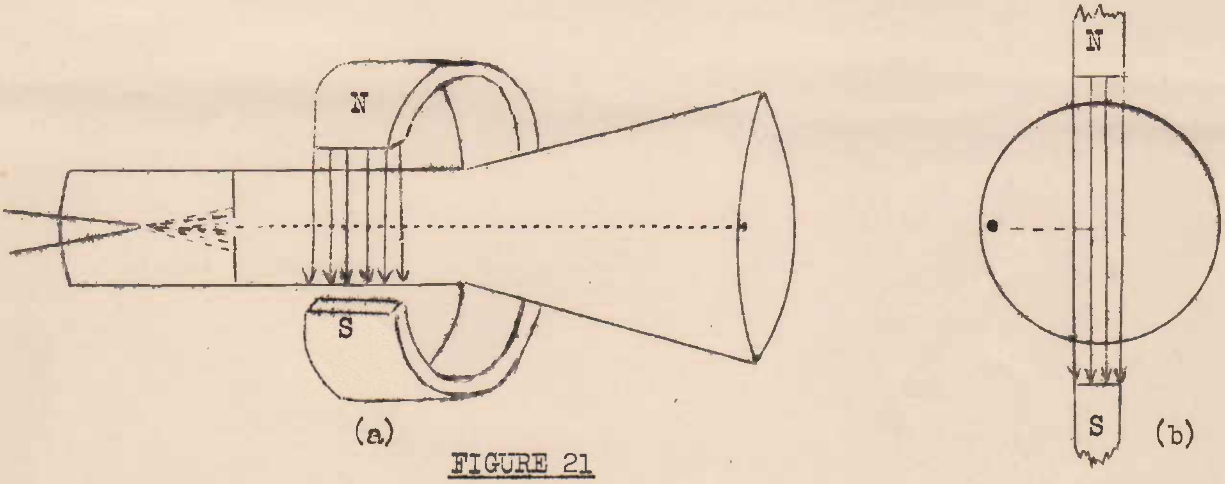
deflector plates because their action on the beam and spot is in a horizontal plane or direction. The two pairs of plates are shown in Figure 20.

MAGNETIC OR ELECTRO-MAGNETIC DEFLECTION.

The deflection of the beam explained in the last section was brought about by utilising the electrostatic field produced between a pair of plates, which may be regarded as forming a simple condenser, when a potential difference was applied between them. A magnetic field may, however, also be used for deflection of the beam.

The effect of a magnetic field was explained in some detail when dealing with magnetic focusing, and this section should, if necessary, be re-read. The important point to remember is that the bending of the electron is at right-angles to (not parallel with) the lines of magnetic force.

Magnetic deflection is illustrated in Figure 21, where a horseshoe permanent magnet produces vertical lines of force through the tube. When the moving electrons pass through this field, their paths will be bent outwards from the paper towards the observer. At (b) in this figure, the front view of the screen's tube is shown, where a deflection of the spot to the left is indicated. Of course, if the polarity of the magnet (and therefore the direction of the lines of force) were reversed, the spot would be moved to the right. The amount of deflection obtained will depend upon the strength of the magnetic field, as well as upon other factors mentioned under electrostatic deflection.



(a) (b)

FIGURE 21

The magnetic field produced by a current carrying conductor is exactly the same as that produced by a permanent magnet. The two magnetic poles shown in Figure 21 may therefore be replaced by a pair of coils to produce a similar field for deflection. Such a pair is shown in Figure 22. The coils, are placed on either side of the neck of the tube and are shaped like a saddle to fit the rounded glass surface. In this case the coils produce a horizontal field through

the tube, and are therefore used for <u>vertical</u> deflection. To obtain horizontal deflection a separate pair of coils would be required. These would be placed horizontally one above, and one below the tube.

The amount of deflection occurring will depend on the number of turns in the pair of coils concerned, and upon the current flowing (as well as the speed of the electron beam which is controlled by the anode voltage used, as explained above under electrostatic deflection). The deflection may therefore be controlled by varying the current in the coils. Reversing the direction of current flow will reverse the magnetic field produced and will therefore cause a reversal of deflection of the light spot on the screen.

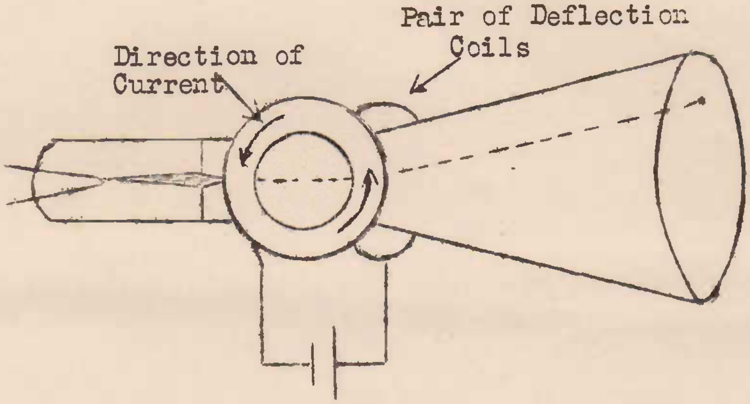


FIGURE 22.

Cathode ray tubes which use magnetic focusing and deflection usually have but a single anode, which may take the form of a disc with a central aperture as shown in Figure 21. In some cases the anode is simply a conducting coating on the inside of the tube walls. It will be appreciated also that the internal electrode structure of an electro-magnetically focused and deflected tube is very much simpler than that of an electrostatic type tube. This makes for reduced manufacturing cost, and also allows of a much shorter tube for a given screen diameter. This latter point is an important one when considering the problem of incorporating a large screen tube in a television receiver, and the tendency now is well in favour of the magnetic tube for picture reception.

SPOT POSITIONING.

Due to inaccurate alignment of the electrodes of a tube, the spot of light, when no voltages are applied to the deflector plates (or no current to the deflector coils), may not be in the exact centre of the screen. It will be necessary to correct this defect by electrical methods. On the other hand it may be desired, under certain circumstances, to move the spot to some position other than the centre of the screen.

In the case of electromagnetic tubes, this spot "shift", as it is called, is achieved by altering bodily the position of the <u>focus</u> coil on the neck of the tube. Adjustments for moving the coil are provided.

Spot shift, in electrostatic tubes, is carried out by electrical methods. Steady voltages, whose values may be adjusted by means of potentiometers, are applied between each pair of deflector plates. One method -- the method usually used for television receiver tubes -- is shown in Figure 23.

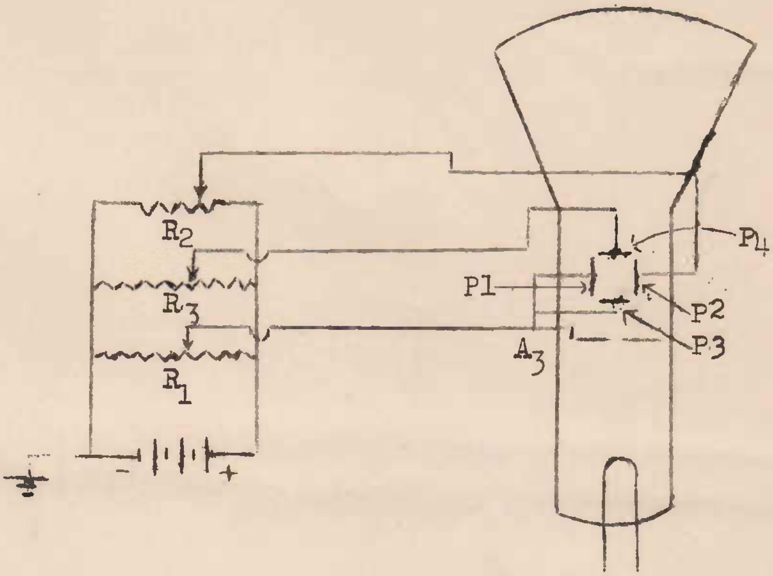


FIGURE 23.

The final anode, it will be remembered, is usually grounded, the cathode of the tube being maintained at a high negative potential (say - 5,000 V). In figure 23, however, the final anode is connected to the centre point of a resistor across a <u>comparatively</u> low voltage source, say 300 V, the negative side of which is earthed. This means that the anode will be at a potential of + 150 V with respect to ground and its potential with respect to <u>cathode</u> will be 5,000 — 150 V = 4,850 V. instead of the full 5,000 V, if portion of the output from the 5,000 volt power supply appears across the resistor R_1. This slight reduction in anode working voltage will not, however, materially effect the operation of the tube. The voltage source in Figure 23 may, in practice be the ordinary H.T. supply, as distinct from the cathode rays tubes' V.H.T. (very high tension) supply. In this case the final anode voltage may be 5000 + 150 or 5150 volts positive with respect to the cathode ray tube's cathode.

R_1 is paralleled by two potentiometers R_2 and R_3 connected respectively to deflector plates P2 and P4 of the tube. Deflector plates P_1 and P_3 are connected to the final anode, i.e. to a point + 150 V above ground. Incidentally the representation of the deflector plates in Figure 23 is purely a diagrammatic one, and is usually used in circuit diagrams.

When the sliding contact of R_2 is at its central point, the potential applied to P_2 is + 150 V with respect to ground. That is, with this adjustment, there is no potential difference between P_1 and P_2. If the sliding contact is moved to the right, P_2 will take up a steady positive potential with respect to P_1, and the spot will be moved to a new position on the screen. Moving the sliding contact of R_2 to the left, will apply a negative potential to P_2 in respect to

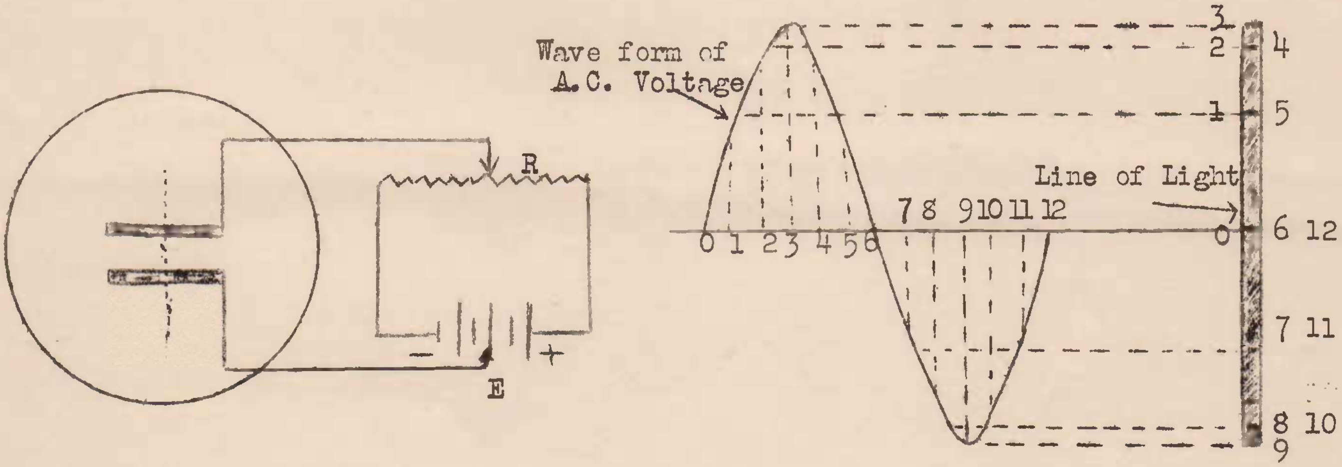
P 1, and the spot will be moved in the opposite direction.

The potentiometer R3 operates in an exactly similar manner on plates P3 and P4. R2 is the horizontal shift control, and R3 the vertical shift control. By adjustment to both R1 and R2 the spot may be moved to any desired position on the screen, limited only by the range of voltages which may be applied between each pair of plates, in this case 300 ÷ 2 = 150 V.

A.C. VOLTAGE BETWEEN DEFLECTOR PLATES.

If an A.C. voltage is applied between any one pair of deflector plates, or an A.C. current passed through a pair of deflector coils, the observer will see a straight line of light on the screen.

This effect will be explained by reference to Figure 24 showing at "A" a front view of the screen with the two vertical deflector plates of an electrostatic tube.



(a) (b)

FIGURE 24.

The plates are connected to a potentiometer (R) and Battery (E) circuit in such a way that the voltage between them is zero when the sliding arm of R is at the centre point. As the arm is moved to the right the upper plate will take up a positive potential with respect to the bottom, and the spot will move from the central position up the screen. The farther the arm is moved from the centre of R, the greater will be the P.D. between the plates, and therefore the greater the spot movement. Remember that the displacements of the spot is proportional to the voltage applied, so that equal increases in voltage will cause equal displacements of the screen. Moving the sliding arm of R to the left will reverse the polarity of the P.D. between the plates, so that the lower one will become positive with respect to the upper. This will cause a downward movement of the light spot on the screen.

If now the sliding contact is moved at a very rapid rate backwards and forwards, the spot will perform a correspondingly rapid movement up and down on the screen and the eye will perceive a continuous and steady line of light. The persistence of vision effect applied here, as well as a persistence of fluorescence, whereby any point on the screen continues to glow for a short period after the spot has passed.

It should be noted that this backward and forward motion of the potentiometer arm applied an alternating voltage between the deflector plates. If now the circuit of Figure 24 (a) is replaced by source of A.C. having a sine-wave form, the effect will be the same except that the A.C. changes smoothly in the sine wave shape.

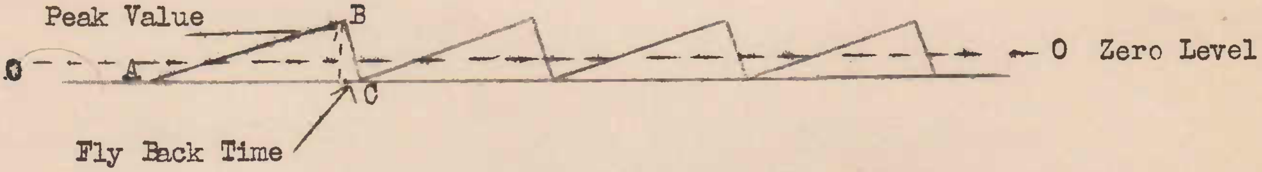
Referring to Figure 24 (b) the voltages at 0, 6 and 12 are zero and leave the spot in the central position. The peak positive voltage at (3) produces the maximum upward deflection, and the peak negative voltage at (9) produces the maximum downward deflection. Other positions of the spot, 1, 2, 4, 5, 7, 8, 10, 11, with the corresponding values of instantaneous voltages are shown, as it moves continuously to fill in the solid line of light.

Observe the following points: (a) the thickness of the line depends upon the diameter of the spot, and this is determined by the sharpness of focus.
(b) The distance travelled between (2) and (3) or (3) and (4) is less than that between (0) and (1) or (5) and (6). Since these represent equal periods of time, it means that the speed of travel of the spot is slower near the ends of the line than near the centre. The effect of this will be that the line may appear slightly brighter near the ends, than near the middle. The spot movement is said to be non-linear, and this non-linearity is due to the fact that the rate of change of current of sine wave form is not constant, but is most rapid near the points of zero current. (c) The length of the line is an indication of the peak value of the A.C. If the deflection sensitivity of the tube is known, the peak value of an unknown A.C. may be obtained by applying it between a pair of deflector plates and measuring the length of the "trace", as the line is called.

OBTAINING A LINEAR TRACE.

For television purposes it is necessary, as the student should realise at this stage, to sweep the spot across the screen at a uniform rate in order to secure correct scanning. Further, having moved the spot in one direction, say left to right, across the screen, it is necessary to return it to the left-hand side in the shortest possible time. As we have seen, a sine-wave voltage will satisfy neither of these conditions.

The type of A.C. voltage required for this "linear" sweep is that having a Saw-tooth wave form (Figure 25).



SAW-TOOTH VOLTAGE

FIGURE 25.

Here the voltage rises from negative value at A, at a uniform rate, to some maximum positive value at B. The voltage then returns, very rapidly to its former value at C. This completes one cycle. The number of those cycles per second is the frequency. The effect of applying such a voltage between, say, the horizontal deflector plates, of a tube is shown in Figure 26. The spot will move across the screen from X to X' at a uniform rate as the voltage rises from A to B. Then as the voltage is suddenly returned to its negative value at C, the spot will rapidly return to X, and the trace will commence again under the influence of the second cycle. If the frequency is high enough a continuous line of light will appear.

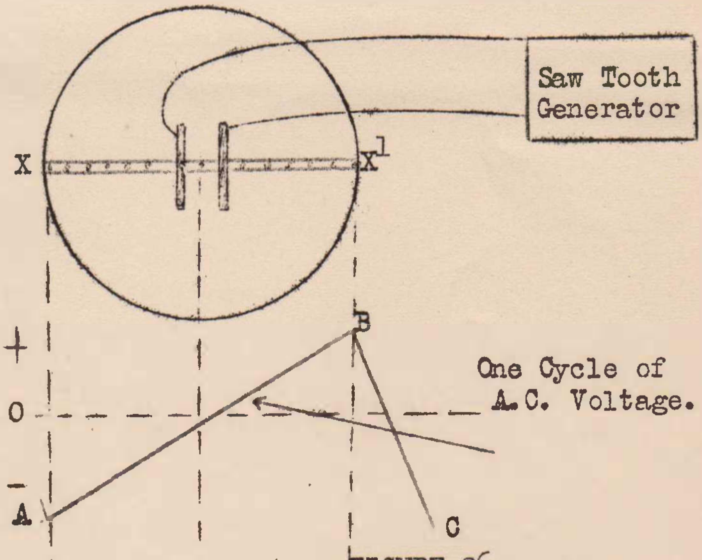


FIGURE 26.

APPLICATIONS OF SAW-TOOTH VOLTAGE.

Saw-tooth voltages are generated in special generator circuits, the operation of which will be dealt with in detail in a later lesson.

We are interested here in the use of saw-tooth voltages on the deflector plates of cathode ray tubes in two main connections: (a) in oscilloscopes for observing wave forms of voltages under test and (b) for scanning purposes in television transmitter and receiver.

In relation to (a) above, the saw-tooth voltage is applied between the horizontal deflector plates, and the unknown voltage (say the sine wave voltage) between the vertical deflector plates. When this is done the spot will trace out a graphical representation (in this case the well-known sine curve) upon the screen. Further details of the oscilloscope circuits and operation are dealt with in a later lesson.

Referring to (b) above, suppose it is required to scan, at the receiver, a 400 line picture, 25 pictures per second. The line frequency is 400 X 25 = 10,000 cycles per second, this being the rate at which the spot must trace out horizontal lines. A saw-tooth generator — the horizontal scan generator — operating at this frequency 10,000 cycles per second is connected between the horizontal deflector plates. Another saw-tooth generator of frequency 25 cycles per second ("picture" or "frame" frequency) is applied between the vertical plates (Figure 27).

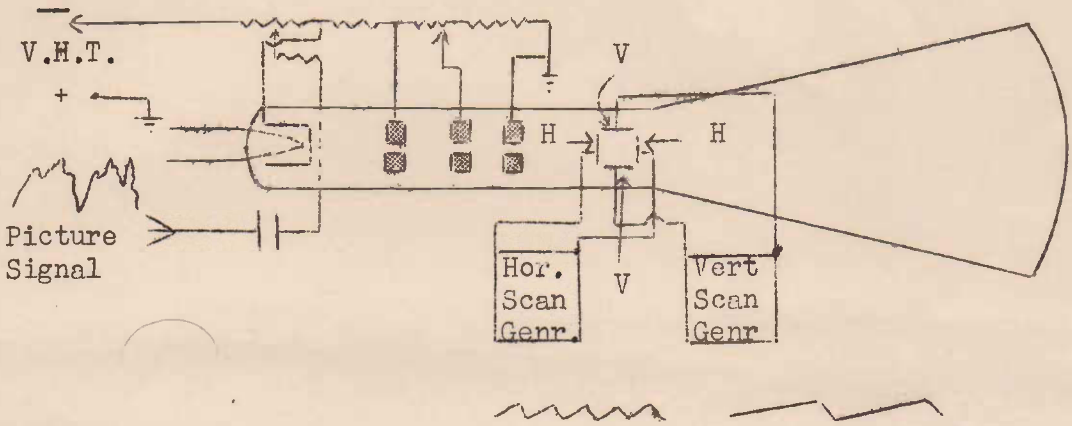


FIGURE 27.

Each cycle of the horizontal scan generator sweeps the spot across the screen from left to right in 1/10,000 = .0001 sec., and then almost instantaneously returns it to the left hand side, when the next cycle begins a second sweep, and so on. Simultaneously with this action the vertical scan generator is slowly (comparatively) moving the spot in a vertical sense down the screen. This results in the spot finishing each horizontal line slightly below (a distance equal to the width of the spot itself) the level at which it commenced the line. As a consequence the subsequent line will be adjacent to, and slightly below, its predecessor, as shown in Figure 28. It will be observed also that this method of scanning results in the lines being at a small angle to the horizontal, this peculiarity being due to the continuous downward motion produced by the saw-tooth voltage on the vertical plates, which motion acts simultaneously with the horizontal scanning sweep. Such angle, however, is immaterial, and is so small in the case of a

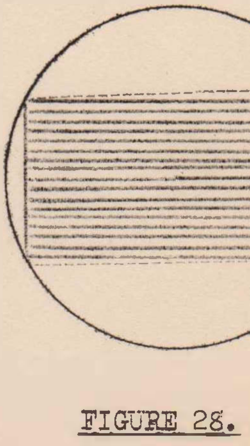


FIGURE 28.

400 line scan as to be unnoticeable.

After a time equal to 1/25 sec. the vertical saw-tooth oscillator will have moved the spot down the screen a distance equal to the picture height. In this time the horizontal oscillator will have performed 10,000 X 1/25 (f x t) = 400 cycles, i.e. 400 "lines" will have been traced out. At this instant the "frame" frequency saw-tooth voltage will suddenly fall to its minimum value, and the spot will "switch" to the top left-hand corner of the screen to commence a new scan.

Consider now the manner of reproducing the picture. The picture (video) signal from the detector of the receiver is applied to the grid (or control cylinder) of the tube. The grid potential, varied at the signal frequency, produces corresponding changes in electron beam intensity, and therefore in spot brightness on the screen. This method of operating the tube is universally used, and is known as "intensity modulation". So we have the spot of light continuously traversing the screen in the normal scanning manner, while at the same time its brilliancy is varying in accordance with the light from the picture elements at the transmitter. In this way, assuming we provide means for maintaining correct synchronisation of transmitter and receiver scanning, a reproduction of the original scene will appear on the screen. The <u>average</u> brightness of the picture may be adjusted by means of the intensity control, shown in Figure 27, which adjusts the negative bias on the grid. Maximum sharpness or clarity in the picture is secured by adjustment to the focus control which operates on the second anode. If the picture is not correctly centred or "framed" on the screen manipulation of the two "position" or "shift" controls (explained above) is made.

TELEVISION, FREQUENCY MODULATION & FACSIMILE COURSE

LESSON NO. 3

EXAMINATION QUESTIONS.

(1) State briefly the nature of a cathode ray.

(2) A certain two-anode electrostatic tube operates normally with 500 V on the 1st anode and 2,000 V on the second. If only 1500 V is available for the second anode what voltage (approx.) should be applied to the 1st anode? What will be the result if this readjustment to the latter's potential is not made?

(3) Explain briefly the principles underlying focusing of (a) an electrostatic tube (b) and electromagnetic tube.

(4) What is meant by "deflection sensitivity" as applied to an electrostatic tube? How is this property affected (if at all) by (a) increasing anodes' voltages? (b) Increasing negative potential on control electrode?

(5) State two advantages of the electromagnetic type tube over the electrostatic.

(6) An electrostatic tube has a deflection sensitivity of 0.25 mm/volt. The spot is adjusted to be exactly at the centre of the screen, then the following voltages are applied in turn between the horizontal deflection plates (a) a steady D.C. of 100V (b) A.C. of R.M.S. value 100 V. State in each case the affect as seen on the screen.

(7) Give two reasons why sine wave voltages (or currents) are unsuitable for television scanning purposes.

(8) A tube has a horizontal deflection sensitivity of 0.3 mm/V and a vertical of 0.25 mm/volt. State completely the characteristics of the two voltages (waveform, frequency, peak value) required to produce a 400 line picture 4" high, at 25 pictures per second, aspect ratio being 5:4 (take 1" = 25 mm).

(9) What coloured light is produced by Phosphors 1 to 5 employed in cathode ray tubes?

(10) State briefly the purpose of the following controls, mentioning the electrode upon which they operate:-
(a) Focus control, (b) Intensity control, (c) Vertical position (or shift) control.

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TELEVISION FREQUENCY MODULATION AND FACSIMILE COURSE.

LESSON NO. 4.

ELECTRONIC SCANNING AND TELEVISION ELECTRON CAMERAS.

Having studied in the last lesson how a narrow electron beam may be formed, focused, made to give out light, and deflected at practically any desired speed for scanning purposes, we propose now to deal with developments of cathode-ray tubes for producing the electrical picture signal at the transmitter. It should be understood that the tubes explained so far are only useful for picture reproduction at the receiver. They provide means only for producing a spot of light which may be moved in the usual scanning fashion, and which may be varied in intensity by the incoming signal to reproduce the varying lights and shades of the original picture elements. They do not, however, provide means of creating an electrical signal from the varying lights and shades of the scanned scene at the transmitter. It is the purpose of this lesson, therefore, to describe and explain several types of tubes which have been developed to produce the picture signal at the transmitter. All of these tubes make use of focussed electron beams and are a special development of the ordinary cathode ray tubes. We shall consequently refer to all of them by the general term "Electron Cameras".

THE FARNSWORTH CAMERA.

This ingenious device was the first tube developed to make use of the great advantages of electronic scanning. It might be mentioned here that electronic scanning at the receiver, i.e. the use of the ordinary cathode ray tube, was put into practice while mechanical methods were still relied upon at the transmitter. The improvement of picture definition, by increasing the number of picture lines, and therefore the scanning speeds, was thus largely held up pending the application of electronic scanning at the transmitting end.

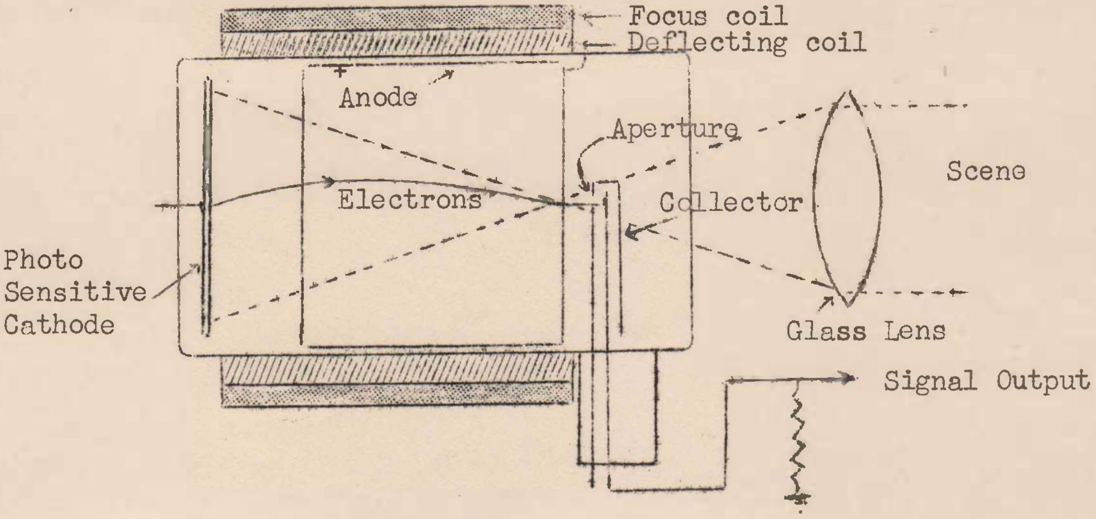


FIGURE 1.

Figure 1. shows the Farnsworth Camera. At the left-hand end of the tube we have a cathode in the form of a flat plate coated over its whole surface with a photo sensitive material, such as caesium. Light is focused, by means of a lens system, onto this cathode, in much the same way as the lens focuses an optical image of the scene on to the plate in an ordinary camera. Electrons are liberated, due to the photo-electric effect, from the cathode surface. These electrons will be liberated proportionately to the amount of illumination at any point. The light image is thus converted into an "electron image" near the surface of the cathode, the density, or concentration, of the electrons varying with the light and shade of the various parts of the picture.

Immediately the electrons are freed from the cathode by the action of light, they are attracted up the tube by a hollow cylindrical anode, to which a positive potential is applied.

If these liberated electrons were left to themselves they would diffuse, that is electrons in the regions where the density was high would spread out into the less dense regions, so that very quickly we would have an ordinary photo-electric current, of uniform electron density, flowing up the tube. If this occurred the electron image would be lost, the electron current being simply proportional to the average illumination of the cathode.

To prevent this diffusion of the liberated photo-electrons as they move up the tube they are subjected to a magnetic focusing field of the type used in ordinary cathode-ray tubes for focusing the beam. The result is that when the electrons have reached the far end of the tube they are still concentrated in their original densities as when they were liberated from the cathode, i.e. the "electron image" has been retained.

The magnetic focussing field is produced by a coil of wire wound around the outside of the tube. This coil carries a steady current. It should be noted that the action of the focusing field is not to produce a concentrated beam of electrons as in an ordinary cathode-ray tube, but rather to form an electron image at the right-hand end of the tube from the electron image produced at the cathode by the photo-electric action. The function of this focusing field might be likened to the focusing effect of a lens where used to project a light image on to a screen, by controlling the diverging light waves reflected from an object.

At the far end of the tube is the collector electrode which is surrounded by a screen except for a small hole which corresponds to the scanning aperture. As a consequence, the collector will collect only those electrons which pass through the hole, i.e. only the electrons of one point of the electron image. Now with this arrangement the scanning aperture cannot be moved to scan the whole picture (as with the Nipkow disc). Instead the electron image is moved, as a whole, in such a way that the electrons passing through the hole to the collector are taken from the image in a succession of scanning lines. This is accomplished by two sets of scanning coils which act similarly to the deflecting coils of a cathode-ray tube. One set of coils moves the electron image, bodily, in a horizontal direction at the "line" frequency while the other moves it vertically at the slower picture or frame frequency. These deflections are, of course, obtained by using saw-toothed currents in the scanning or deflector coils.

The useful output from the tube is the electron current flowing from the collector electrode. It will be seen that this current varies in sympathy with the varying amounts of light reflected from different parts of the scene, as the scanning action proceeds.

The Farnsworth Camera, sometimes called an "image disector", thus does away with the difficulties of mechanical scanning, but its output in the form described is no greater than that of the ordinary photo-tube. This draw-back was overcome by the use of the electron-multiplier described below.

HOW WEAK PICTURE SIGNAL OUTPUTS HAVE RESTRICTED TELEVISION.

The picture signal (video) current output from a photo-electric cell (or from the Farnsworth tube in its original form) is very minute -- much smaller than the audio output from a microphone. It might be thought, at first, that this position could be rectified by using more amplifying stages, or stages having greater gain. The student probably, however, realises that it is impossible to amplify effectively, an extremely weak signal. In the case of audio amplification a very weak signal would be drowned in "noise", no matter how great the overall gain of the amplifier might be.

This "noise" is due to two causes:- (a) the "shot" effect, due to irregular emission from the heated cathode of the amplifying tube, (b) the generation of irregular voltages across the resistor in the input circuit of the tube, due to continuous random motions of the electrons in it. Unless the signal voltage is considerably greater than these "noise" voltages very high gain in the amplifiers will be useless, for the latter will be amplified as well as the signal.

In the case of television signals the undesired voltages which are generated in all amplifying circuits will appear on the scene as flashes of light, and might completely "mask" the signal if the latter is very weak. These voltages will therefore, be referred to as "masking" voltages where dealing with television work.

It will be appreciated, then, that the photo-electric devices so far dealt with are uselss unless the scene can be very brightly illuminated. Such illumination requires very special studio arrangements, and the televising of outdoor scenes would normally be impractical.

THE ELECTRON MULTIPLIER.

This device, first suggested in 1919, but developed considerably by Dr. Zworykin and Farnsworth since that date, largely overcame the difficulties associated with the amplification of the very weak outputs from the photo-electric devices. It is incorporated, in various forms, in the very latest electron cameras to boost still further the extreme sensitivity of these tubes.

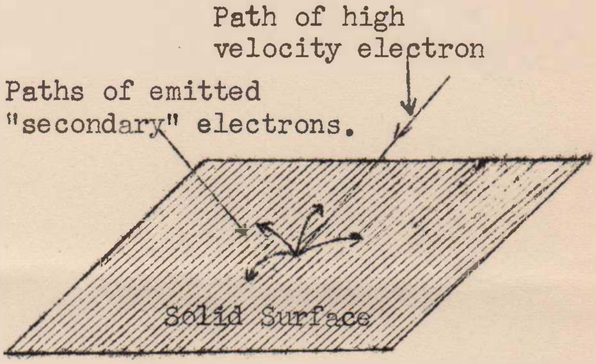


FIGURE 2.

SECONDARY EMISSION OF ELECTRONS.

Various types of electron multipliers have been developed to a high state of efficiency. All types, however, operate on a common principle -- they all utilise the phenomenon known as "secondary emission", whereby a single electron striking a solid surface may liberate from that surface a number of other electrons. This effect occurs, or tends to occur, at the anode of the ordinary amplifying valve, where, since it is undesirable, a suppressor grid is included to reduce it.

Only one type of electron multiplier will be described here since the general principle of operation of all types, and in particular the net results obtained is the same in all cases. This is illustrated in Figure 3, where we show a type of photo-electric tube into which an electron-multiplier has been incorporated between the photo-sensitive cathode and the collecting anode.

Light falling on to the photo-sensitive cathode at the left hand-end of the tube liberates a few electrons. A number of pairs of plates are arranged at intervals down the tube, the upper plates P1, P3, P5, P7 being "staggered" with respect to the lower ones P2, P4, P6 and P8. Gradually increasing potentials are applied to the pairs of plates as they go down the tube. The "photo"electrons thrown off by the cathode are first attracted towards plate P1, but a strong magnetic field applied across the tube deflects them on to plate P2. This plate is coated with a substance which readily emits secondary electrons, and on impact of the electrons

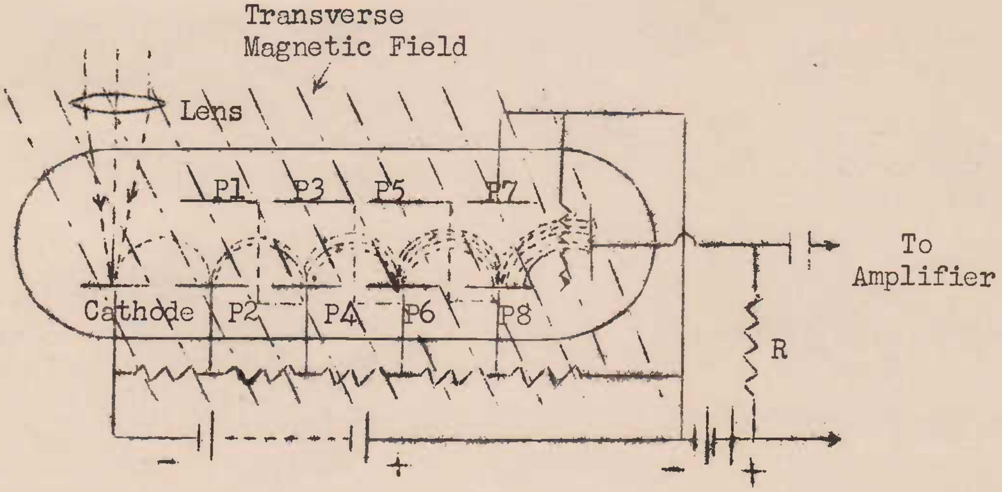


FIGURE 3.

ELECTRON MULTIPLIER.

arriving from the cathode a large number are emitted. These in turn are attracted towards P3 but strike P4, due to the deflecting magnetic field. Here many more "secondary" electrons are emitted, and so on until the number which are finally collected by the anode may be hundreds or thousands of times as great as those originally freed at the cathode. Thus we have a comparitively large electron current flowing through the resistor R, across which corresponding voltage changes appear. The latter are then fed to the external circuit and amplified further in the usual way.

The electron-multiplier is really an amplifier, but it possesses the advantage over ordinary thermionic tube amplifiers in that extremely great amplification may be obtained with very little "noise" or "masking" voltages. It will be noted that there is no hot cathode to produce the "shot" effect, and no large resistors (as in the input circuits of tube amplifiers) across which random voltages due to thermal agitation would appear. Dr. Zworykin's electron multiplier gave an amplification of 5,000,000 — an extremely high figure.

The electron multiplier was introduced into Farnsworth's camera to increase its sensitivity. The multiplier was enclosed in the shield containing the simple collector electrode of Figure 1. The primary electron stream was that entering through the shield's aperture. These electrons set up a series of secondary emissions from a number of plates in a manner similar to that described in connection with Figure 2. In this way

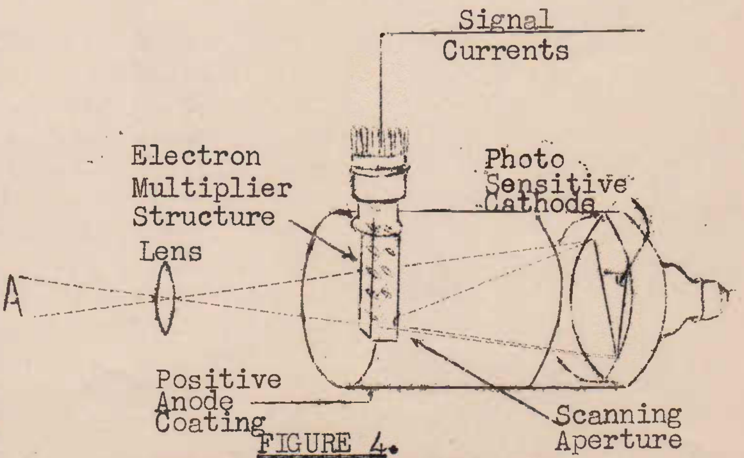


FIGURE 4.

A MODERN IMAGE DISSECTOR TUBE.

the output of the camera was magnified many times.

A drawing of a modern image dissector is shown in Fig. 4. This tube was specially developed for the transmission of motion picture film images. For this purpose, where intense lighting may be used, the image dissector is eminently suitable, as it does not introduce certain technical difficulties which are characteristic of some of the "storage" type cameras described below. These latter types, however, have displaced the image dissector in the field of ordinary studio and outdoor work.

LOW SENSITIVITY DUE TO INEFFICIENT USE OF AVAILABLE LIGHT.

The extremely small current output from the photo devices so far discussed is largely due to the failure of the systems to utilise fully all the light available on the scene. Considering mechanical scanning, the light spot remains on each picture element for only a minute fraction of a second. Suppose for example that the picture contains 150,000 elements the area of an element being taken as the area of the light-spot. If the picture is scanned at 25 pictures/sec, these 150,000 elements are swept by the spot in $\frac{1}{25}$ second. The time for which the spot remains on any one element will therefore be $\frac{1}{25} \div 150{,}000$ second = $\frac{1}{3{,}750{,}000}$ sec. Since the number of electrons emitted by a photo-sensitive surface is affected by the light, as well as the light intensity, the reason for the extremely minute current outputs of photo-cells, and the like, will be apparent. Summarising, then, the light only affects a particular picture element for $\frac{1}{150{,}000}$th of the total scanning period (i.e. time for 1 complete scan). For the remainder of the period, i.e. $\frac{149{,}999}{150{,}000}$ of it, this particular element is remaining in darkness.

A somewhat similar state of affairs exists in the case of the image dissector. In this device light from the entire scene illuminates the photo-sensitive surface, but the light effectively used, at any moment, is that confined to producing the electrons which are entering the aperture of the shield around the anode or electron multiplier. All the light producing other electrons, at the same instant is wasted, since these electrons do not enter the aperture. For a picture containing 150,000 elements, as before, only $\frac{1}{150{,}000}$ th of the total number of photo-electrons emitted during a scan period are utilised, the rest are wasted. It will be seen therefore, that the theoretical efficiency of these devices is very low -- only $\frac{1}{150{,}000} \times 100 = .0007\%$ (approx).

STORAGE TYPE ELECTRON CAMERAS -- THE "ICONOSCOPE" AND EMITRON".

Rosing and Campbell - Swinton suggested, very early in the history of television, that the great wastage of light explained above might be avoided by devising some method of "storing" the photo-electric effect. Practical success was first achieved by Zworykin in America, in 1925, when he applied for his patent on the "Iconoscope". Since then parallel work, following Campbell-Swinton's original suggestion, was carried out by the E.M.I. (Electrical and Musical Instruments) company in England. The latter resulted in a camera similar to the Iconoscope and called the Emitron.

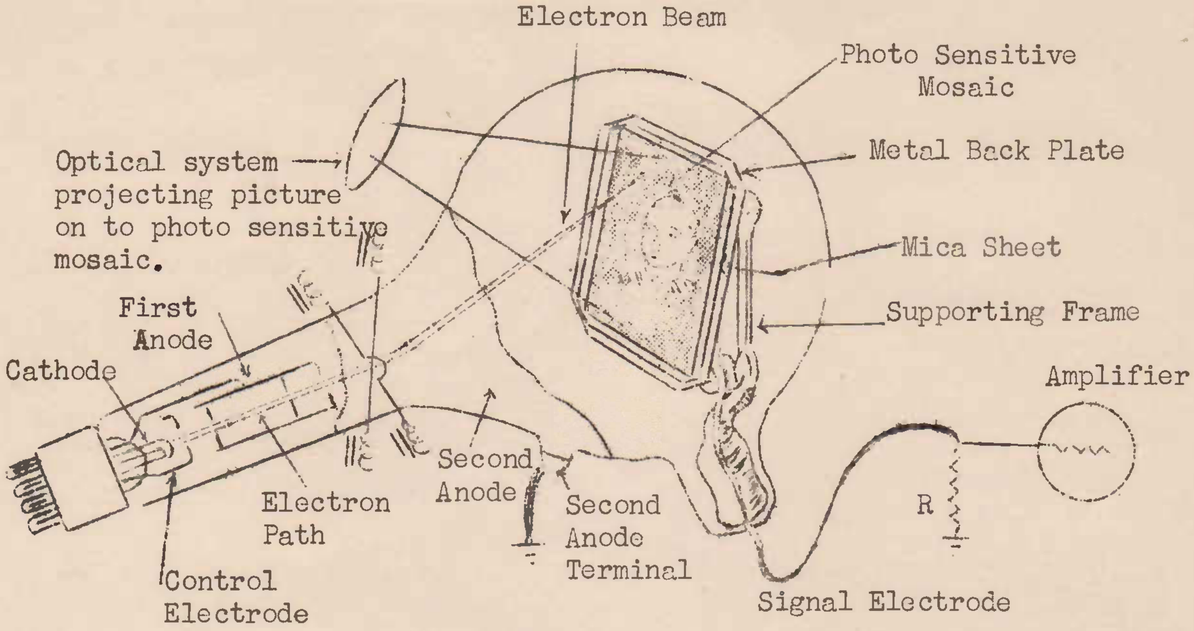


FIGURE 5.

AN ICONOSCOPE-EMITRON TYPE OF TUBE.

An "Iconoscope-Emitron" type camera is shown diagrammatically in Figure 5. The tube contains an "electron-gun" and beam deflection coil as in an ordinary cathode-ray tube. Electrostatic focusing, using two anodes is used, the second anode being a metallic coating on the inside walls of the tube, as shown in Figure 5. The deflection of the beam for scanning purposes is achieved electromagnetically, by using two pairs of deflection coils outside the tube neck. The image to be televised is focused on to a special photo-sensitive plate, usually referred to as the mosaic, because of the nature of its construction, described below. A photograph of an Iconoscope is shown in Figure 6.

The mosaic consists of a thin sheet of mica, about $\frac{1}{1,000\text{ th}}$ inch thick, and measuring about 5" X 4". The front side of this sheet, i.e. the side upon which the light image is focused is covered with millions of tiny globules of silver, each globule being coated with a thin layer of photo-sensitive caesium. The globules are isolated and insulated one from the other. The back of the mosaic sheet is covered with a thin metallic conducting layer (the "signal plate") to which the wire band which conveys the electrical signal to the external circuits, is connected. Each silver globule may be regarded as the cathode of a tiny photo-electric cell, which emits electrons when light falls upon it. The millions of these tiny cells all have a common collector electrode, which is the second anode of the tube's electron gun. Electrons liberated from the mosaic drift back towards this second anode which collects and removes them. A simple explanation of the operation of the tube is given in the succeeding paragraphs.

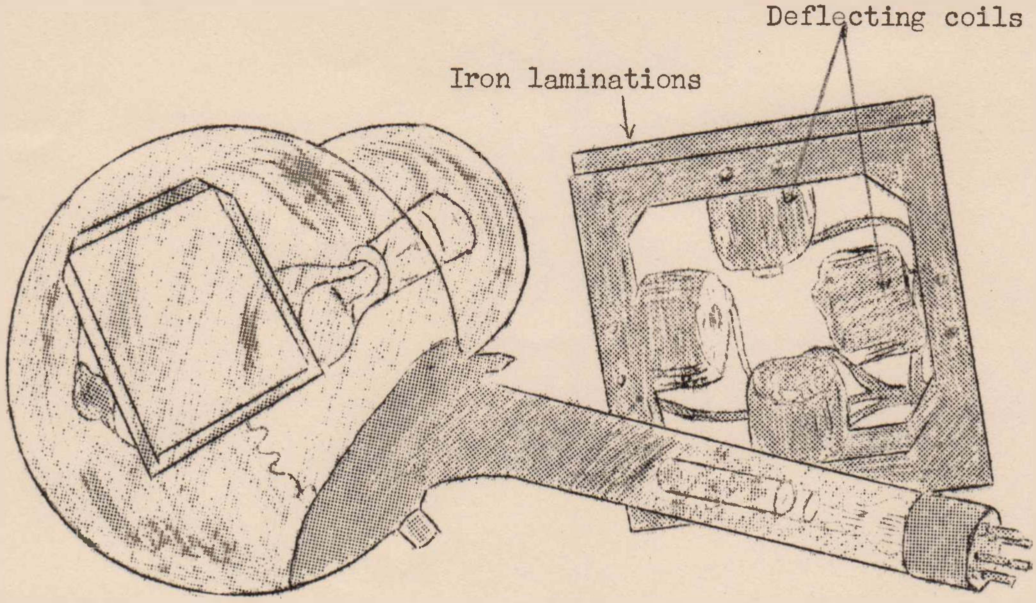


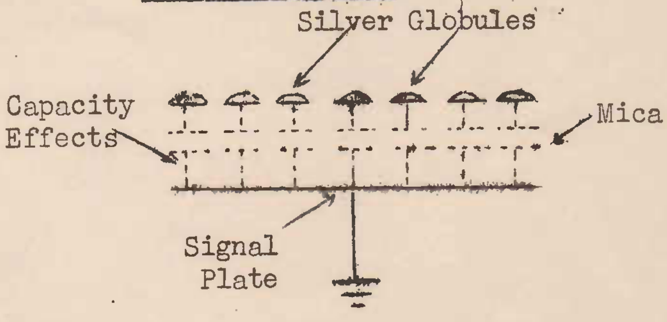
FIGURE 6.

AN ICONOSCOPE TUBE.

When a light image is focussed on the mosaic electrons are liberated from the surface proportionately to the light intensity at any point. Each silver globule forms a tiny capacity with the metal signal plate, the mica being the dielectric. Thus the whole mosaic may be cosidered as consisting of millions of tiny condensers, all of which have one common plate — the signal plate on the back of the mica. This idea is illustrated in Figure 7.

FIGURE 7.

SHOWING HOW EACH GLOBULE TOGETHER WITH SIGNAL PLATE AND MICA DIELECTRIC FORMS A TINY CONDENSER.

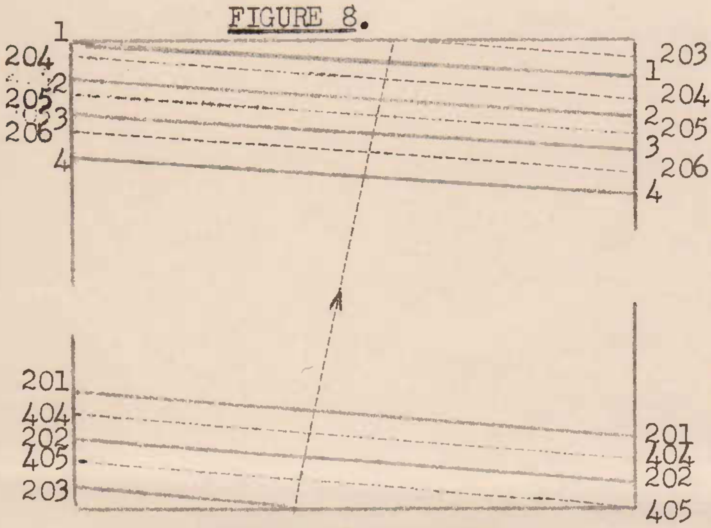


The effect of the emission of electrons from the globules will, therefore be to leave them positively charged (with respect to the signal plate). Remembering that the amount of electron emission is proportional to the light intensity of the mosaic at any point, it will follow that the degree of charge over the mosaic surface will vary with the light and shade distribution of the light image focused from the scene being televised. We can therefore visualise the light image building up an electrical image or pattern on the mosaic surface. In the absence of scanning, this electrical image would remain indefinitely if the insulation of the mica were 100% perfect. It is for this reason that the iconoscope is sometimes described as the "cathode-ray tube with a memory"!

Now let us see what happens when the mosaic is scanned. The scanning, of course, is carried out by the electron beam which is formed, focused, and deflected in the normal scanning motion just as described in the previous lesson.

Of course interlaced scanning is used, whereby the beam first scans every other line, thus covering one complete "frame". The second frame scanning fills in the lines omitted during the first frame. How interlaced scanning is achieved electronically will be explained in a later lesson, but Figure 8, will indicate how the electron beam moves over the mosaic. Here 405 lines are used. The beam, in the first frame scans the heavy lines marked 1,2,3,4 ---- 203. The 203rd line only traverses half the screen, then the beam is jerked back, and scans the other half of the 203rd line at the top of the screen. The next frame is now commencing, and the dotted lines are scanned, filling in the gaps left by the first frame. Note that each frame consists of $202\frac{1}{2}$ lines - a total of 405 for the whole picture scan.

FIGURE 8.



INTERLACED SCANNING.

Both line and frame deflection of the beam is achieved by magnetic coils which are symbolised in Figure 5 (also see Figure 6). If the picture frequency is 25/sec. the frame scanning frequency will be 50/sec (2 frames per second) and the line scanning frequency will be

$202\frac{1}{2} \times 50 = 10,125$ c/sec.

As the scanning beam passes over any particular globule the positive charge caused by the emission of electrons from the latter is instantly neutralised, with a corresponding electron movement from the back signal plate through the external resistor (see Fig.5). This current will represent one part of the "Picture signal" current, and its value will depend upon the amount of charge the globule in question had acquired, and therefore upon the light intensity reflected from the corresponding point of the scene. As the scanning beam passes over the mosaic all the globules will be progressively discharged in turn, and hence the current output from the tube will vary according to the intensity of the charge of the "electrical image" on the mosaic surface.

The electrical action involved in the foregoing explanation may be further elucidated by reference to Figure 9.

Here a single globule on the mosaic surface is represented as the cathode Pc of a small complete photo-electric cell P. The anode of this cell, Pa, is the collector electron, i.e. the second anode of the camera gun. C. represents the capacity effect existing between globule and the metal signal plate at the back of the mosaic . Light falling on the photo-sensitive globule Pc emits electrons which are collected by Pa. This leaves the left-hand plate of C positively charged with respect to the right hand plate. Remember that this charging action is going on comparatively slowly, for the whole time, and the final charge reached depends upon the light intensity coming from the particular point of the picture scene in question. When the scanning beam passes rapidly over the globule the positive charge on the left-hand plate of C is instantly neutralised, with a corresponding electron movement away from the right-hand plate through R. The voltage developed across R will thus be proportional to the intensity of the light.

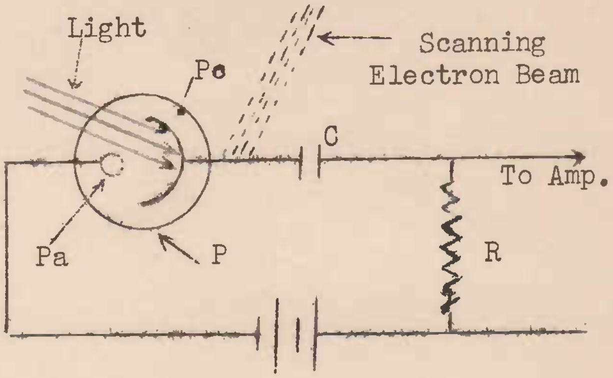


FIGURE 9.

THE ADVANTAGE OF THE "STORAGE" ACTION.

The important point to note is that, although the scanning beam is acting upon each element of the mosaic for only $\frac{1}{150,000}$ (assuming 150,000 picture elements) of the total scanning period (say 1/25th sec), the light is effective for the whole of this scanning period. As soon as the mosaic globule is discharged by the beam passing over it, the light gets busy in storing up a charge on that globule for the next 1/25th second until the scanning beam returns again. For this reason one would expect that these "storage" type tubes would be 150,000 times as sensitive as devices in which no such storage action takes place. In actual practice the Iconoscope-Emitron type of tube is only 5% to 10% efficient, i.e. only 5 - 10% of the output predicted from the above theory of operation is actually realised. Even so this gives a sensitivity from 7,500 to 15,000 times as great as that of the old systems.

WHY THE STORAGE ACTION OF THE ICONOSCOPE IS NOT 100%.

The storage effeciency of this type of tube is comparatively low for several reasons: (a) all of the electrons emitted by the light are not collected and many return to the mosaic, (b) loss of globule charge due to secondary emission.

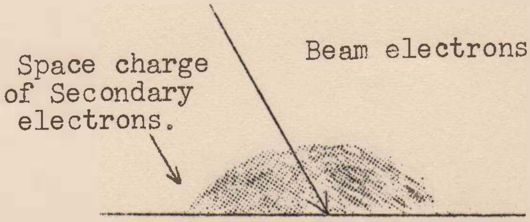
(a) The photo-sensitive globules, together with the collector anode form very inefficient photo-cells, because the voltage difference between them is only several volts, which does not produce an electric field to draw off from the mosaic all of the emitted electrons, i.e. the photo-emission is not saturated. The result is similar to that which would be obtained if an ordinary photo-tube were operated at a low collector anode potential. Of the electrons emitted from the mosaic then, many will return to it, and the globules will not be charged to the extent they otherwise might be. This factor reduces the sensitivity to a factor of about ¼ or 1/3rd.

The student might wonder why there is any potential difference at all between the mosaic and the collector (second anode), since no voltage is applied between them from an external source. The mosaic takes up a potential several volts negative with respect to the second anode (which is at ground potential) due to the electron beam continually impinging upon it. Consider the scanning beam in operation when no light is falling upon the mosaic. The latter will be collecting the electrons of the beam, and its charge as a whole will tend to go more and more negative. But the high velocity electrons will knock secondary electrons out of the surface and some of these will return to the collector. The mosaic.

in practice, is found to take up an equilibrium potential of several volts negative when, for every electron arriving to it from the beam, one secondary electron leaves it. This means that the collector (second anode) is several volts positive with respect to the mosaic.

(b) Loss of effeciency due to secondary electrons occurs thus. Each beam electron liberates, on the average, about 4 or 5 secondary electrons, and, as explained under (a) above, most of these eventually return to the mosaic. At any moment, therefore, there will exist a cloud of these electrons just outside the mosaic, (Figure 10), forming a negative space-charge (similar to the space-charge surrounding the cathode in an ordinary thermionic tube).
This negative space charge will tend to repel, back to the mosaic photo-electrons which are emitted by the light image, so retarding the building up of the desired electric charge image. It is thought that this secondary electron effect reduces the tube sensitivity by another one-third.

Thus, as a result of the two factors discussed under (a) and (b) above it appears that the sensitivity of the iconoscope-emitron type camera would be about 1/9th (1/3 X 1/3) or 1/12th ($\frac{1}{4}$ X 1/3) of that which would be obtained if 100% "Storage" action were achieved. In practice a storage effeciency ranging between 5 and 10% is obtained.



SPACE CHARGE DUE TO SECONDARY EMISSION. FIGURE 10.

"SPURIOUS" SIGNALS AND "SHADING" CORRECTION.

By these we mean electrical signal output from the tube which is not due to the light image. Spurious signals appear in the output of the tube even when no light at all appears on the mosaic, and are due to the secondary electrons falling back on the mosaic in an irregular, or non-uniform manner. We will not attempt to explain the details of how these spurious signals are generated, but will simply note their nature, and discuss how they are compensated for.

If the mosaic were scanned by the beam in the absence of any light upon it, the electrical output, say measured in the plate circuit of one of the transmitter's video amplifiers, should be a D.C, represented by a straight line in Figure 11 at (a) (i.e. no A.C. signal). Instead, however, it is found, due to the undesirable action of the secondary electrons that, during the scanning of one line, the current output varies as shown at (b). Note that there is a curve or "bend" in the graph of the current, as well as a gradual upward "tilt" as the scanning proceeds from left to right. A similar effect occurs as the scanning beam moves from the top of the screen towards the bottom at frame frequency. Since the effect of more light normally produces an increase in current, the effect of

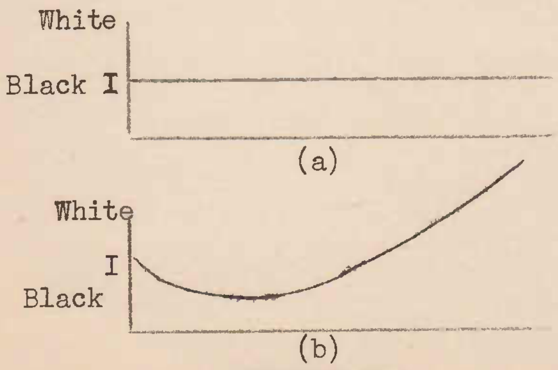


FIGURE 11.

those undersired signals would be to produce a shading on the receiver scene, whereby the right-hand side of the picture is lighter than the left and the bottom of the scene is lighter than the top. When an actual scene is scanned the real video signal will be superimposed upon this spurious signal as shown at (a) in Figure 12. Here we have shown the output for three scanned lines.

These "bend" and "tilt" spurious signals are compensated for in practice, at the transmitter by generating equal and "opposite" signals (see Fig. 12b) in special "bend" and "tilt" generators, and mixing these with the camera's output. One pair of "bend" and "tilt" generators is necessary for the line correction, and another pair for the frame correction. The result obtained for line "shading" correction, as it is called is shown at "c" in Fig. 12.

It will be noted that the camera also generates a large amplitude signal in the interval between the end of one line and the beginning of the next (i.e. where the beam is rapidly returning from the right-hand edge of the screen to the left). This spurious signal would overload the amplifiers, and is therefore suppressed, by means of special circuits. The result is now shown at (d) Fig. 12. It will be noted that a time-interval gap remains between successive scanning lines. This gap is made use of for carrying synchronising voltage pulses, shown inserted at (e) (Fig.12). These are shown as sharp negative surges of voltage, and when separated from the rest of the signal in the receiver, are used to ensure that the latter's line scanning saw-tooth generator keeps in step with that at the transmitter. It might be mentioned here that additional voltage pulses are inserted at the end of each frame, for the purpose of synchronising the receiver frame scanning saw-tooth generator with that of the transmitter's electron camera.

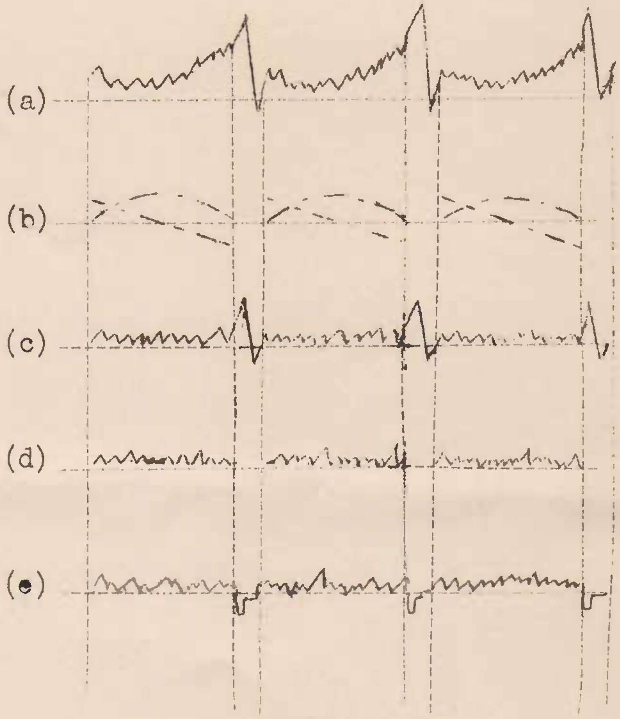


FIGURE 12.

THE IMAGE ICONOSCOPE AND SUPER-EMITRON TYPE CAMERA.

These are similar cameras, the one being a development of the American Iconoscope, and the other a development of the Emitron in England.

The operation of this type of tube combines that of the Farnsworth Image Dissector and the Iconoscope (or Emitron). The sensitivity is about 10 times that of the latter type tubes.

Referring to the diagram of Figure 13, a lens system focuses the light image on to a transparent photo-electric cathode Pc. This emits electrons, proportional to the light intensity at any point, from its rear surface, thus forming an electron image as explained in connection with the image dissector. These emitted electrons are accelerated up the tube by an anode, taking the form of a conducting coating on the inside surface of the tube, and maintained at a high positive potential (500V) with respect to the photo-cathode. The iron-clad magnetic coil C. produces a magnetic field within the tube, and this focuses the electron streams, thus projecting the electron image on to the "mosaic" or screen M. This is not photo-sensitive, and is not really a mosaic at all, but simply a sheet of insulating mica backed by a metal signal plate.

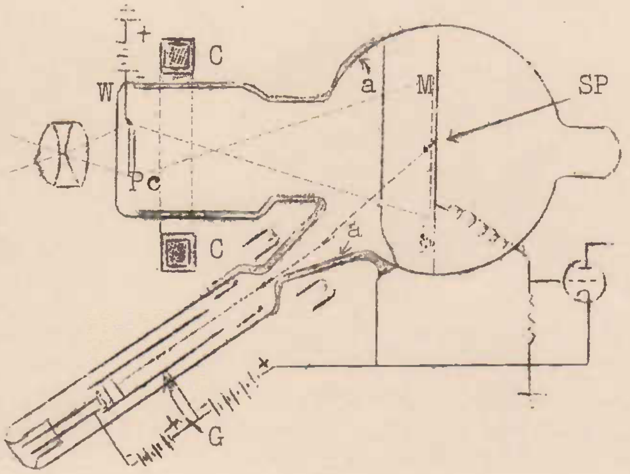


FIGURE 13.

THE IMAGE ICONOSCOPE.

When the photo-electrons from Pc impinge on the mosaic at high velocity they release a larger number (about 5 times as large) of secondary electrons. These latter are drawn away to the anode, which is extended around the walls of the bulb. Thus the mosaic's surface is positively charged, in a pattern similar to that of the original light image. Note that the charge distribution on the mosaic surface cannot "spread" and wipe out the "charge image" because the surface is a good insulator.

The tube has an extension containing an electron-gun and deflector coils, which produces an electron beam, just as in the iconoscope, which scans the mosaic. The action from now on is similar to the earlier type tubes. The electrons in the beam progressively dischargesthe various sections or elements of the mosaic, thus causing current impulses in the circuit connected to the signal plate (SP).

The gain in sensitivity over the older type tubes is due to two factors. Firstly a powerful field is available (500V) to draw all of the electrons emitted by photo-electric action away from the cathode. Secondly an electron multiplier effect occurs at the mosaic screen. A single photo electron from the cathode impinging upon this screen causes that particular point to loose, say 5, secondary electrons - a net loss of 4 electrons. Remembering that a loss of electrons means a positive charge it will be seen that the charge distribution on the screen, corresponding to the image, will be much stronger than in the case of the Iconoscope or Emitron.

An additional advantage gained by this type of tube is that the photo-cathode, upon which the light image is focused is quite close to the end of the tube, where a ground glass window (W) Fig. 13 is provided. This allows lenses of short focal length to be used. Thus it has been found possible to adopt miniature camera technique, using the high quality lenses specially developed for small cameras. The tube is also particularly suitable for outdoor telephoto work because of its high sensitivity, and also because of the fact that high quality telephoto lens can be obtained to suit it.

The Image Iconoscope (and Super Emitron) also produce spurious "tilt" and "bend" signals described earlier, these being due, as in the case of the Iconoscope, to secondary emission caused by the scanning beam. The student should take care not to confuse this secondary emission with that caused by the "electron image" electrons falling on the mosaic. The latter is advantageous, since, as explained, it results in an increase in sensitivity, due to the electron multiplication effect.

THE ORTHICONOSCOPE.

Details of the Orthiconoscope (Orthicon for short) were released early in 1939. The tube, unlike the Iconoscope, has a "storage effeciency" of 100%, i.e. full advantage is taken of storing the effect of the light by building up the charge on the mosaic during the whole scanning period. Furthermore, since no secondary emission occurs in the new tube it produces no spurious signals. The sensitivity is from 10 to 20 times as great as the Iconoscope.

A schematic diagram of an orthicon is shown in Figure 14.

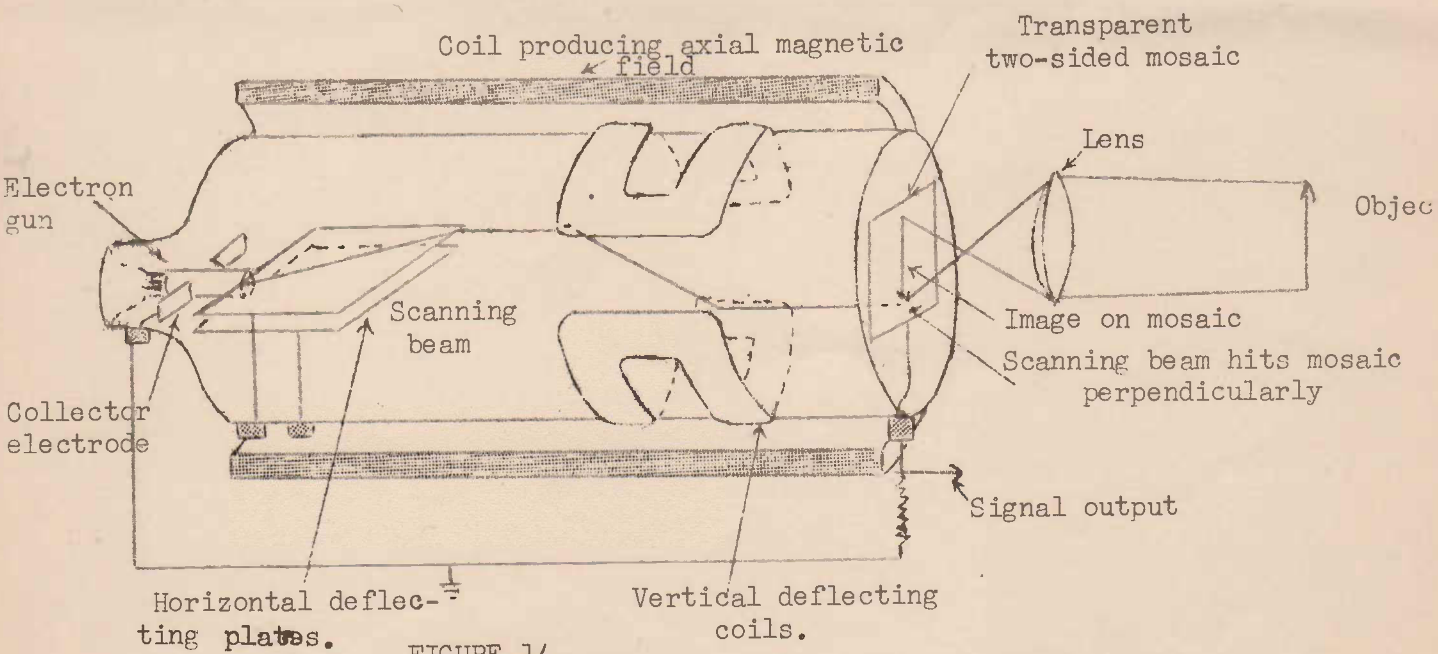


FIGURE 14.
DIAGRAM OF ORTHICON.

The secret of the success of this tube is that secondary emission at the mosaic is avoided by using an electron scanning beam which strikes the former at very low velocity. This low velocity beam is achieved thus:- an electron beam is produced, in the usual manner, by the electron gun, shown at the left of Figure 14. In this gun the anode is at a high potential in respect to the cathode. Hence as the electrons leave the gun's aperture they have a fairly high velocity. After they leave the gun, however, and as they pass up the tube towards the target screen, or mosaic, the electrons are continually decelerated, or slowed down, to a low velocity. The reason for this is that the screen itself is at cathode potential; hence between the screen and the final anode of the gun there exists an electrostatic field which is continually acting <u>against</u> the electron stream.

This state of affairs is illustrated in Fig. 15. When the screen is at zero (or cathode) potential the electrons in the scanning beam will be stopped just in front of the screen. They will then turn back and will be finally collected, and removed by a special collector electrode shown as a flat rectangular plate near the electron gun (Fig. 14). Thus, when no light falls on the screen the latter collects no electrons.

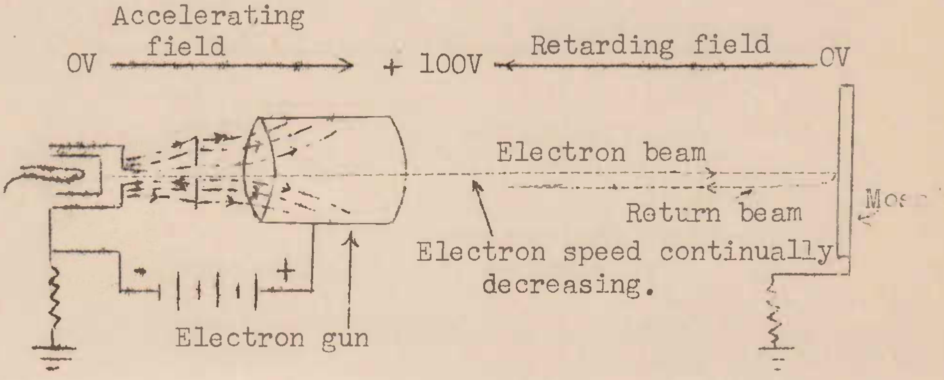


FIGURE 15.

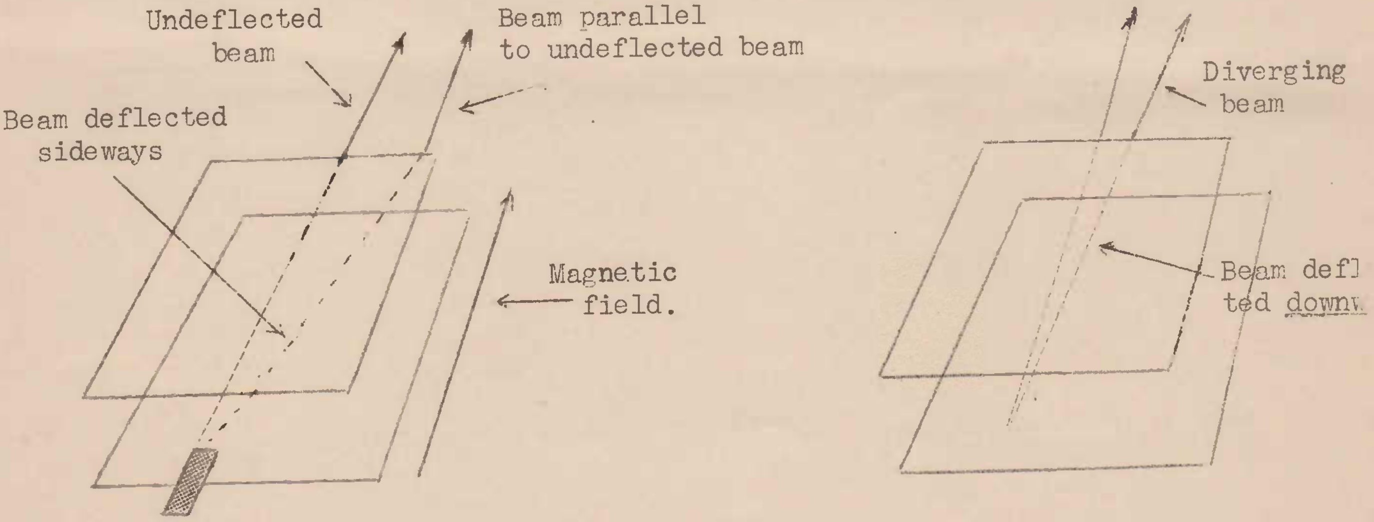
The screen or mosaic itself is a transparent plate upon whose outer surface the light image is focused. The inner surface of the screen is photo-sensitive, and emits electrons proportionately to the light intensity at the various points on its surface. Hence, as in the iconoscope, an electric charge image is built up. Note that the charges on this surface are <u>positive</u>, since electrons have been lost from it by photo-emission.

The scanning beam is made to scan the screen line by line, frame by frame. When the beam encounters an area which is "black", i.e. no light, it is turned back as described above, and the screen collects no electrons. When an illuminated area is encountered, however, this area will be slightly positive, and electrons from the beam will be collected, sufficient to neutralise the charge. When this occurs a number of electrons will now move away from the signal plate to the external circuit. This current will represent the signal for that particular signal area. The greater the light intensity on any point, the greater will be the electric charge produced, and hence the greater the number of electrons collected from the beam, and the greater the signal current.

Since there is no secondary emission from the screen no spurious signals are produced, and no hindrance is encountered by the photo-electrons (due to the light) in leaving the surface. Furthermore a powerful field drawing off the emitted photo-electrons is available (about 100V) between the screen and the collecting electrode. (Remember that in the case of the iconoscope type tube this field was only several volts, and insufficient to remove <u>all</u> the electrons released from the mosaic). These two factors account for the substantial increase in sensitivity.

In the development of this tube it was found that great difficulties were encountered in focusing a low velocity beam when the latter was being continually deflected for scanning purposes. The chief of these was that the beam became de-focused when deflected to any point not near the centre of the screen. Now in an ordinary cathode ray tube, as in the iconoscope etc, the beam is rarely if ever, striking the screen perpendicularly. It was found that if the beam could be made always to fall on the screen in a perpendicular manner, despite the fact that it was being continually deflected, then no de-focusing occured.

For these reasons a special method of beam deflection, for scanning purposes is employed. A coil wound around the <u>whole</u> length of the tube produces a magnetic field parallel to the tube itself. This coil focusses the beam, and guides all electrons in parallel paths perpendicular to the screen (see magnetic focusing, lesson 3). For horizontal or line deflection a pair of electrostatic plates are used. Note, however, that the beam is only deflected <u>while between these plates</u>;



Electrostatic Deflection in Magnetic Field.

(a)

Ordinary Electrostatic Deflection

(b)

FIGURE 16.

after emerging from them the powerful magnetic field causes the electron beam to travel parallel to the tube again. The nature of this deflection is shown in Fig. 16(a). As a result of the powerful axial magnetic field combining with the electrostatic field of the plates a peculiar effect occurs. Instead of the beam being deflected in a direction perpendicular to the plates, it is deflected parallel to them. Figure 16(b) shows ordinary electrostatic deflection, for comparison purposes.

In this way the beam can be deflected right across the screen, and yet it always strikes it in a perpendicular manner.

The vertical deflection for frame scanning is brought about by a pair of magnetic coils which produce a vertical field across, or transverse to, the tube (Fig.14). Here also the beam is deflected only while passing between these coils, and after emerging from them moves perpendicular to the screen, as shown in Fig. 14.

Here the deflection occurs in two fields acting at right angles to each other, and the deflection is found to be in a direction parallel to the lines of force of the deflecting field. (Remember that, normally, magnetic deflection is at <u>right-angles</u> to the magnetic deflecting field.)

THE IMAGE ORTHICON.

This is a very recent type of electron camera and is a development of the ordinary orthicon. The image orthicon separates the functions of converting a light image into an electrical image, and of scanning the image. Because of this division of functions each component can be designed for maximum performance, thus obtaining a high degree of sensitivity.

Figure 17 shows a somewhat simplified schematic diagram. The image is focused on to a transparent photo sensitive surface which emits electrons from its inner surface, thus forming an electron image as in the case of the Image Iconoscope and

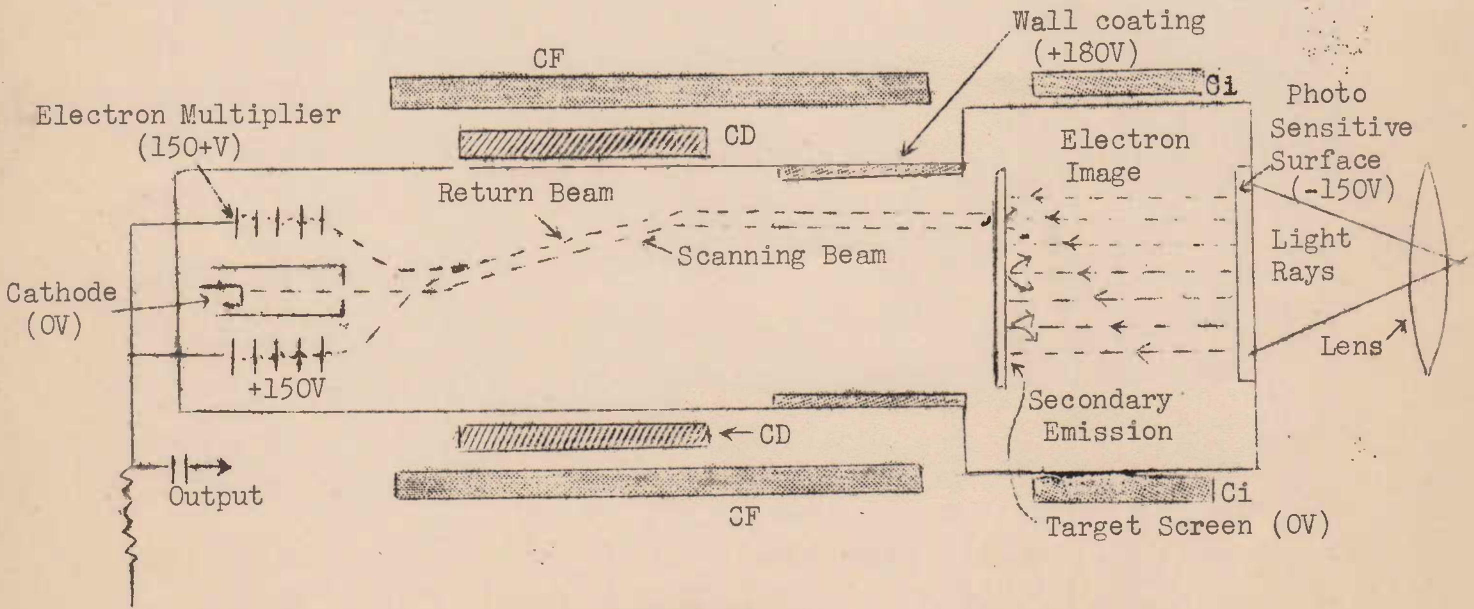
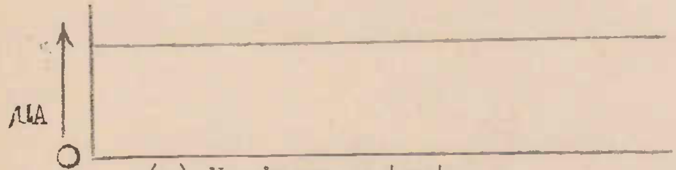


FIGURE 17.

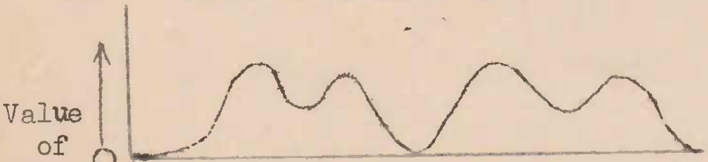
Farnsworth Image Dissector. Referring to Figure 17, the photo-sensitive surface is at a potential of -150V, while a wall coating further up the tube is at - 180V. This provides a field which accelerates the emitted electrons towards the target screen. The electron image is focused by means of a magnetic field due to coils Ci. The photo-electrons of the electron image impinge upon the target screen, and each one dislodges from the latter several electrons by secondary emission, thus leaving the surface with a <u>positive</u> charge. In this way the right-hand side of the screen is covered with positive charges forming an electric charge image as described in the case of the image iconoscope.

Now the target screen is a very thin semi-conductor, being a glass plate .001 inch thick. The conductivity of this plate is sufficient for the positive charges formed upon the right-hand surface to seep through in the time required to scan one picture (say 1/25th sec.), thus charging the left-hand surface with a similar charge (positive) distribution (or image). The conductivity over the surface, however, is not sufficient for the charges to spread appreciably in this time and wipe out the image.

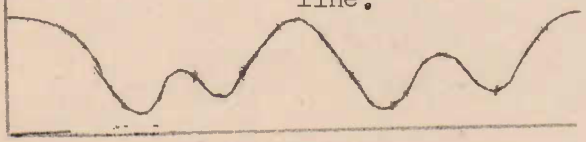
The scanning beam is formed in the conventional manner. As in the ordinary orthicon coils CF provide a focusing magnetic field which extends over practically the whole path of the electrons. The result is as previously described, viz. the beam is only deflected while in the transverse (i.e. across the tube) field due to the deflector coils CD, and after leaving the latter travels perpendicularly to the target screen, thus avoiding de-focusing. Two sets of deflector coils - one set for horizontal line scanning are provided - although one set only is shown.



(a) No image output.



(b) Variation of Charge along a line.



(c) Signal output.

FIGURE 18.

As in the case of the ordinary orthicon a low velocity beam is used, due to the fact that the target screen is at zero or cathode potential (when no image is received). As explained earlier, in this condition the beam will come to a halt just before the screen and then will turn back, almost exactly retracing its original path. Instead of returning to the anode of the electron gun, however, it will be attracted to the more positive plates of the electron multiplier. Thus, when no light image falls on the tube, the output current is a steady D.C. equal to <u>the full value of the beam current</u>, as at (a) Fig. 18.

When a light image is received electric charges are produced on the screen surface, the sizes of the charges varying with the light intensity at the various points. At (b) in Fig. 18 is shown the charge variation along one scanning line. As the beam scans this line not all of the beam electrons will be reflected back from the screen, but the latter will collect sufficient to neutralise the positive charges on its surface. Hence the return beam current will equal the forward beam current less those electrons collected. The return beam current will therefore decrease in value when the screen positive charge image is intense, i.e. when the light from the scene is intense and vice versa. This return beam current is shown at (c) in Figure 18. It is this return current, collected by the electron multiplier near the gun, which forms the signal. Note that the electrical signal output is an inverted or negative one, unlike that of other tubes. The electron multiplier produces an amplification of the signal current of several hundreds of times.

The charge image on the target plate is built up for the whole time between successive scans, and since all photo-electrons are utilised 100% storage efficiency is obtained. The secondary emission effect from the target screen gives a further gain, as of course does the electron multiplier. Those facts, together with the one mentioned earlier, that each component can be separately designed for maximum efficiency results in an extremely sensitive camera. It is claimed that the sensitivity exceeds that of a 35 mm super XX cinema film -- which means that scenes may be televised with the most adverse conditions of lighting.

CA RA CONTROL APPARATUS.

Ha ng reviewed the various types of electron cameras which have been developed to roduce the picture signal, we shall conclude this lesson by a brief description of he circuits which are closely associated with the camera itself, and of the ca ra control apparatus.

Fi re 19 shows a typical set-up.

Th first stages of the amplifiers are built into the camera itself. Fig. 20 sh 's an Emitron Camera with four stages of amplification built in. The signal is hen fed to the so-called "A" amplifier. It is into this stage that the "shading" signals, from the special generators shown, are fed to correct for the spurious "tilt" and "bend" signals. Of course with the later type cameras, such as the Image Iconoscope, Orthicon and Image Orthicon, these generators are not required, since no such undesired distortion occurs in the camera output.

A number of cameras, of which two are shown may be used. The different cameras may be focused on different parts of an outdoor event, such as a cricket match, and the operator can, at will, fade one picture into another by means of the fading control shown.

The "B" and "C" Amplifiers are video amplifiers, the former having a variable gain.

The "Suppression generator" provides voltage pulses, at line scanning frequency, and, these fed into the suppression mixer, block out the spurious signals formed between successive scanning lines.

The sync. generators provide the synchronising voltage pulses, which are fed into the signal, between successive scanning lines and successive scanning frames. These pulses partially fill the gaps left after suppressing the spurious signals eliminated in the previous stage.

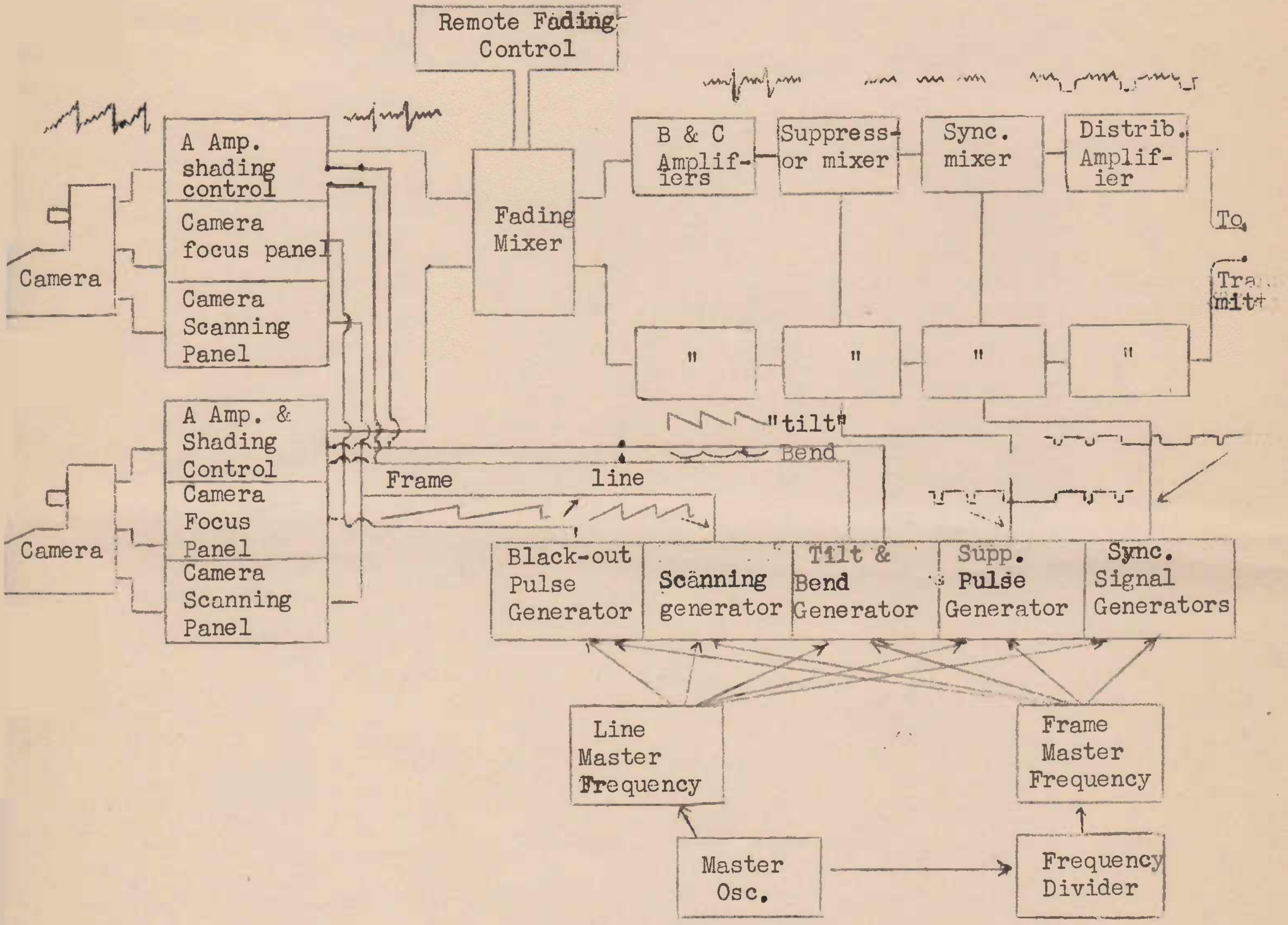


FIGURE 19.

The final signals are taken, by means of special lines, or links (described next lesson) to the transmitter and monitoring units.

The camera scanning generators provide the line and frame frequency saw-tooth voltages (or currents) which deflect the camera beam for interlaced scanning purposes. Here the framefrequency is 50/sec, giving a picture frequency of 25/sec: (remember two frames per picture with interlaced scanning.) The line frequency is, with 405 lines equal to 405 X 25 = 10,125/sec.

All of the generators used are fed from a single master oscillator, in order to ensure correct synchronisation. This master oscillator is "locked" to the frequency of the power mains (50c/sec).

The signals in the various stages of the equipment are shown by their waveform graphs.

In the next lesson we will follow the passage of the video signals through the transmitter.

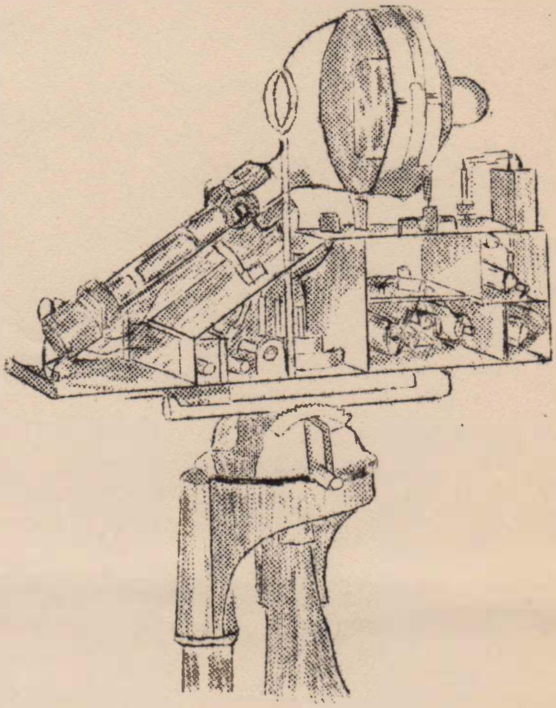


FIGURE 20.

T.FM & F. LESSON NO. 4.

EXAMINATION QUESTIONS.

(1) Why are the current impulses from a photo-electric cell so very weak when used as a source of picture signal?

(2) What is the chief advantage of the electron-multiplier as a pre-amplifier of the picture signal compared with an ordinary thermionic tube?

(3) Upon what effect or phenomenon does the operation of the electron-multiplier depend.

(4) Describe the nature of the mosaic in an iconoscope tube.

(5) What is meant when it is said that the "storage" efficiency of the iconoscope is between 5 and 10%?

(6) Explain the difference between the electron image and the charge in the Image Iconoscope or Super-Emitron type of tube.

(7) What is meant by "spurious" signals in an electron camera's output? State briefly the chief cause of spurious signals.

(8) What is the chief characteristic in the operation of the Orthicon tube? What was the idea behind the development of this design?

(9) State <u>three</u> reasons for the great sensitivity of the Image Orthicon tube.

(10) How does the signal output of the Image Orthicon differ in nature from the outputs of all other tubes discussed in this lesson?

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T.F.M. & F. LESSON NO. 5.

VIDEO AMPLIFICATION

We are all familiar with the term "Audio Signal" or "Audio Frequency Signal" used in connection with radio telephony. This Audio signal (Latin-Audio = I hear) cannot, of course be heard directly. It is in the form of an alternating voltage or current, which, however, has the required frequency and wave form necessary to reproduce the desired sound when passed through the appropriate reproducing device, viz: the loudspeaker.

In the case of the vision side of television transmission, it is the "video" signal (Latin - Video = I see) which corresponds to, or is analogous to, the audio signal of sound transmission. This video signal is not itself visible, being also a varying electric current or voltage whose frequency and wave form are such that when passed into the television receiver reproducer, the cathode ray tube, it re-creates a visible picture or scene.

If we consider carefully a complete sound transmission and reception system we will realise that the audio signal is not to be found throughout the whole of the circuits. Referring to Figure (1) (a) the signal voltages are generated by the microphone, and persists throughout the amplifying circuits to the modulated amp. These are the audio amplifying stages of the transmitter. Once passed into the mod. amp. the audio signal, as such disappears. From this stage onwards, the signal is of radio frequency, although, of course, it is "modulated" in such a way that the audio signal may be caused to reappear again in the receiver. This re-appearance takes place in, or after, the detector. From the latter stage the audio signal persists right through the audio amplifier stage to the speaker.

In a similar manner, the video signal is generated by one or another of the electron cameras described in the last lesson and is passed through the various transmitter stages to the modulator, where it "modulates" a much higher (radio) frequency signal.

The video signal reappears again after the detector in the receiver. It then persists through the final stages until the cathode ray tube is reached (see (b), Fig. 1)

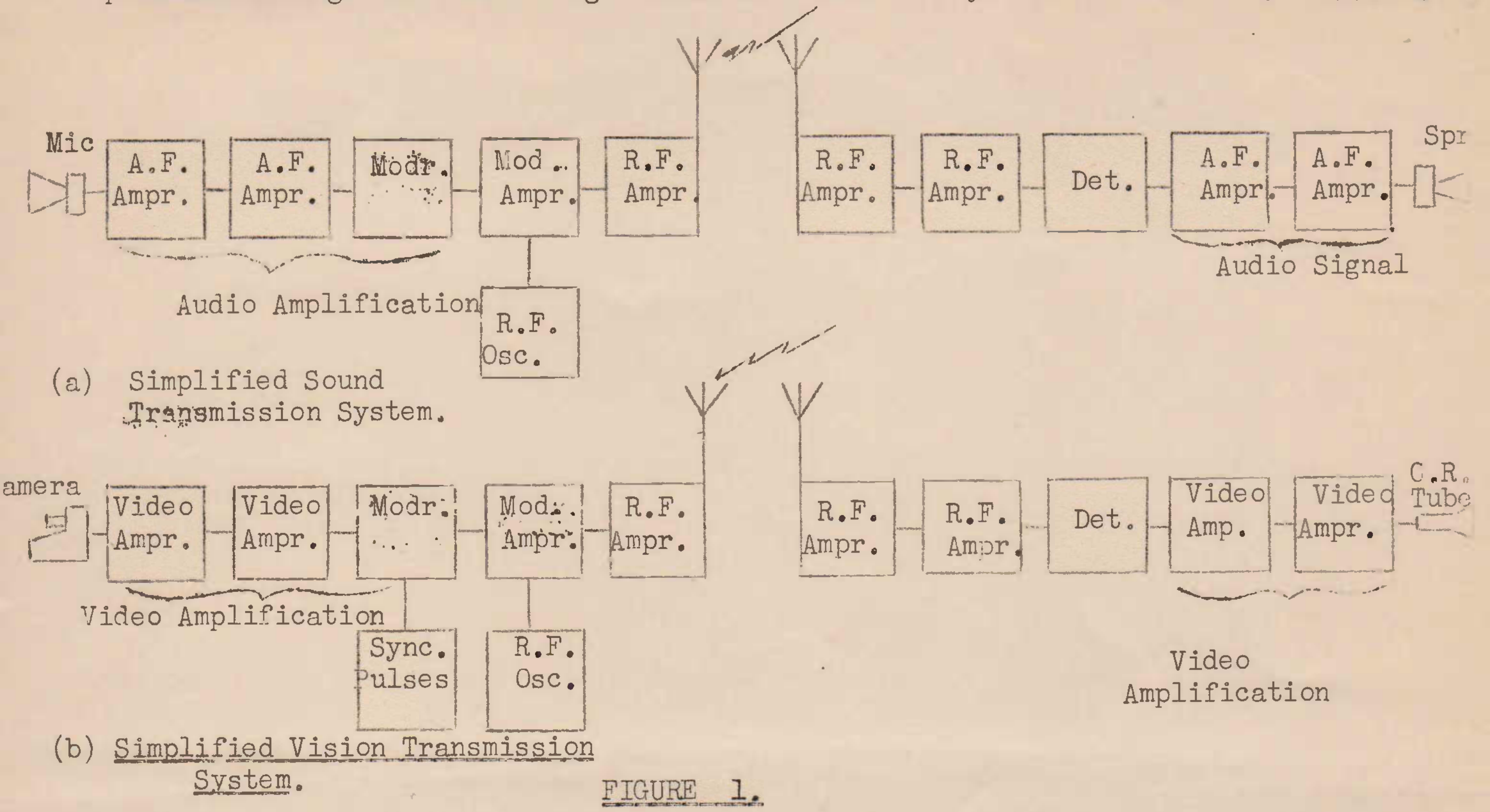


FIGURE 1.

This lesson, then, will deal with the problems associated with those stages between the electron camera and the modulator in the transmitter, and, in the case of the receiver, the stages existing between the detector and the cathode ray reproducing tube. The modulated radio-frequency signal, which cannot be used directly to reproduce the scene, we shall henceforth refer to as the "television" signal. The transmitter and receiver stages which handle the latter will be dealt with in subsequent lessons.

THE NATURE OF THE VIDEO SIGNAL.

The video signal consists of a series of current or voltage changes, as shown in Figure 2. Each change in current or voltage corresponds to a change in light intensity reflected from the scene as the latter is scanned. The changes are shown as occurring in groups, each group separated from the next by a short gap or time interval. Each group corresponds to the signal generated in one scanning line. The gaps represent the short intervals taken by the scanning spot to return from the right hand side of the picture to the left. Figure 2 shows the signal for three complete lines.

The frequency of the video signal varies over a very wide range indeed, and upon the ability of the video amplifiers to handle this range of frequencies will depend the quality of the reproduced signal.

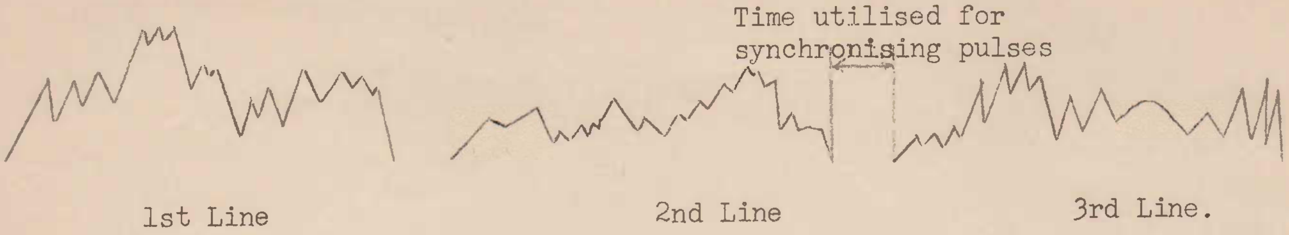


FIGURE 2.
VIDEO SIGNAL FOR 3 LINES.

THE FREQUENCY OF THE VIDEO SIGNAL.

We shall first discuss the upper frequency limit of the video signal. This will depend primarily upon the amount of picture detail which the electron camera can handle. In Lesson 2 it was explained how the performance of a scanning system could be measured in terms of a number of "picture elements". This section should be re-read if necessary. It was pointed out that the number of those elements, and therefore the picture detail which could be reproduced depended mainly, but not entirely, on the number of scanning lines used. This also determines the number of changes in the signal current occurring in one second. The formula given for the number of picture elements per second was:-

$$\text{Number of Picture Elements per sec.} = (\text{No. of Lines})^2 \times \text{Picture Frequency} \times \text{Aspect Ratio} \times \frac{7}{10}$$

This formula, however, does not give the frequency, measured in cycles/sec., of the camera output current. The reason why this is so may be understood by referring to Figure 3.

Here we suppose the scanning beam is scanning a line consisting of a number of alternate black and white squares, each ~~square~~ element being equal to the size of the spot. This will represent a pattern giving the greatest amount of picture detail, since, as we have already seen, (Lesson 2), picture elements which are smaller than the scanning spot cannot be reproduced as separate details.

As the leading edge of the scanning beam passes from the beginning of the line onto the first black spot the reflected illumination from the spot will be gradually decreasing. The video current will therefore decrease from some maximum value to a minimum (from (a) to (b)).

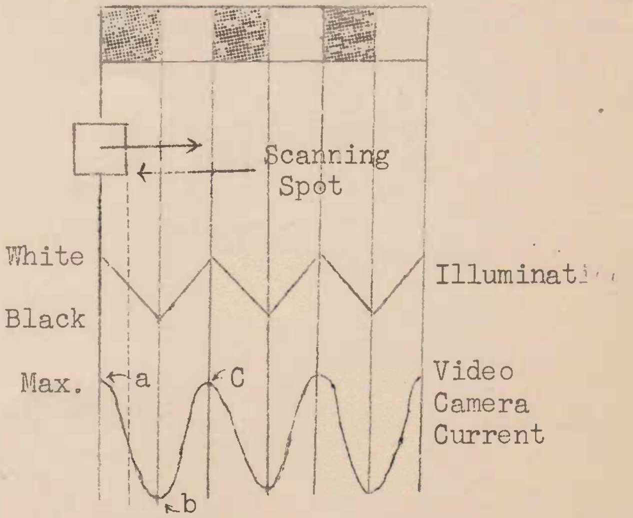


FIGURE 3.
SHOWING HOW THE SCANNING BEAM GIVES RISE TO A FREQUENCY OF HALF THE NUMBER OF PICTURE ELEMENTS.

The word "illumination" here refers to the coverage of the scene by the scanning beam and may be the illumination by light through holes in the scanning disc, in the older disc system, or the "illumination" by electrons of the mosaic or target screen in the modern electron cameras.

Then as the leading edge of the spot moves off the black onto the next white square the current will rise. When the white square is completely covered the current will have attained its maximum value again at (c). Note carefully two facts: (1) the scanning beam has travelled a distance equal to two picture squares or elements, (2) the video current changes represent one cycle only. When the beam has moved a distance equal to the length of the scanning line, and is lying over the last white square, six picture elements will have been covered. In this time however, the video current has performed three complete cycles only.

From the above considerations it follows that the frequency of the video current, measured in cycles/sec., will be one-half of the number of picture elements scanned in one second. This fact enables us to alter the formula repeated above to give this frequency instead of the number of picture elements per second, thus:

$$\text{Frequency of Video Signal} = \frac{(\text{No. of Lines})^2 \times \text{Picture Freq.} \times \text{Aspect Ratio}}{2} \times \frac{7}{10}$$

The frequency of the signal, using the above formula, will be in cycles/second.

Notice that we have divided the right hand side of the equation by two. Remember that the factor $\frac{7}{10}$ was a figure arrived at by theoretical considerations, and practical experiments, to account for the fact that some picture elements are not reproduced even though they be no smaller than the scanning spot (see Lesson 2).

The formula still requires a certain amount of modification, on account of the fact that the original result for the number of picture elements was based on the assumption that no time was lost between successive scanning lines, i.e. that each new line was commenced immediately after the end of the previous one. In actual fact, however, a time interval of 15% of the total time for the line trace occurs between successive lines. This short interval occurs as the scanning beam is returning rapidly from the right hand side to the left hand side of the screen, and is utilised for carrying the line synchronisation pulses (see Figure 2). This means that the actual scanning of each line must be done in 85% of the time available in the ideal case. In other words the scanning speed, and therefore the rate of repetition of picture elements (and cycles in the video current) will be increased by $\frac{100}{85}$ times. Hence the corrected formula for video frequency is:-

$$\text{Video Frequency} = \frac{(\text{No. of lines})^2 \times \text{Picture Freq.} \times \text{Aspect Ratio}}{2} \times \frac{7}{10} \times \frac{100}{85}$$

$$= \frac{(\text{No. of lines})^2 \times \text{Picture Freq.} \times \text{Aspect Ratio}}{2} \times \frac{7}{17} \text{ C/Sec.}$$

Taking an actual case, consider scanning of 525 lines, 30 picture per second, aspect ratio being $\frac{4}{3}$.

Video Frequency = $(525)^2 \times 30 \times \frac{4}{3} \times \frac{7}{17}$ = 4,500,000 C/sec. (approx.)
i.e. a frequency of 4.5 megacycles/sec.

This figure represents approximately the highest video frequency dealt with in the standard equipment for black and white reproduction at present in use in America.

In England, at present, where a total of 405 lines are used, with a picture frequency of 25/sec, and an aspect ratio of $\frac{5}{4}$, the highest video frequency is about 2.1 megacycles per second.

It should be remembered that these results obtained from the formula represent the maximum video frequency which we will obtain in scanning the picture, no matter how much detail the picture might contain. It is a frequency which allows a horizontal resolution or definition equal to the vertical resolution or definition. It represents the most severe requirements.

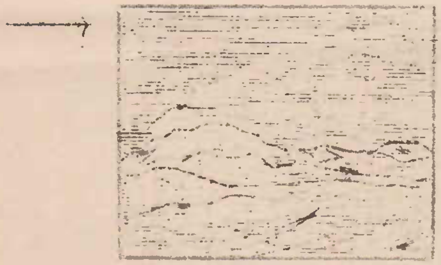


FIGURE 4.

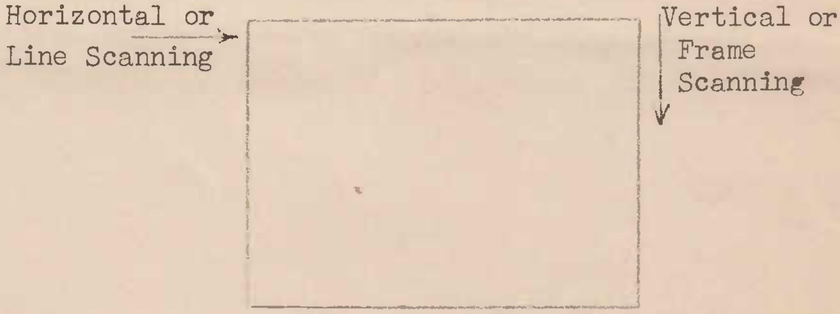


FIGURE 5.

If we were to transmit a simple picture having no fine detail and no sharp outlines from black to white or vice versa, we would not come anywhere near this maximum or "limiting" frequency. The changes in current brought about by the changes in light while scanning across the picture would be comparatively gradual, and gradual changes of current are equivalent to a low frequency. A picture of this kind is shown in Figure 4.

Scanning across the line indicated by the arrow we find only comparatively few changes from light to dark and from dark to light, and these changes are comparatively gradual. This means a low video frequency. If there were any sharp outlines or fine detail in the picture the light changes and current changes would be more rapid, and would be equivalent to a much higher frequency. We could say that in the average type of picture the frequencies produced would be very much less than the maximum obtained from the formula above.

The video frequency obtained from the formula may be taken as the highest possible one we shall have to handle. What, then, is the lowest frequency? If the picture consisted of no changes in light and shade at all, for example a white wall (having no fly marks on it) as in Figure 5, it might be thought that the video frequency from the camera would be zero. This is not the case however. Every time the scanning beam comes on to the picture area the camera produces a sudden rise in current, and every time it leaves the area a corresponding fall. This represents one cycle (one rise and one fall) in output current, and occurs at the line frequency, say 10,125 cycles per second for 405 lines, 25 pictures per second. This is, of course, by no means a very low video signal. But in addition to the line scanning we have the vertical frame scanning, see Figure 5. When the beam passes on to the frame at the top of the picture a sudden rise in camera current occurs, with a sudden drop when the beam leaves the frame $\frac{1}{50}$ sec. later (with interlaced scanning). Hence the camera output will contain a frequency of 50 cycles/sec.

Now it is important that the video amplifiers be able to handle a frequency as low as 50 cycles/second. In practice they are designed even better than this, to amplify without loss of gain or distortion, frequencies down to 25 cycles/sec. which is the picture frequency. The necessity for this low frequency will be seen if a picture containing a gradual increase (or decrease) in shading from top to bottom is considered. To reproduce a complete picture containing this gradual shading (as well as the super-imposed detail) it will be necessary for the amplifiers to handle effectively a frequency equal to the rate of repetition of the pictures, viz: 25 per second.

Our video frequency, then, will range from 25 cycles/sec. to between 2 and 4 megacycles/sec. Compare this with the usual range of audio frequencies, from about 100 cycles/sec to, say, 7,500 cycles/sec. at the most. It is immediately obvious that a video amplifier must be much more carefully designed than its counterpart - the audio amplifier.

REQUIREMENTS OF A VIDEO AMPLIFIER.

The video amplifying stages of a television transmitter or receiver must satisfy the following conditions:-

(a) Amplify equally well all signals whose frequencies extend over the video range. In other words there must be no variation in gain with frequency.

(b) Produce no phase distortion in the signal. Phase distortion means the introduction of a time delay in the signal passing through the amplifier, whereby different frequencies are delayed for varying amounts of time.

The idea of "phase" and the meaning of phase shift and phase distortion will be discussed a little later in the lesson.

WHAT TYPE OF AMPLIFIER?

It will be recalled that several methods of inter-stage coupling are used in audio amplification work. These are:- (a) Choke Capacity (Impedance) Coupling, (b) Transformer coupling and (c) Resistance capacity coupling.

Of these, the first two are right out of the question. Choke coupling, for example, will not give a "flat"response over an extended range of frequencies. The reason for this is that, as the frequency rises the reactance of the choke increases, yielding an increased amplifier gain, until some particular frequency is reached when the gain rapidly falls off. The latter effect is due to stray capacities, between the windings and in the valves, "shunting" the inductance of the choke. A somewhat similar result is obtained when using transformer coupling. Figure 6 shows a typical amplification curve (gain plotted against frequency) for a transformer coupled amplifier. Using triode tubes, a fairly flat curve may be obtained over a limited range for audio work. In the graph shown the useful part of the range is from about 200 cycles/second to about 2 or 3 thousand cycles/sec. Note that the gain has fallen to a very low value at about 11,000 c/sec.

Remembering that we require equal amplification for all frequencies over a range from 25 cycles/sec up to about 500,000 cycles/sec. it will be realised just how far short of our requirements this type of amplifier coupling falls.

For wide-range amplification we must depend on the resistance-capacity coupled amplifier. The merit of this type of amplifier lies in the fact that the value, measured in ohms, of a pure resistance does not vary with frequency.

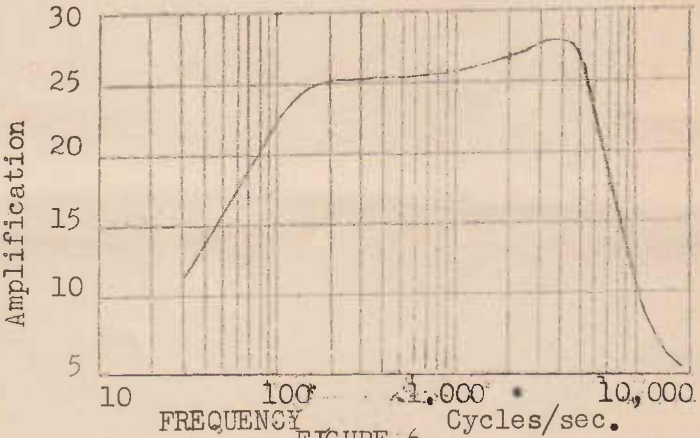


FIGURE 6.

CHARACTERISTICS OF RESISTANCE-CAPACITY COUPLED AMPLIFIERS.

The essentials of a voltage amplifier, with the necessary resistor and capacity for developing the signal voltage, and passing the latter on to the next stage is shown in Figure 7.

The load resistor R_L in the plate circuit develops, or builds up, the A.C. signal voltage, and the coupling condenser Cc passes the latter to the grid of the next tube. The greater the value of R_L, the larger will be the output voltage from the stage, that is the greater the gain.

The voltage gain (G) from such a stage is usually calculated from formula (1) below, when a triode tube is used.

$$G = \frac{\text{Amplification Factor X Load Resistance}}{\text{Plate Resistance} + \text{Load Resistance}} \qquad (1)$$

When a pentode valve is used a more useful formula is:-

$$G = \text{Mutual Conductance X Load Resistance} \qquad (2).$$

In both of these formulae there is no factor which appears to vary with the frequency of the signal. It would seem therefore that such an amplifier would amplify signals of all frequencies equally well; and, in point of fact, the resistance-capacity amplifier does have a very flat amplification curve over a much greater frequency range than can be handled by stages using other coupling arrangements. A "frequency response" curve (i.e. graph showing variation of gain, or amplification, with frequency) is shown, for a typical audio resistance-capacity coupled amplifier, in Figure 8.

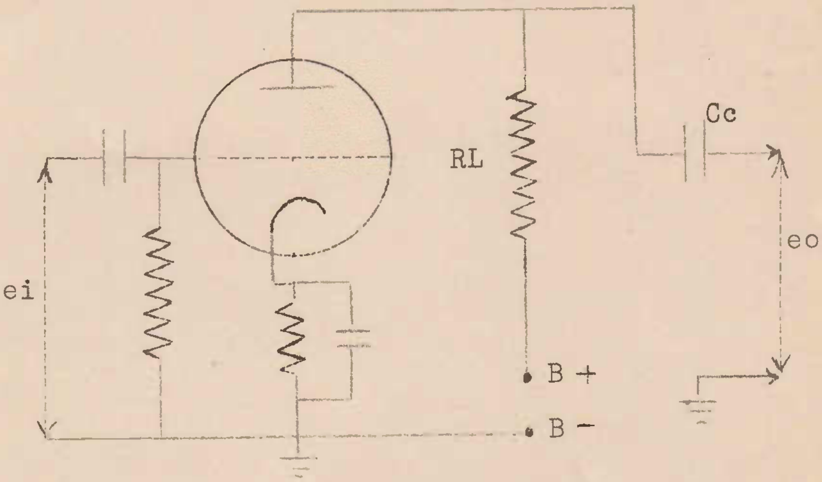


FIGURE 7.

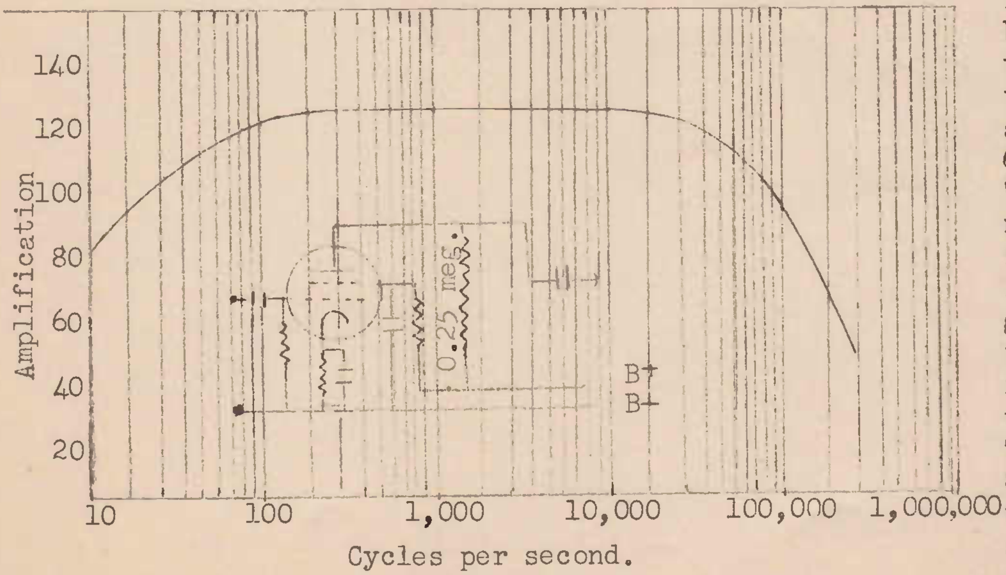


FIGURE 8.

This curve should be compared with that given for a transformer coupled amplifier in Figure 6. Note that the "response" over the middle range of frequencies is much flatter, and that the gain is maintained to a much higher frequency, compared with the former case. The curve of Figure 8 is drawn for a typical audio voltage amplifier -- a 6 J 7 operating with a .25 meg. plate load resistor. Note that the response is "flat" over a range of frequencies from about 200 cycles/sec up to 30,000 cycles/sec. At

100,000 cycles (100 Kc/sec.) the gain has dropped off to about .7 of its normal value, and thereafter there is a rapid deterioration. Similarly at the low frequency end of the curve there is a serious loss of gain below 50 cycles/sec. The high frequency response of this amplifier is more than adequate for audio-amplification work, but hopelessly inadequate for video amplification, where the response must be flat up to at least 2.5 megacycles/second.

We have seen then that even a resistance-capacity coupled amplifier suffers from a loss of gain at both high and low frequencies. What are the reasons for these losses? We shall consider each case separately.

THE HIGH FREQUENCY RESPONSE.

The formulae(1) and (2) given above are accurate for the middle frequencies where the only factor which appreciably affects the gain, apart from the characteristics of the tube itself, is the load resistance in the plate circuit. At high frequencies, however, the load resistor is seriously "shunted" by the reactance of "stray" capacities, with the result that the total impedance in the plate circuit may be very much less than the actual value of the resistor itself. When this occurs, we should replace the term "load resistor" in the formulae for gain (1) and (2) given above by "Total impedance in plate circuit", and then a lower result for the gain will be calculated.

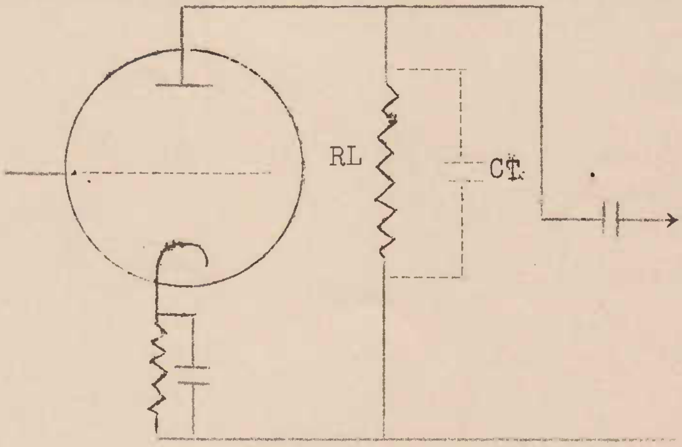


FIGURE 9.

This effect of stray capacities shunting the load resistor is illustrated in Figure 9, where the latter is represented by R_L. The "stray" capacities whose total effect is represented by C_T arise from several different causes discussed below. Notice that C_T is in parallel with R_L, and remember that the total effect of two impedances in parallel is always less than either impedance alone. The value of the stray capacities, may be anything up to 100 micro-micro-farads (100 mmfd), 50 mmfd being quite a representative value. Now this, measured by ordinary standards, is a very small capacity and its effect in shunting R_L at low and medium frequencies is entirely negligible. To explain this point remember that the reactance, measured in ohms, of a capacity is given by

$$\text{Reactance in ohms} = \frac{1}{2 \pi f c} \text{ ohms.}$$

Where π = 3.14 (approx.), f is frequency in cycles/sec., and C is capacity in farads.

Now, since C_T (stray capacities) is small this reactance will be very large (much larger than R_L) at low and medium values of frequency (f). Hence, in this case, the shunting effect of C_T on R_L will be negligible, and no loss of gain will be suffered. As the frequency of the signal increases, however, the reactance of C_T becomes smaller and smaller. When this reactance is reduced to a value not very much larger than R_L, the shunting effect becomes noticeable, and the gain begins to fall off, as shown by the curve of Figure 8.

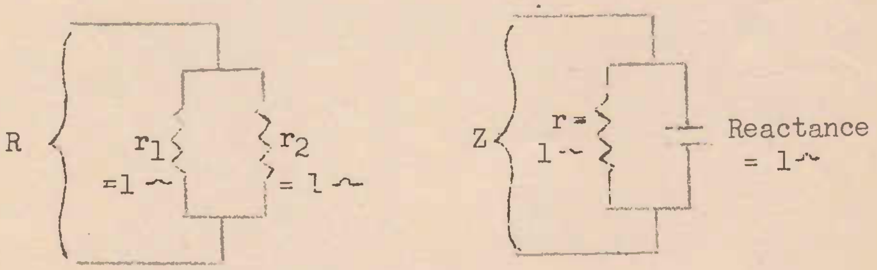
The gain for a pentode tube at any high frequency will be given by:-

G = (Mutual Conductance) X (Total Impedance in Plate Circuit) (3)

Where Total Impedance in plate circuit = impedance of R_L and reactance of C_T in parallel.

As the frequency increases further, the reactance of C_T is further reduced, and hence plate load impedance becomes smaller. At very high frequencies the reactance of C_T may be only a small fraction of R_L, and the gain as calculated from formula (3) may be reduced to a value less than one. This, of course represents a loss in signal amplitude instead of a gain. An interesting and important case is the one when the frequency is such that the reactance of C_T exactly equals the resistance of the plate load resistor. When these conditions obtain the total plate load impedance works out at .707 ($1/\sqrt{2}$) of the value of the resistor alone. With a pentode this reduces the gain to .707 of its normal value. (Note: in the case of two equal resistances in parallel, the effective value of the combination is one-half of each branch. With a resistance and capacity in parallel, however, the calculation is not so simple, and the effective value works out as stated at .707 of each equal branch. See Figure 10).

In Figure 8. the gain at 100 Kc/sec. is about .707 of that at middle frequencies, this representing the frequency where the reactance of the stray shunting capacities equals the load resistance. As the frequency is increased still further this reactance falls below the value of R_L, and the response curve is seen to fall off very rapidly.



R = ½ ohm.

Impedance (Z) = .707 ohms.

FIGURE 10.

The stray capacities, which cause the loss of gain at high frequencies, consist of:-

(a) Wiring capacities to ground, i.e. capacity effects existing between the plate lead of the tube and ground, plus similar capacities between the grid lead of the next tube and ground. These are represented by Cw in Figure 11.

(b) The output capacity (Co) of the tube itself, i.e. the capacity measured between the plate of the tube and cathode.

(c) The input capacity (Ci) of the following tube, i.e. the effective capacity between grid and cathode of this tube.

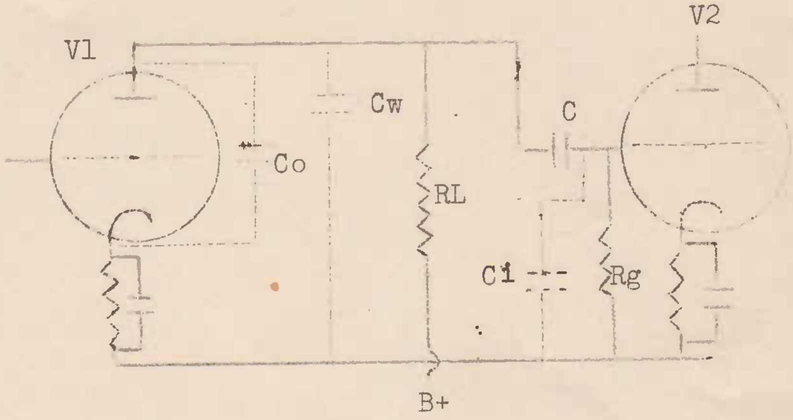


FIGURE 11.

All of these capacities are in parallel with each other, and also in parallel with the load resistor RL. The total stray capacity (Ct) is therefore the sum of Cw, Co and Ci and in Figure 9 has been represented by the "lumped" capacity Ct in parallel with RL.

In addition to distributed capacity one must also consider the effect of the plate load resistor of V1 and the grid leak resistor of V2. The frequency-voltage characteristic of a resistance capacity coupled amplifier is not determined by any of these factors alone but by a combination of all three.

At middle and high frequencies the ultimate load presented to the plate of the first valve, and thus the gain of the amplifier, will be equal to RL and Rg (Fig.12) in parallel. At low frequencies we can no longer afford to neglect the reactance of the coupling condenser C (Fig. 12), which is in series with Rg. The grid of the valve is connected to the junction point of C and Rg, consequently as the reactance of C increases, at low frequencies, the voltage supplied to the grid of V2 will be reduced.

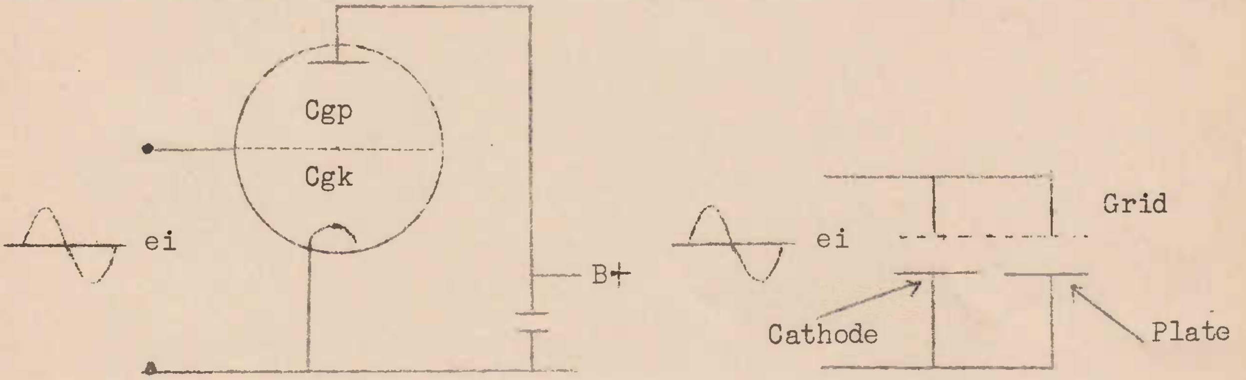
At extremely high frequencies the gain of the amplifier is limited not merely by the resistive combination of Rl and Rg but by the impedance of the parallel combination of Rl, Rg and the circuits stray capacities.

The inter-electrode capacities of a triode tube are indicated in Figure 12, where Cgk is the capacity between grid and cathode, Cgp is that between grid and plate, and Cpk that between plate and cathode. The latter represents the "output" capacity shown in Figure 11.

The input capacity shown in Figure 11 is not simply the grid cathode capacity, as might be expected. The inter-electrode capacities referred to are characteristics of the tube itself, depending only upon the electrode sizes and spacings. The input capacity, which is measured under actual operating conditions between grid and cathode capacity, and varies with the stage gain. The reason for this is due to an important phenomenon, known as the "Miller Effect".

THE MILLER EFFECT.

Consider first the input capacity of a tube when the tube is not operating, e.g. when there is no load resistor in the plate circuit as represented by the broken line short circuiting the plate load resistor in Figure 13a. If an alternating voltage is applied between grid and cathode as at (a) in Figure 12 an alternating current will flow between the input terminals, its value depending upon the total effective capacity between these terminals. One capacity which contributes to this current flow is the grid-cathode capacity (Cgk). But since a capacity exists between grid and plate (Cgp), and since the plate is connected back to the cathode by way of the B+ by-pass condenser (Figure 12 (a)), the input voltage will cause an additional A.C. flow via this plate circuit path. Now the total input alternating current is the sum of these two branch currents which pass through Cgk and Cgp respectively. In other words Cgk and Cgp must be regarded as in parallel with one another as far as the input signal voltage is concerned. Hence, in the case of zero amplification or gain, the total input capacity (Ci) is the sum of Cgk and Cgp, i.e. Ci = Cgk + Cgp.



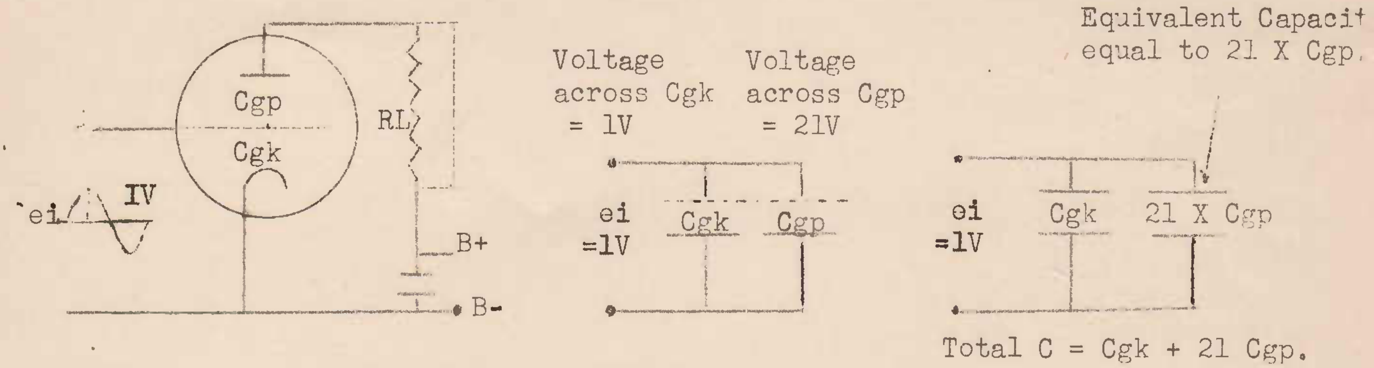
(a)
Triode not Amplifying

(b)
Equivalent Input Circuit of (a).

FIGURE 12.

Now suppose a load resistor is inserted in the plate circuit and the stage gain is, say, 20. (Fig. 13). Further, suppose that the input voltage has a peak value of 1V. This latter voltage is applied directly across Cgk, and an A.C. flows through this capacity and has a value depending upon the size of Cgk. In addition, there still exists, between the input terminals, the path via the grid-plate capacity. Now the A.C., due to input voltage, flowing through Cgp will be much greater than what it was in the non amplifying state, due to the fact that the A.C. voltage acting across Cgp is much greater than the 1V input voltage.

The reason is as follows: Since gain is 20 times, the A.C. voltage, measured between plate and cathode will be 20V. (peak). The peak value of the A.C. voltage between plate and grid will be the 1V (peak) between grid and cathode, plus the 20V (peak) between plate and cathode -- a total A.C. voltage of 21V (peak). These voltages are added because when, for example the grid voltage is at its negative peak of -1V, the plate A.C. voltage will have gone 20V positive (remember grid



Amplifying Stage. Gain = 20.
(a)

Input Circuit
Equivalent of (a).
(b)

Equivalent of (b).
(c)

FIGURE 13.

and plate A.C. voltages out of phase). Hence, at this instant, the peak voltage between grid and plate will be 21V.

Now this 21V A.C. acts across Cgp (See (b) Fig. 13) an alternating current to flow through this capacity 21 times as great as was the case when no amplification was occuring (see Fig 13 (b)). As far as the input signal is concerned the net result is the same as though we connected a simple condenser, of capacity equal to Cgk, in parallel with another condenser whose value is 21 times as great as Cgp. This is shown at (c) in Figure 13.

The total input capacity is thus equal to grid-cathode capacity plus 21 times grid-plate capacity, i.e.

$$Ci = Cgk + 21\ Cgp.$$

or $$Ci = Cgk + (20 + 1)\ Cgp.$$

Now since 20 here represents the stage gain we may write:

$$Ci = Cgk + (G + 1)\ Cgp.$$

As an illustration, take the case of the 6B6-G (75) tube, with Cgk = 2.7 m.m.fd, Cgp = 1.7 mmfd and stage gain (G) = 60.

$$\begin{aligned} Ci &= 2.7 + (60 + 1) \times 1.3 \text{ mmfd.} \\ &= 2.7 + 61 \times 1.3 \text{ mmfd.} \\ &= 83 \text{ mmfd. approx.} \end{aligned}$$

It will be observed that in a case like this the grid-plate capacity causes far more trouble than does that existing between the grid and cathode itself.

The electrical effect whereby the input capacity of a tube is greatly increased as a result of the presence of capacity between grid and plate, is known as the "Miller Effect".

For practical purposes the best way of visualising the action is that an extra capacity is "reflected" into the grid circuit from the plate circuit. Note that the amount of this reflected capacity depends directly upon the stage gain obtained.

From the foregoing it will be realised that the Miller Effect is an important factor in adding to the total stray capacities which shunt the load resistor, and cause a deterioration in gain towards the high frequency end of the video range. The Miller Effect is not nearly so serious in the case of pentode valves as it is in triodes. The screen grid of a pentode shields the grid from the plate, and thereby reduces the grid-plate capacity almost to zero. For example in the case of the pentode 6AC7 the Cgp = 0.015 mmfd compared with 1.3 mmfd for the triode 6B6. If both tubes are producing a stage gain of, say, 20, the "Miller Effect" capacity for the pentode is only (20 + 1) X .015 = 21 X .015 = 0.315 mmfd. compared with (20 + 1) X 1.3 = 21 X 1.3 = 27.3 mmfd. for the triode.

It must be remembered that with a pentode valve the "Miller Effect" and grid-plate capacity are not the sole factors influencing the high frequency response of an amplifier. We have also to consider the effect of its grid-cathode capacity and grid-screen capacity on the gain at high frequencies of the preceeding valve. These capacities would add to those due to "Miller Effect" and Cgp thus reducing slightly the advantage which the pentode holds over the triode in the matter of improved high frequency response.

INCREASING THE HIGH FREQUENCY RESPONSE.

Referring back to Figure 8 it will be realised that the frequency point at which the gain of the amplifier commences to fall must be very greatly extended, if the video range of 25 c/sec -- 2 or 4.5 mc/sec is to be adequately covered.

This may be partially achieved by the following methods:-

(a) Reducing to a minimum the stray capacities across the load of the stage concerned.

(b) Reducing the value of the load resistor.

With reference to (a) above, wiring capacities may be kept down by careful design. Long plate and grid leads should be avoided, particularly if they run close and parallel to a metal chassis. The wire should be as thin as possible, consistent with mechanical rigidity. Tubes specially designed for video amplification usually have the grid connected to a base pin instead of a metal cap. This avoids the necessity for using a long lead passing through the chassis from the plate of one tube to the grid of the next.

Secondly a tube should be chosen having a low output capacity. Video tubes are specially designed having this characteristic. The miniature "acorn" tubes are especially valuable in this respect.

Thirdly the input capacity of the <u>following</u> tube should be kept as small as possible.

This generally involves the use of a following pentode on account of the very small plate-grid capacity of this type of tube, as explained above. In this way the Miller Effect is minimised. The Miller Effect may be further reduced by reducing the gain of the following stage. Another expedient which has the effect of decreasing the input capacity is the use of negative feed-back (degeneration). This feed-back is sometimes achieved simply by omitting the by-pass condenser across the cathode bias resistor.

Concerning (b), above, the size of the load resistor in the plate circuit has a very important bearing on the highest frequency which can be handled without loss of gain.

Earlier in the lesson it was pointed out that with a pentode value the gain falls to .707 of its normal value at that frequency which gives a reactance of the stray capacities equal to the load resistance. If the load resistance is reduced to one-half, the reactance of the stray capacities will also have to be reduced to one-half before the gain in the new case falls to .707 of its value at middle frequencie This means that the signal frequency will be doubled (since reactance = $\frac{1}{2\pi fc}$ ohms) before the response curve shows any serious drop. This, of course, is assuming that the stray capacities remain equal in the two cases. Thus halving the load resistance will approximately double the high frequency range of the amplifier, and so on. Figure 14. shows the effect of various values of load resistor upon high frequency response. Of course, reducing the load resistor will reduce the normal gain of the amplifier for all frequencies. This is the price we pay for the wide-band amplification obtained. When studying the curves of Figure 14 it should be remembered that a logarithmic scale is used for frequency, and that the improvement in high frequency response obtained by reducing RL is much greater than a casual glance at the diagram would seem to indicate. For example when using a 50,000 ohm resistor the upper frequency limit of the amplifier is about 80 Kc/sec. When the load resistor is reduced to $\frac{1}{50}$ of this value, viz: 1,000 ohms the frequency response will be flat up to 2,000 Kc/sec. (2 mc/sec.). An even greater relative improvement would be obtained if a pentode tube were used. In the case of pentodes it may be taken as a rule that the upper frequency limit increases proportionately to the reduction in plate load resistor.

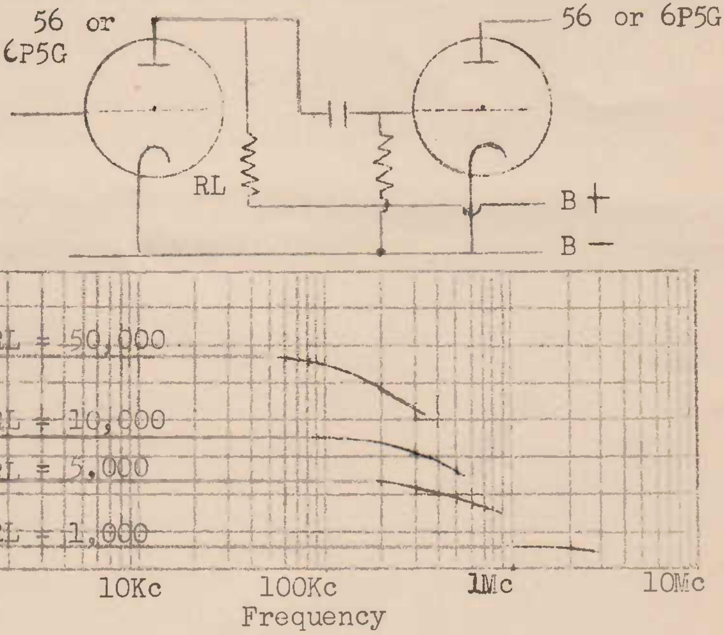


FIGURE 14.

GAIN-FREQUENCY RESPONSE CURVE OF A R-C COUPLED AMPLIFIER SHOWING EFFECT OF EXTENDING RANGE AT THE EXPENSE OF GAIN.

Referring again to Figure 14, we see that the amplifier will nearly cover our required video frequency range by reducing RL to 1,000 ohms. But when this is done the amplification is reduced to nearly one. This, of course is no good, since it would mean that all signals would appear at the output of the amplifier with no greater amplitude than they possessed at the input. In practice we would require a load resistor at least 5 or 10 times 1,000 ohms.

Since we desire to use a load resistor of the smallest possible value, and yet still retain some appreciable amplification, the solution of this problem is to choose a tube having a very high value of mutual conductance (Gm). Formula (2) given above for stage gain shows that loss of gain experienced by reducing RL may be offset by increasing Gm. Since Gm may be defined as

$$\text{Gm} = \frac{\text{Change in Plate Current}}{\text{Change in Grid Voltage}}$$

a high Gm will mean that a given signal voltage on the grid will produce large changes in plate current; and these will be capable of developing large signal voltage changes across the (comparatively) small plate load resistor. Now a high Gm will involve a comparatively heavy d.c. plate current. We find therefore that a tube specially designed as a video voltage amplifier, with large Gm, carries a very much larger plate current than does a tube used for audio voltage amplification. In this respect a video voltage amplifier tube is more closely similar to a power amplifier for audio work. For example the 6AC7 pentode (designed as a video voltage amplifier, as well as an I.F. amplifier) has a Gm of 9,000 µA/V and carries a normal plate current of 10 m.a. Compare this with the audio voltage amplifier 6J7, having a Gm of 625 µA/V. when its plate current is 0.56 m.a.

From the foregoing it will be noted that the most important characteristics of a tube as a video amplifier are a higher value of mutual conductance and low values of inter-electrode capacities. The amplification factors alone are no criteria whatever of different tubes' relative merits as video amplifiers; for a large value of amplification factor might (and often does) mean a large value of plate resistance, with comparatively low values of plate current and mutual conductance. Since tubes designed as output power amplifier for audio work usually have high values of Gm, they are sometimes used for voltage amplification of video signals. For example the beam power tetrode 6V6 having a Gm of 4,100 µA/Volt makes quite a good voltage video amplifier if the video range is not too wide.

Since large values of Gm mean close spacing of the grid wires and close spacing between grid and cathode within the tube, it is unfortunate that this results in an increase of inter-electrode capacities. It requires very careful design in order to obtain large Gm's and low values of these capacities. The term "Figure of Merit" is sometimes used to denote the efficiency of a tube as a video amplifier.

$$\text{Figure of Merit} = \frac{\text{Mutual Conductance}}{\text{Total Electrode Capacities}}$$

This figure should be as high as possible.

HIGH FREQUENCY COMPENSATION.

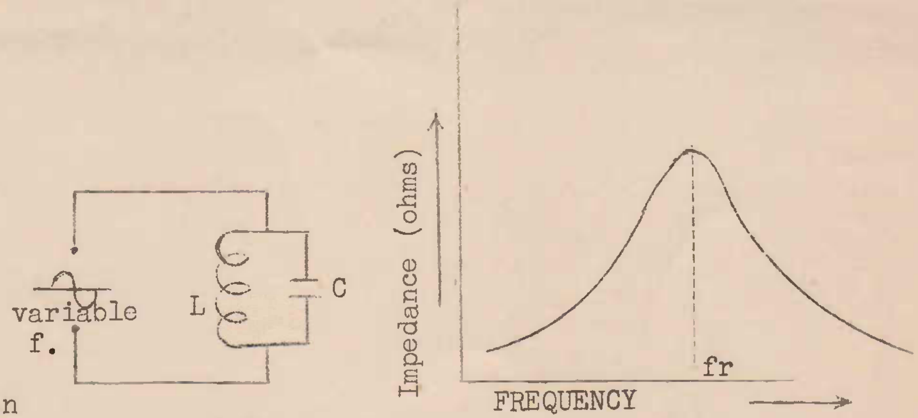
We have seen that it is impossible even when using specially designed tubes, to extend the frequency range of an ordinary resistance-capacity coupled amplifier to that required in television. The problem is solved in practice by "boosting" the higher frequencies, where the amplifier gain begins to fall off due to the shunting effect on the load resistor by stray capacities. This process is known as high frequency compensation.

This compensation is achieved by connecting a small inductance, or two inductances, in the plate circuit of the tube. The principle of the various schemes depends upon two important facts, viz:-

(1) The <u>impedance</u> of a parallel tuned circuit rises as the resonant frequency of the circuit is approached, and is a maximum at the resonant frequency.

(2) The <u>voltage</u> developed across either L or C in a series tuned circuit increases as the resonant frequency is approached, and is a maximum at the resonant frequency.

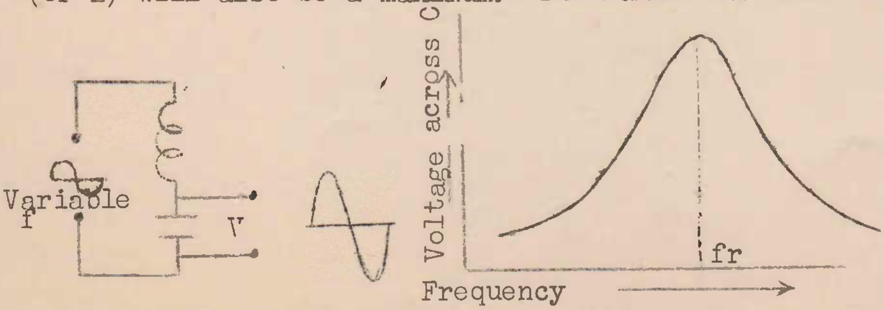
In Figure 15 is shown at (a) a parallel tuned circuit, consisting of L and C, across which an alternating voltage of variable frequency is applied. As the frequency of the voltage is varied, the impedance of the circuit varies, and is a maximum at the <u>resonant</u> frequency of L and C. This is shown by the graph at (b), where fr is the resonant frequency.



(a) (b)

PARALLEL TUNED CIRCUIT.
FIGURE 15.

At (a) in Figure 16 is shown a <u>series</u> tuned circuit, consisting of an inductance L and capacity C in series. A variable frequency voltage is applied across this circuit. Here the <u>current</u> through the circuit increases as the resonant frequency is approached, and becomes a maximum at resonance. When the current through C (or L) is a maximum the voltage (A.C.) developed across C (or L) will also be a maximum. The manner in which the voltage across C increases to a maximum as the resonant frequency is approached is shown at (b) Figure 16.



(a) (b)

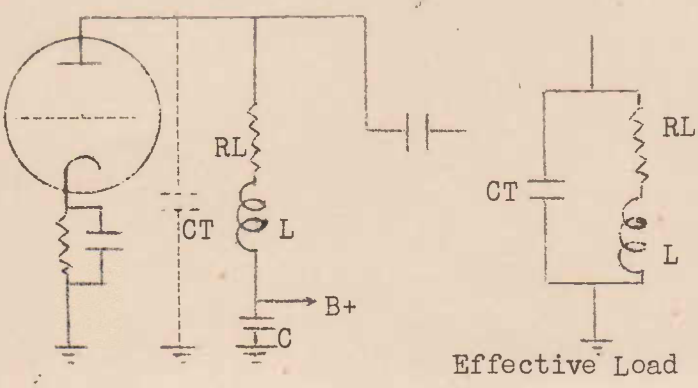
SERIES TUNED CIRCUIT.
FIGURE 16.

"SHUNT PEAKING" COMPENSATION.

Figure 17 shows how a small "peaking" inductance coil may be inserted in series wit the load resistor to compensate for the effect of stray capacities at high frequencies

The condenser CT dotted in represents the total stray capacities.

Inductance L and capacity CT form a parallel tuned circuit with the resistance RL in one branch as shown at (b) in Figure 17. Remember that the B+ end of L is connected to ground, i.e. to the lower side of CT, by means of the high tension by-pass (or filter) condenser C, as shown at (a). In Figure 17(b) this condenser is omitted since its reactance is negligible at all signal frequencies, and it therefore acts as a short-circuit.



(a) (b)

SHUNT PEAKING COMPENSATION. FIGURE 17.

The value of L is chosen so that the resonant frequency of the parallel circuit lies a little above the highest frequency it is desired to amplify. As this frequency is approached the impedance of the parallel circuit tends to rise, as explained above. Since this circuit now forms the effective load in the plate circuit, the effect described compensates for the loss of gain which otherwise would occur due to CT shunting RL.

The effect of the compensation is shown in Figure 18. Here, with no compensation the gain is shown as dropping off at about 200,000 c/sec. The compensation has maintained the gain curve "flat" up to a frequency of 1,000,000 C/sec (1mc/sec). Note that the gain actually rises slightly after this as the resonant frequency of L and CT is reached.

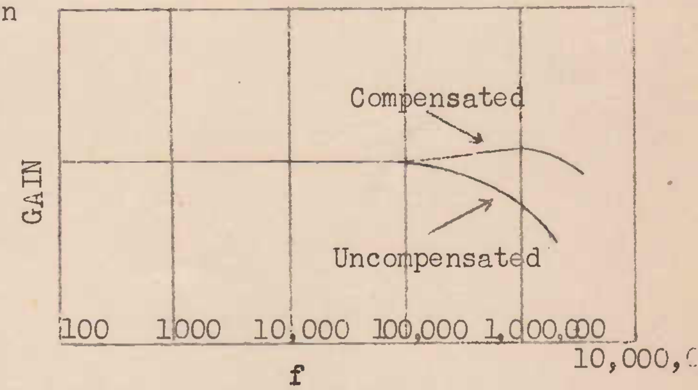
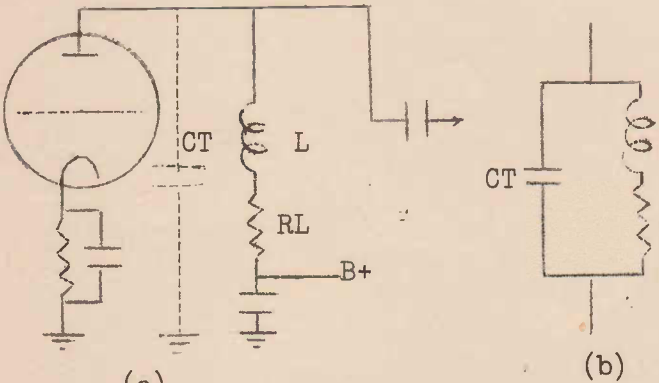


FIGURE 18.



(a) (b)

FIGURE 19.

Figure 19 shows a slightly different arrangement of "shunt peaking" compensation, where the "peaking" coil L is placed between the tube's plate and the load resistor. The effective plate load is shown at (b), and is seen to be electrically equivalent to that of the first arrangement.

It should be remembered that the peaking coil is a very small inductance, and its effect is entirely negligible in the circuit, until the very high frequencies are reached. The same, of course applies to the stray capacities Cs.

SERIES PEAKING COMPENSATION.

Here (**Figure** 20) the peaking coil is placed in the load to the grid of the next valve. Note that L separates the output capacity (Co) of the first tube from the input capacity (Ci) of the next tube. L and Ci form a series tuned circuit which resonates at a frequency just outside the desired video range. In deriving the "equivalent" circuit, shown at (b) the coupling condenser has been omitted, since at high signal frequencies it is, in effect, a short circuit. Note that the output voltage to be applied between grid and cathode of the next stage is taken from across Ci, see (b) Figure 20. As explained above, as the resonant frequency of the series circuit L and Ci is approached, an increased voltage is obtained across Ci. This compensates for the loss of gain due to the shunting effect of Co upon RL.

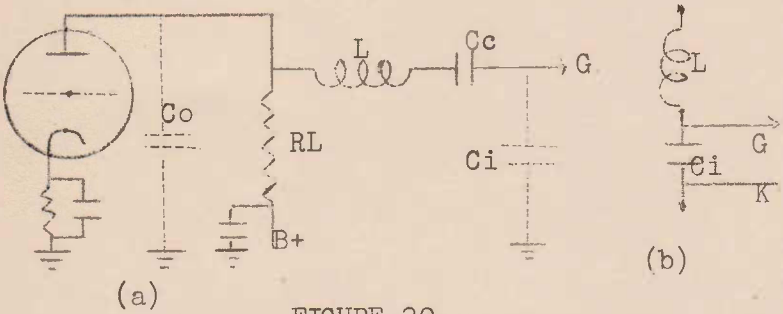


FIGURE 20.

This series peaking has the advantage that it divides the total stray capacities into two parts, shown as Co and Ci. It will provide a flat response to a much higher frequency than can be attained with shunt peaking.

COMBINATIONS OF SHUNT AND SERIES PEAKING.

A very effective arrangement is shown in **Figure** 21. Compare this circuit with that of Figure 19, and note the difference. Here the output to the grid of the next tube is taken from the lower (B+) end of L.

The equivalent plate load is shown at (b) Figure 21. Note that as in series peaking the inductance separates the output capacity of the tube (Co) from the input capacity of the next tube (**Ci**). This capacity Ci is in series with L, thus tending to produce a voltage step-up to off-set any loss of gain due to the shunting effect of Co. The latter shunting effect, in addition is minimised as a result of Co forming a parallel tuned circuit with the combination of L and **Ci**. Thus the characteristics of series and parallel peaking are combined in this circuit.

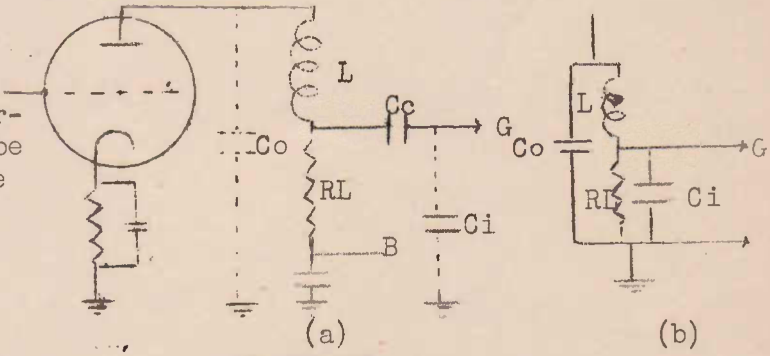


FIGURE 21.

By making use of two inductances, a direct combination of shunt (parallel) peaking (Figure 22) and series peaking (Figure 20) may be obtained, as shown in Figure 22.

COMPARISON OF SHUNT, SERIES, AND SHUNT-SERIES COMPENSATION.

It is found that the characteristics of series compensation are such that, for the same high frequency response, a larger load resistor may be used than for shunt compensation. This of course means a higher stage gain. If series-shunt is used a still higher load may be inserted, Hence the shunt-series combination is the best method from the point of view of gain for a given frequency response, or of frequency response for a given gain. In the following table the *relative* gains for the three methods, covering the same frequency range are shown.

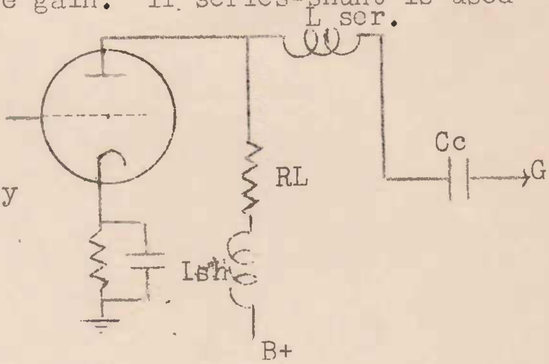


FIGURE 22.

Type	Gain
Uncompensated	.707
Shunt	1.0
Series	1.5
Shunt-Series (Fig. 22)	1.8

LOSS OF GAIN AT VERY LOW FREQUENCIES. Referring back to the frequency-response curve (Figure 6) of an uncompensated amplifier, we have seen that below a certain frequency the amplifier gain falls off, slowly at first, then rapidly. The reasons for this effect are:-

(1) Reactance of coupling condenser Cc increasing and becoming appreciable to very low frequencies.
(2) Inefficient by-passing of cathode bias resistor by by-pass condenser at low frequencies.
(3) Inefficient by-passing of screen dropping resistor by screen by-pass condenser at low frequencies (in the case of screen-grid tubes)

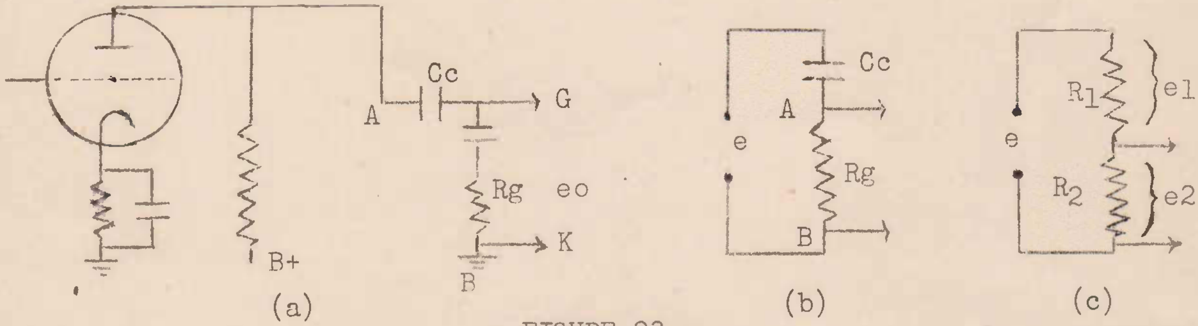


FIGURE 23.

At (a) in Figure 23 the signal voltage developed by the stage is applied between the points A and B- (ground across the combination of the coupling condenser (Cc) and grid resistor Rg. These form an A.C. voltage divider and only that fraction of the total voltage which is developed across Rg is applied between grid and cathode of the next tube. This idea is illustrated diagramatically at (b) Figure 23. A simple resistance voltage divider is shown, for comparative purposes at (c).

At all but the very low frequencies the reactance of Cc is negligibly small compared with Rg, and practically all the signal voltage appears across Rg. At very low frequencies, however, the reactance (measured in ohms) might become large. When this occurs the total voltage divides between Cc and Rg, as in the divider shown at (c). Now, only that A.C. voltage developed across Rg is utilised as the output of the stage. That appearing across Cc is lost. As the frequency falls further, the reactance of Cc is further increased, and the output voltage across Rg, and on the grid of the next valve, suffers a further reduction. In this way the loss in gain becomes more and more serious as the frequency of the signal is lowered. At the frequency at which the reactance of Cc equals Rg only .707 of the voltage applied between A & B will reach the grid of the following tube.

Concerning the effect of the cathode by-pass condenser, refer to Figure 24(a). The purpose of the by-pass condenser Ck is to provide a low impedance (low reactance) path for the A.C. signal component of the plate current, in order that the cathode potential might remain at a steady positive value with respect to ground. (i.e. so that the grid bias might remain steady).

At all except the very low frequencies, the reactance of Ck is very small, and this purpose is realised. At some very low frequency, however, the reactance of Ck is no longer negligible, and the A.C. component of plate current is forced to flow through the impedance of Rk and Ck in parallel. In other words Rk is not completely by-passed. An un-by-passed cathode resistor is shown at (b) Figure 24. The result will be that the cathode potential will rise and fall with the plate current variations due to the signal. When the grid goes positive, plate current rises, cathode also goes more positive. When the grid goes negative, plate current falls, and cathode potential also falls (i.e. less positive or more negative). The effect of these cathode potential variations is thus partially to cancel the A.C. signal voltage applied between grid and <u>cathode</u>. This means a weaker signal, or a loss of gain.

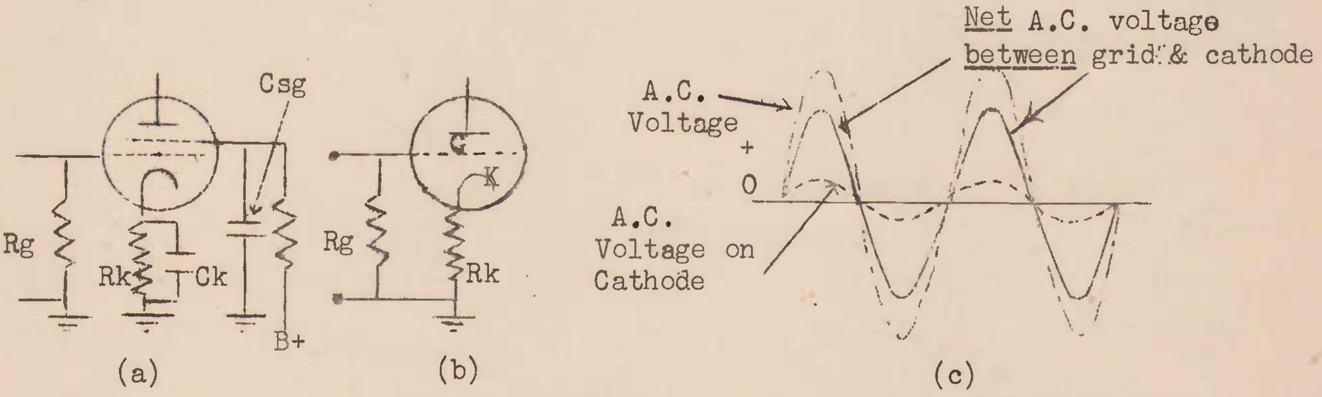


FIGURE 24.

The A.C. voltages on grid and cathode (measured in respect to ground) and the net P.D. between grid and cathode, are shown at (c) Figure 24. Note that this P.D. is always the difference between grid and cathode potentials.

The by-passing action of the screen by-pass condenser (CSG) shown at (a) in Fig. 24 is similar to that of CK. Its purpose is to maintain the screen grid at a steady D.C. potential. At low frequencies, when the reactance of CSG becomes large, the by-passing action becomes ineffective, and the screen's potential rises and falls in a similar manner to that of the plate. The screen-grid tube then operates in a similar manner to a triode, with a consequent loss of gain.

MINIMISING LOSS OF GAIN AT VERY LOW FREQUENCIES.

The low frequency loss of gain due to the coupling condenser Cc may be minimised by:-

(a) Increasing value of grid leak Rg.
(b) Increasing the capacity of coupling condenser Cc.

Bearing in mind the voltage-divider action of the grid circuit as shown at (b) in Figure 23 it will be seen that, in order to obtain the maximum value of output voltage across Rg, the resistance of Rg should be as large as possible and the reactance of Cc as small as possible. The reactance of Cc can only be reduced, for a given frequency, by increasing the condenser's capacity. Thus for a good low frequency response we require a large grid-leak and a large coupling capacity. The product Cc X Rg will therefore be a measure of the low-frequency response of the coupling circuit. This product is sometimes called the circuit's "Time-Constant" for a reason which will become apparent in later lessons.

There is a limit to the value of the grid leak for any particular type of tube. For most tubes this limit is 1 megohm or less. The question then arises, is there any limit to the value of the coupling condenser we might use? In practice, we are limited here too, for two reasons. In the first place, larger condensers usually have a greater leakage across the plates. If the coupling condenser is made too large the effect of any leakage will be to cause an incorrect value of grid bias, due to a leakage from the plate (at high potential) of the previous tube. This will produce a distortion of the signal causing a distorted image on a television screen. Again, a large capacity condenser is bulky in size, and will therefore add to the stray capacities to ground, causing a loss of gain at high-frequencies.

The poor response at low frequencies may also be improved by using cathode and screen by-pass condensers of the maximum practical capacities. A point to remember here is that the smaller the resistor being by-passed the greater must be the capacity of the by-pass condenser. Sometimes we find the cathode by-pass condenser omitted entirely. The result, of course, will be a reduction of gain, but this occurs at all frequencies, and the flatness of the frequency-response curve will be improved.

LOW FREQUENCY COMPENSATION.

Even though the precautions dealt with above are carried to the limit, we find that the low frequency response is not good enough. This is particularly the case when a number of video stages are used in cascade. Under these conditions any "drooping" of the response curve at low (or high) frequencies will be magnified by the number of stages used.

Low frequency compensation is achieved as shown in Figure 25.

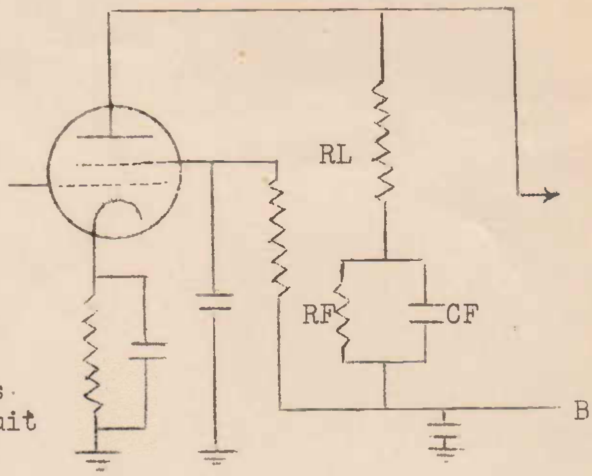


FIGURE 25.

An extra resistor RF is placed in series with the normal load resistor RL. RF is shunted by a condenser CF. The capacity of the latter resistor is such that, at all but the very lowest of frequencies CF effectively by-passes RF, and the load in the plate circuit is simply RL. At very low frequencies however, when the gain commences to fall off due to the causes previously discussed, the reactance of CF rises and forces part of the A.C. component of plate current through RF. In this way the total impedance in the plate circuit increases as the frequency becomes lower. Remembering that the gain depends upon the load in the plate circuit it will be seen that the amplification will be boosted where it tends to fall off due to other causes. By careful design of the amplifier, choosing correct values of RF and CF in relation to RL, Ck, Rk, Csg and Rsg, the response curve may be maintained flat down to a few cycles/sec.

PHASE DISTORTION.

Lack of phase distortion was mentioned earlier in the lesson as a requirement of a good video amplifier.

When an A.C. voltage is applied across a pure resistance the current remains "in phase" with the voltage as shown at (a) Figure 26.

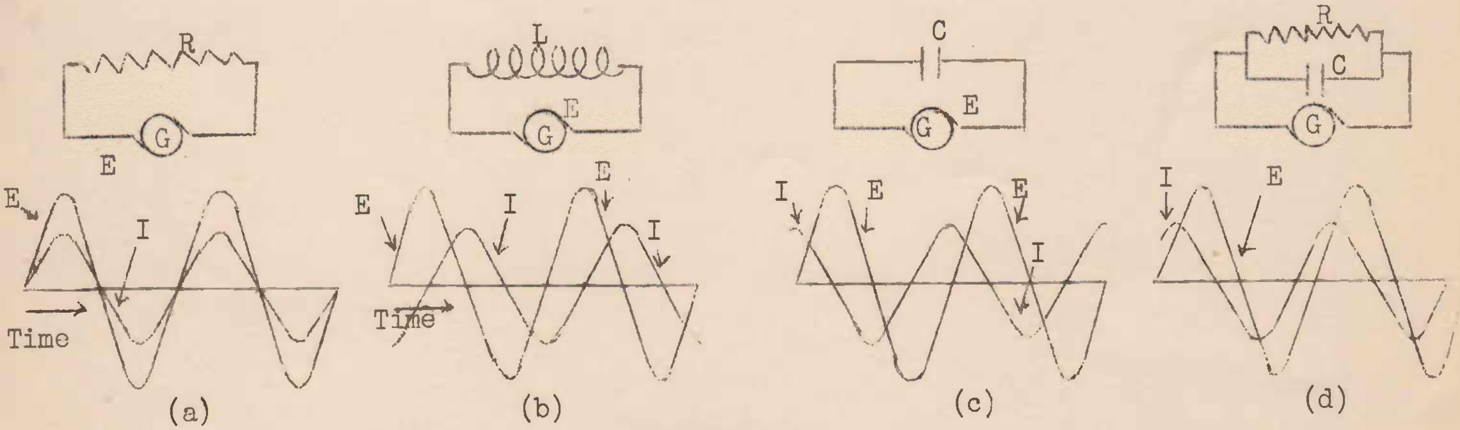


FIGURE 26.

When however the circuit contains reactance (either due to an inductance or a capacity) a difference in phase between voltage (E) and current (I) occurs. If the circuit contains "pure" reactance, i.e. either a condenser or an inductance alone, E and I are out of phase by $\frac{1}{4}$ cycle, as shown at (b) and (c) Figure 26. This represents a phase "difference" or phase $\angle$ of 90° (1 cycle = 360°). In the case of the inductance the current "lags" behind the applied voltage, since, as the graph at (b) shows, I reaches a peak value $\frac{1}{4}$ cycle or 90° later than E attains its corresponding peak. When capacity is in the circuit, as at (c), E and I are also 90° out of phase, but here I is in advance of E by $\frac{1}{4}$ cycle or 90°. In other words the current "leads" the voltage. If the circuit contains a combination of resistance and reactance (e.g. for a capacity in parallel with a resistance as at (d)) a phase difference also occurs, but the current and voltage are now less than 90° out of phase. The phase angle in such a case as this depends upon the relative values of reactance and resistance. Now the reactance of a given capacity changes with frequency. Therefore if the frequency of the voltage across the circuit shown at (d) changes, the phase angle will also change.

Summarising we may say that, if reactance is present in a circuit, a phase displacement of current occurs. The graphs of Figure 26 show that this phase displacement represents either a time lag or a time advance in the signal.

In a video amplifier the reactances are negligible at normal frequencies. At very high, and very low frequencies the effects of stray capacities, coupling condensers etc. become appreciable, and these signals suffer a phase displacement, or a time lag or advance. This will result in the picture elements, corresponding to these frequencies, being reproduced a little later or early (usually the former) on the screen. Such a displacement will obviously result in serious distortion of the image.

Both the high-frequency and low-frequency compensation circuits described tend to correct these phase displacements, as well as the amplifier gain. A good video amplifier may therefore be designed to yield uniform gain, without serious phase distortion, over a wide frequency range.

THE CATHODE FOLLOWER.

This is an "amplifier" in which the load resistor is placed entirely in the cathode lead, i.e. in the lead from B- to cathode. The tube's plate is connected directly to B+ (or sometimes through a filter circuit to exclude the last traces of 50 or 100 cycle/sec. power voltages or "hum". The circuit is shown in Figure 27. The input voltage Ei is applied between grid and ground as is normal. The output voltage, however is that developed across the cathode resistor Rk. The tube may be either a triode or a pentode, providing the Mutual Conductance (Gm) is high.

The word "amplifier" was inserted in inverted commas, because the cathode follower's gain is always slightly less than 1, i.e. it produces no real gain at all, but rather introduces a slight loss. What then are its advantages and its uses? We may state that the stage has a very high input impedance and a very low

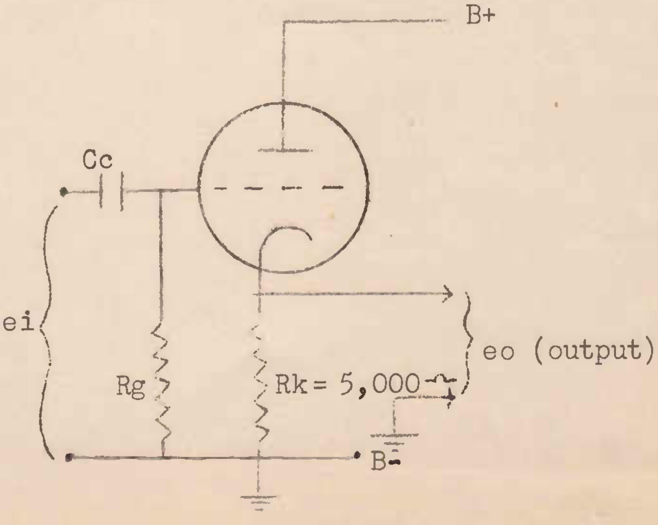
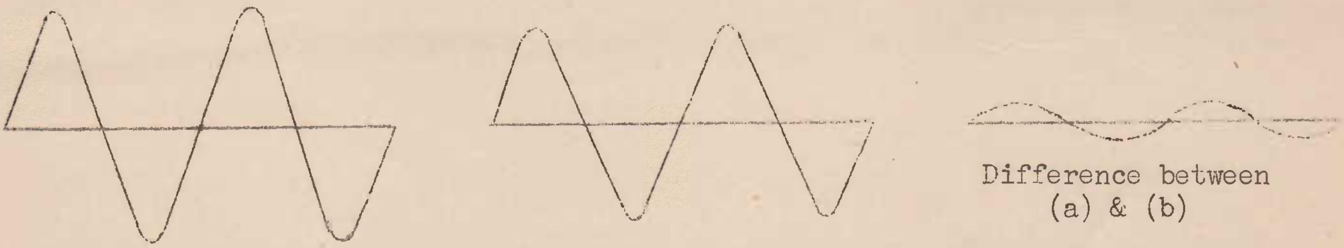


FIGURE 27.

output impedance, and proceed to explain the meaning of these terms, and how they may be turned to our advantage.

OPERATION OF THE CATHODE FOLLOWER.

Referring to Figure 27. Suppose the input signal voltage (Ei) applied between grid and ground is 10V. This A.C. voltage causes the plate current to vary accordingly, and develops a varying (A.C.) P.D. across Rk. The result is that the cathode potential will rise and fall (at signal frequency) in respect to ground. For example when the grid goes 10V positive (with respect to ground), plate current will increase, developing a larger voltage across Rk, i.e. cathode potential will also rise. Suppose the increased voltage across Rk is 9.8V +. Although the grid potential has increased by 10V with respect to ground, the increase in respect to cathode is only 10V- 9.8V = 0.2V. On the other hand when the grid goes 10V negative with respect to ground, plate current will fall, the voltage drop across Rk will decrease by 9.8V, and the cathode will go 9.8V less positive (i.e. more negative). Once again the grid-cathode potential has changed by only .2V. Notice that the cathode potential follows that of the grid, and nearly, but not quite, completely cancels the signal voltage. Only a small fraction of the latter, i.e. $\frac{.2}{10} = \frac{1}{50}$, is effective in driving the tube.



Grid-Ground Voltage.
(a)

Cathode-Ground Voltage
(b)

Grid-Cathode Voltage.
(c)

FIGURE 28.

The grid, cathode, and grid-cathode voltages are shown in Figure 28.

The first important point to notice from this explanation is that the gain of the stage must always be less than one. The output voltage (Eo) is that taken across Rk (i.e. it is the cathode A.C. voltage shown at (b) Figure 28) and this is 9.8V, compared with an input of 10V. The cathode, and output voltages cannot equal or exceed the input voltage, because if it did the latter would be completely cancelled, and the tube would not operate at all. In the case given the stage gain is $\frac{9.8}{10} = .98$.

Secondly notice that the effective A.C. voltage operating across the tubes grid-cathode capacity (Cgk) is only .2V, i.e. $\frac{1}{50}$ of the total input voltage. This will mean that the A.C. current through Cgk will be only $\frac{1}{50}$ of the value it would normally be. The result is that the reactance of Cgk appears to be increased by 50 times, or in other words the effective electrical value of Cgk is reduced to $\frac{1}{50}$ of its normal value. This is what we mean when we say the input impedance of the cathode follower is very high. It is obvious that the shunting effect on the previous amplifier stage, at high frequencies, will be greatly reduced, with an improved high frequency response.

OUTPUT IMPEDANCE OF THE CATHODE FOLLOWER.

With regard to the term "output impedance" of a device, we mean here the resistance or impedance across which the output voltage is developed. For example in an ordinary pentode amplifier with a plate load of 5,000 ohms, the output impedance is 5,000 ohms. We have previously seen that the shunting effect of given stray capacities on the amplifier gain is less if the load resistor (output impedance) is reduced.

In the circuit of Figure 27 the load resistor (Rk) of the cathode follower was shown as 5,000 ohms. Due to the electrical action of the circuit, however, the output impedance is very much less than this. This may be seen in a general way as follows. Suppose Rk (Fig. 27) is reduced to 2,000 ohms, i.e. $\frac{2}{5}$. The output voltage will not fall to $\frac{2}{5}$ of its former value, because any reduction in output voltage (i.e. cathode voltage) releases a greater amount of the total input voltage to drive the tube. For example the result might be that the output voltage falls only to, say, 9.5V. If this occurs the A.C. voltage acting between grid and cathode will increase to .5V (10V- 9.5V), as against .2V before. Thus, a small reduction in output (cathode) voltage - from 9.8V to 9.5V- will increase the active grid-cathode voltage by $\frac{5}{2}$ times. This may be seen clearly by referring back to the voltage curves of Figure 28. The result will be that the A.C. plate current will correspondingly increase, i.e. by $\frac{5}{2}$ times. This increase in A.C. component of plate current, flowing through the cathode load resistor (Rk), will easily offset the reduction of this resistor from 5,000 to 2,000 ohms, as far as the stage's output voltage is concerned. Actually in the case taken, the output voltage would not quite be reduced to 9.5V. Thus we see a reduction of load impedance of 80% (5,000 ohms to 2,5000 ohms) causes a reduction in gain of less than 0.3V in 9.8V, i.e. a reduction of about 3% only.

Now as previously explained the effect of stray shunting capacities is to reduce the effective load impedance of a stage. Since, as we have seen, the output voltage of a cathode follower is practically independent of the value of this load impedance it will be appreciated that this type of circuit will show up to advantage when it has to feed into a circuit which introduces large values of stray capacities.

It may be shown mathematically that the output impedance of a cathode follower is equal to $\frac{1}{Gm}$ ohms, where Gm is the mutual conductance of the tube. For example, in the case of the 6AC7 tube, with a Gm of approx. 9,000 µA/volt, (i.e. $\frac{9}{1,000}$ A/Volt) the output impedance will be $\frac{1}{Gm} = \frac{1}{9/1,000} = \frac{1,000}{9} =$ 110 ohms (approx) -- An extremely low value, when we say the output impedance is 110 ohms we mean that the electrical action of the circuit is such that the output voltage appears as though it were developed across only 110 ohms, instead of the actual 5,000 ohms used in the circuit. This idea is illustrated in **Figure** 29, where Ro equals the output impedance $\frac{1}{Gm}$ = 110 ohms as calculated.

SUMMARY OF CHARACTERISTICS OF CATHODE FOLLOWER

(1) Stage gain less than unity.

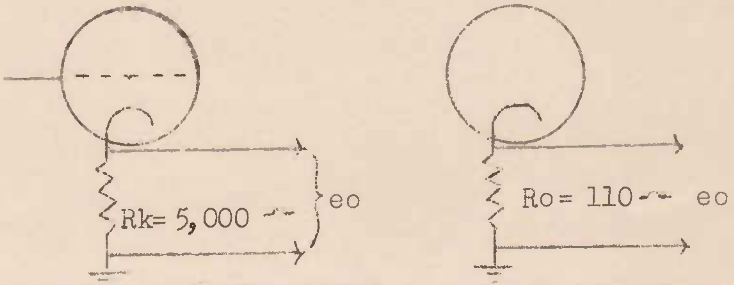
(2) Output Impedance very low ($=\frac{1}{Gm}$ ohms. approx.)

(3) Input impedance very high.

(4) Output voltage in phase with input voltage (see Figure 28).

USES OF CATHODE FOLLOWER.

A cathode follower is sometimes used between successive amplifying stages to reduce the shunting effect of the input capacity of one tube on the load resistor of the previous stage.



Actual output circuit of Cathode Follower. (a)

Equivalent outp Circuit (b)

FIGURE 29.

In Figure 30 V1 and V3 are ordinary pentode amplifying stages, incorporating low- and high- frequency compensation. V2 is a cathode follower, acting as a type of "buffer" between V1 and V2. The shunting, at high frequencies, upon the load of V1 is greatly reduced on account of the very high input impedance of V2. Also the input capacity of V3 is unimportant, since it is across the low output impedance of the cathode follower V2, upon which it has, as we have seen, very little effect. In this way the overall high frequency response of the amplifier is greatly improved.

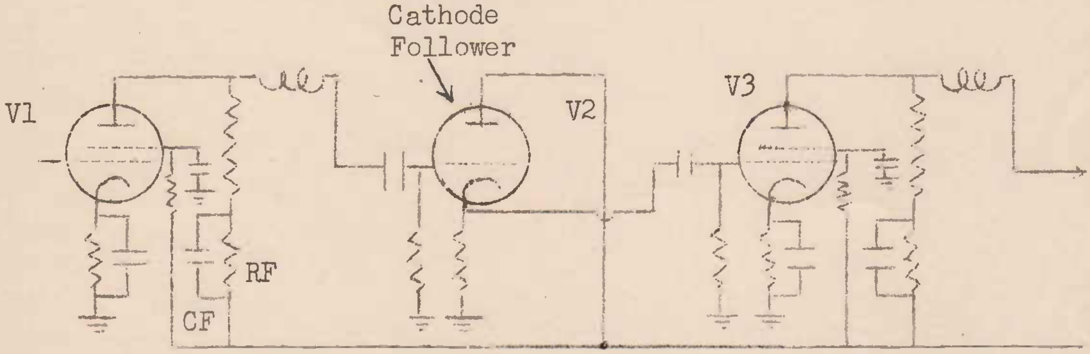


FIGURE 30.

Another typical use of the cathode follower is as an output stage when the amplifier has to feed into a low impedance cable, as shown in Figure 31. Here the cathode follower V2 acts as an impedance matching device between the amplifier V1 (of high output impedance) and the cable whose impedance may be very low. The purpose here may be compared with that of the output speaker transformer in a sound receiver, where it is necessary to match the high output impedance of the speaker's voice coil.

THE ELECTRON MULTIPLIER.

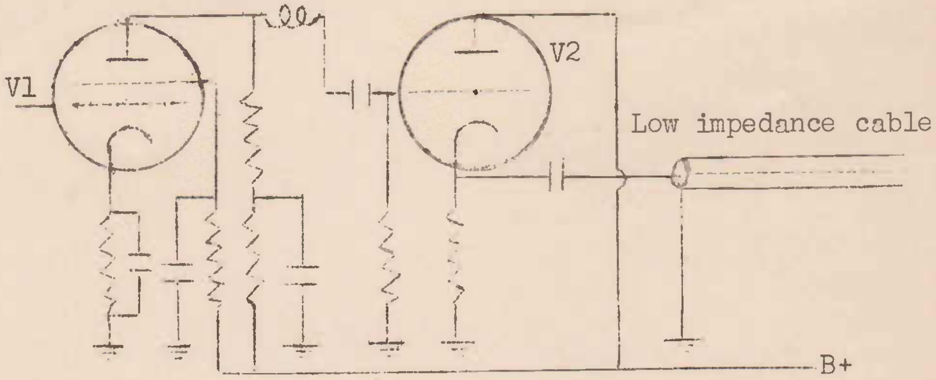


FIGURE 31.

In this lesson we have discussed the problems of video amplification, and how the ordinary resistance-capacity coupled amplifier may be designed, and modified, to meet them. In the future it seems very probable that the electron-multiplier, discussed in relation to electron cameras, might find general application for video amplification purposes. The electron multiplier has the virtue that it can yield considerable amplification, without the introduction of appreciable masking (noise) voltages, over a very wide range of frequencies. In the meantime, however, the thermionic tube can, as we have seen, perform the task of amplifying our picture signals very well indeed, even if the stage gain is low compared with that which can be achieved from the same tube as an audio frequency amplifier.

T.FM. & F. LESSON NO. 5.

EXAMINATION QUESTIONS.

(1) State approximately the range of video frequencies which will be present in a television system operating with 400 lines at 25 pictures per second.

(2) What will be the effect on the reproduced picture if the video amplifiers have an inadequate high frequency response?

(3) Why does the gain of an amplifier with resistance-capacity coupling fall off when the frequency of the signal becomes high?

(4) State three methods of improving the high-frequency response of a r-c. amplifier (without applying high-frequency compensation).

(5) What is meant by high frequency compensation? Draw simple circuit diagrams illustraing three methods of high-frequency compensation. Name the method illustrated in each case.

(6) State three different ways in which the low-frequency response of a pentode amplifier with cathode bias may be improved.

(7) Draw a simple circuit diagram illustraing an amplifier incorporating low-frequency compensation. Explain very briefly how the low-frequency "boosting" is brought about.

(8) What are the three most desirable features to look for in choosing a tube for video amplification?

(9) Draw a circuit diagram of a cathode-follower stage, showing clearly the input and output terminals.

(10) State the approximate gain figure for a typical cathode-follower stage. What is the main characteristic and use of such a stage?

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T.FM & F. LESSON NO. 6.

TRANSMISSION OF TELEVISION SIGNALS.

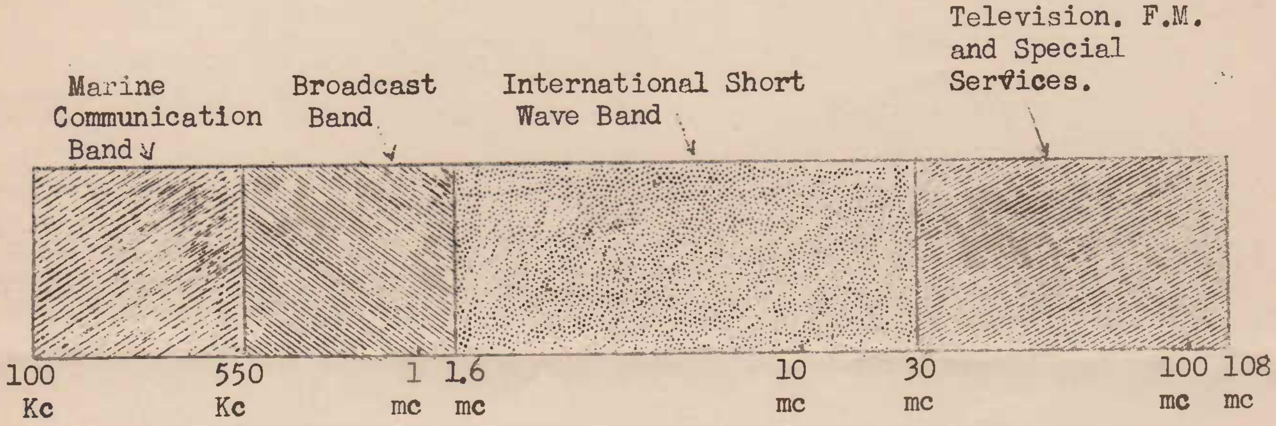
If one is interested purely in the reception side of telephonic communication a study of details and techniques of transmission can be largely dispensed with. A knowledge of the general principles involved, and in particular a clear picture of the nature of the final product of the transmitter, viz: the modulated wave will usually suffice. In the case of television, however, this does not apply. A television transmitter has a much more exacting job to do than that of the ordinary broadcast sound transmitter. The former must produce and radiate a wave carrying the exceptionally wide range of frequencies involved in the picture signal. In addition the transmitted signals must be modulated in such a way that the receiver can reproduce not only the video frequencies corresponding to the picture details, but also the average light or shade on the original scene. Further the signal must contain the "pulses" which accomplish the complicated and difficult synchronisation of receiver with transmitter.

It should be realised, then, that the design and operation of a television receiver is very closely bound up with the nature of the particular transmitter radiating the signal. It is unfortunate that any radical improvement or re-design of the transmitter necessitates a re-design or complete scrapping of the receiver. For example suppose it is decided to improve the picture definition by an increase in the number of lines. The old receiver, without undergoing substantial operations, would be quite useless for receiving the improved signal. The functions and mode of operation of many of the receiver circuits are so closely related to the corresponding techniques in the transmitter that a study of one without the other would be rather a fruitless undertaking.

The above observations are made lest the student who feels that his interests lie entirely in the field of reception should underestimate the importance of this particular lesson.

THE FREQUENCY OF THE VISION CARRIER WAVE.

In the earlier days of television transmissions were carried out on frequencies in the low or medium bands, i.e. on frequencies similar to those with which we are so familiar in connection with ordinary broadcast work. With the development of higher definition pictures, however, it was soon realised that carrier waves lying within the ultra-high frequency band were an absolute essential. By the ultra-high frequency band we mean the region above about 30 megacycles per second and upwards. This corresponds to wavelengths of 10 metres and less. For comparison purposes it should be remembered that our broadcast transmitters operate on frequencies ranging from 550 Kc/sec to 1.6 megacycles/sec. (the medium-waves). The regular short-wave transmissions extend from about 1.6 mc/sec up to 23 mc/sec. The graph of Fig. 1 will show clearly how these various frequencies are related.



WAVE BANDS ALLOTTED TO VARIOUS SERVICES.

FIGURE 1.

REQUIRED BAND WIDTH OF A TELEVISION SIGNAL.

The question now arises why are these high (comparatively) carrier frequencies used? The reasons are several. In the first place it would be a technical impossibility to use medium wave frequencies if we are to carry all the "information" contained in the video signals generated by our modern electron cameras using 400 or more scanning lines. In the previous lesson we have seen that with a 441 lines 30 pictures per second system, as at present used in America, the video frequencies range up to a figure in the vicinity of 3 megacycles/sec. It is this frequency, of course, which corresponds to the audio frequency in radio telephony, and which modulates the outgoing carrier wave. With regard to the subject of modulation the following important facts should be recalled. When a carrier signal is amplitude modulated, the amplitude (strength) of the carrier signal is caused to vary at a rate corresponding to the frequency of the modulating signal. When a carrier signal of varying amplitude is analysed, it is found that the effect of modulation is to generate additional signals having frequencies above and below the carrier frequency. These additional signals are known as "side-band" frequencies. Each frequency in the modulating signal will produce <u>two</u> side frequencies -- one above and one below the carrier frequency. The side-frequencies differ from that of the carrier by an amount exactly equal to that of the modulating signal itself. For example, suppose a carrier of 50 megacycles/sec. is modulated by a video modulating frequency of 2.5 megacycles per second. Two side frequencies 52.5 (50 + 2.5) mc/sec. and 47.5 (50 - 2.5) mc/sec. would be produced. The other (lower frequency) modulating video signals would each result in a pair of side-bands lying within these limits -- 47.5 and 52.5 mc/sec.

Keeping these facts in mind it is seen that for a video signal ranging up to 2.5 mc/sec. a band-width of 5 mc/sec. would be required. Obviously it would be theoretically impossible to use a carrier of frequency less than 2.5 mc/sec. for this would involve lower side-bands extending down to zero frequency. Practical considerations require that the carrier frequency be many times -- preferably at least 10 times -- the band-width involved. This will mean a carrier in the ultra-high frequency range.

In England, at the present time a video signal ranging up to 2.5 mc/sec. is used. This requires a bandwidth of 5 mc/sec. for the vision channel. The radio frequency of the carrier wave is 45 mc/sec. which corresponds to a wavelength of 6.6 metres. The accompanying sound is broadcast on a separate carrier of frequency 41.5 mc/sec. (i.e. 7.2 metres). The sound channel allows for audio frequency modulation up to 10 Kc/Sec, a band-width of double this figure, i.e. 20 Kc/Sec. being provided.

Figure 2 shows the range of frequencies for the complete vision and sound transmission.

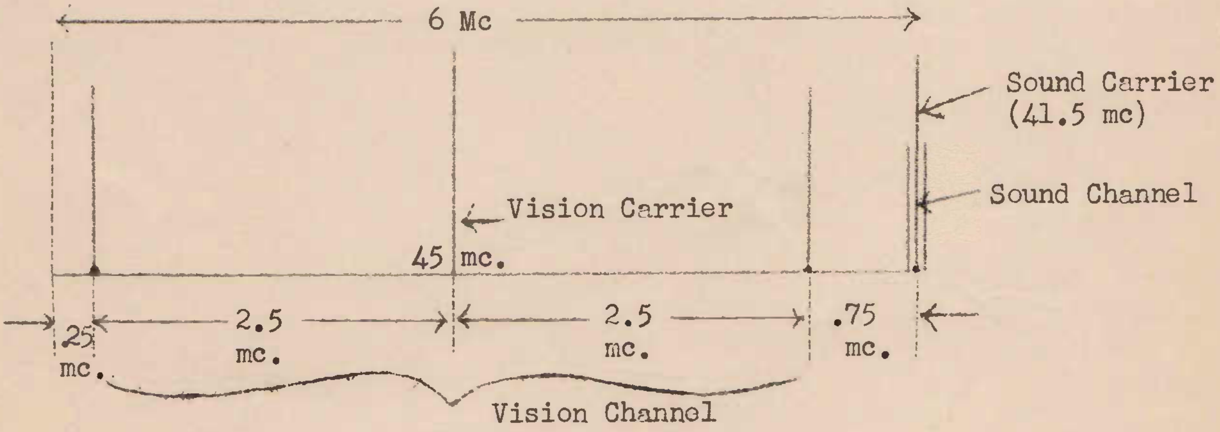


FIGURE 2.

Note that a gap of .75 mc is allowed below the lowest side-band frequency and the sound channel. This is to prevent the vision signals being picked up by the sound section of the receiver. A margin of .25 mc is allowed at the upper frequency end of the channel to separate it from the next television channel. The whole television system thus occupies a channel 6 mc/sec wide as shown. Note that nearly all of this 6 mc is occupied by the vision signal.

A characteristic of high-definition television broadcasts is the width of the frequency channel required. Unless the ultra-high frequencies were used, very few stations could operate within a region without interference to one another.

SINGLE SIDE-BAND TRANSMISSION.

In America the N.B.C. makes provision for a video signal ranging, theoretically, up to 4 mc/sec. This would normally require a vision channel 8 mc. wide, which is too great, even with a carrier of the order of 40-50 mc/sec. The channel would form nearly $\frac{1}{5}$ of the carrier frequency, rendering it difficult to design tuned circuits to accommodate all the side-band frequencies without distortion, and, in addition, leading to other technical difficulties. The problem is solved by utilising "single sideband" transmission.

Since each modulating (video) frequency generates a pair of sideband frequencies -- one above and one below the carrier frequency -- it is obvious that the upper side-bands contain exactly the same information as the lower side-bands. Hence, by eliminating one set of sidebands the channel width may be halved, and perfectly good communication obtained.

In America, most of the lower side-band frequencies are eliminated, after modulation, by means of a band-elimination filter circuit. The first 1.25 mc. of this side-band is transmitted, because if it were attempted to cut out all of these frequencies the carrier frequency itself would be reduced in strength and distorted. Since, however, the remaining 3.75 mc. of the lower sideband is not broadcast, the width of the television channel is reduced by the latter figure.

This type of transmission is sometimes called "vestigial" or "quasi-single-sideband" transmission. A typical channel is shown in Figure 3.

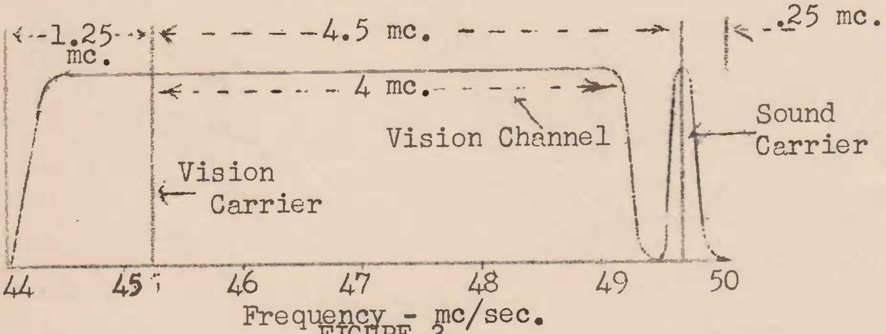


FIGURE 3.

Note that the vision carrier is displaced towards the lower end of the television channel. The total width of the latter is 6 mc/sec., as before, but the wave carries video signals up to 4 mc/sec, as against 2.5 mc/sec, when using double sideband transmission.

In the case of carrier frequencies at present in use in England and America, viz: 40-50 mc/sec, single sideband transmission confers the important advantage of considerably reducing the width of the channel required. The system, however, involves technical difficulties, and with the introduction of higher carrier frequencies of the order of hundreds of megacycles (as seem certain in time) the question of band-width will become less important, and the method will probably be discarded.

CHARACTERISTICS OF ULTRA-HIGH FREQUENCY WAVES.

Radio waves having frequencies above about 30 or 40 mc/sec. behave, in many respects, very differently from those with which we have been acquainted in ordinary sound transmission on the medium frequencies.

The chief of these differences are:-

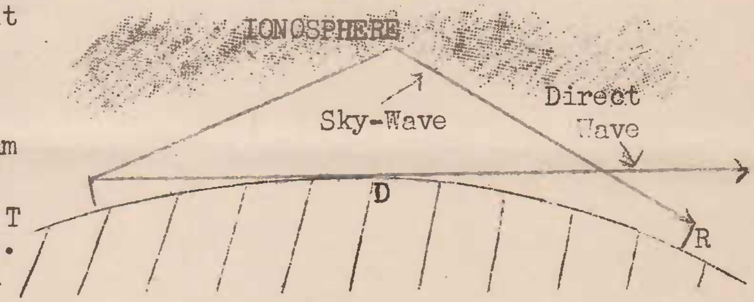
(1) They provide little more than "line-of-sight" communication.

(2) They are practically free of natural "static", although particularly susceptible to "man-made" static (e.g. automobile ignition interference).

(3) They are more readily directed in a beam. This point will be left to the next lesson.

Considering the line-of-sight characteristic it should be remembered that communication over a distance, say a hundred miles or more, is made possible by the wave being reflected back to the earth from the ionosphere -- an electrified layer of particles in the upper atmosphere. The direct wave is blocked, beyond a certain range (depending on the height of the transmitting aerial), by the curvature of the earth. (See Fig. 4.)

Ultra-high frequency waves are <u>not</u> reflected by the ionosphere, but pass into the the latter and are either absorbed by it or lost in space. Communication, with such frequencies is therefore dependent entirely upon the direct -- (or ground) wave. Referring to Figure 4 the maximum range of the direct wave would be about the point D, where the distance TD is, in a typical case, about 30 to 60 miles. The line-of-sight distance depends upon the height, above the land surface, of the observer, and also the nature of the country (whether flat or mountainous etc). It is important, therefore, that a television transmitter aerial be situated as high as possible above the ground. In New York the N.B.C's aerial is atop the Empire State building -- well over 1,000 feet above ground, and a coverage of about 60 miles radius is easily obtained.



<u>FIGURE 4.</u>

This limitation of the range of a television signal is due only to the ultra-high frequency characteristic of the signal -- a characteristic which is required for other reasons already discussed. The fact that the signal of one transmitter is contained entirely within a limited area is in several respects, a decided advantage. In the first place indirect reception (from a sky or reflected wave) involves phase distortions, particularly when a wide range of side-band frequencies is involved. Phase distortions in the case of amplitude modulated sound reception does not affect the quality of the signal to any great extent. The effect of such distortions on a television signal, however, is so serious as to render the reproduction practically useless. Hence, even if we could use medium waves for television, with the greater range obtained, the reception at points distant from the transmitter would not be worth while.

Secondly the restricted coverage of the ultra-high frequency wave reduces the problem of interference between different transmitters situated in different cities. The question of such interference is an important one, on account of the broad channels required by television transmitters, and the consequent scarcity of the number of separate channels available. Transmitters situated perhaps only 100 miles apart, may, in some cases be operated on the same frequency, since the wave of one would not extend to the region covered by the other.

THE VISION TRANSMITTER.

In tracing the passage of a picture signal from its source -- the original scene -- through the television system until it finally reaches the receiver's reproduction tube, we shall now take up the story from the point reached in Lesson 4. It was explained how the electron camera generated the video signal, how the latter was amplified, and how the synchronising pulses were inserted. Figure 19 of the lesson showed in block form, the main studio equipment. Now the actual transmitter may be situated at some distance from the studio, and it will be necessary to discuss how the video signal is transferred from one to the other.

LINKING STUDIO AND TRANSMITTER.

The video signal from the studio is a very complicated affair, with a frequency range from 25 c/sec up to several megacycles/ sec. Ordinary telephone lines or cables are quite inadequate for transferring such a signal, for the higher frequencies would be lost, and phase distortion would be introduced.

The usual link used between studio and transmitter is a special concentric cable of low loss. The construction of such a cable is shown in Figure 5. A hollow cylindrical sheath encloses a solid conductor or wire, the two being separated by insulating material. The sheath acts as one conductor, and the central wire as the other, This type of cable is also sometimes called a "coaxial" cable.

The linking cable must be designed to carry currents of all frequencies in the video signal, say from 25 cycles/sec up to 3 or 4 mc/sec., without attenuating, or reducing, one current more than another. This requires special insulating materials, since most insulators used in ordinary radio work absorb much more electrical energy when the frequency is high than they do at low frequencies.

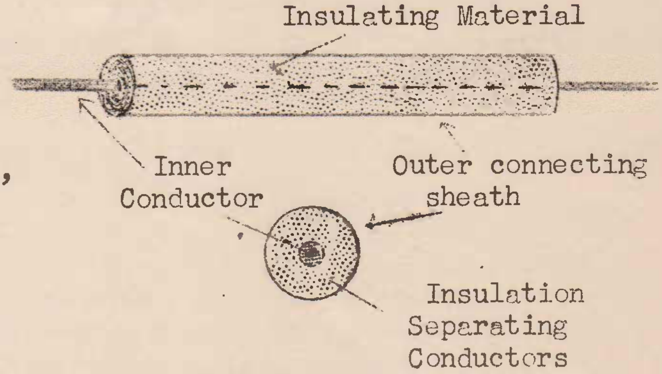


FIGURE 5.

An important characteristic of the coaxial cable is that the outer cylindrical conductor also acts as a shield. For this reason the video signal is free from electrical interference from outside sources.

Another use of the concentric or coaxial cable is for linking the television camera with the studio equipment. In the previous paragraphs we have been discussing the task of carrying the complete video signal to a distant transmitter for radiation. Now we are going back in the system to the original camera signal. When outdoor events are being televised the camera may be some distance from the actual studio. Providing the distance is not too great a coaxial cable may be used. Used in this connection a complete coaxial cable is required for each camera, together with a number of ordinary wire conductors to operate camera electrode circuits, deflection circuits etc. Usually all these conductors are included in the single cable, the coaxial cable (for the camera video signal) and other wires being separated by insulating material . Figure 6 shows a typical cable of such a type. Note that two concentric cables, together with auxiliary wire circuits are provided.

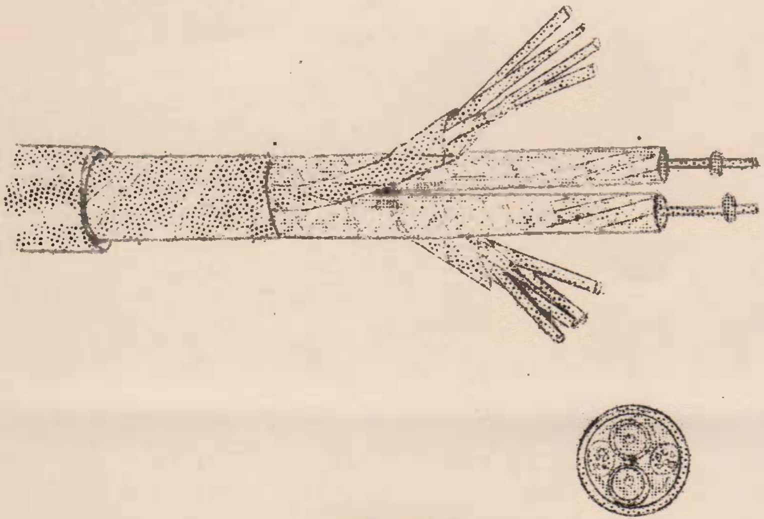


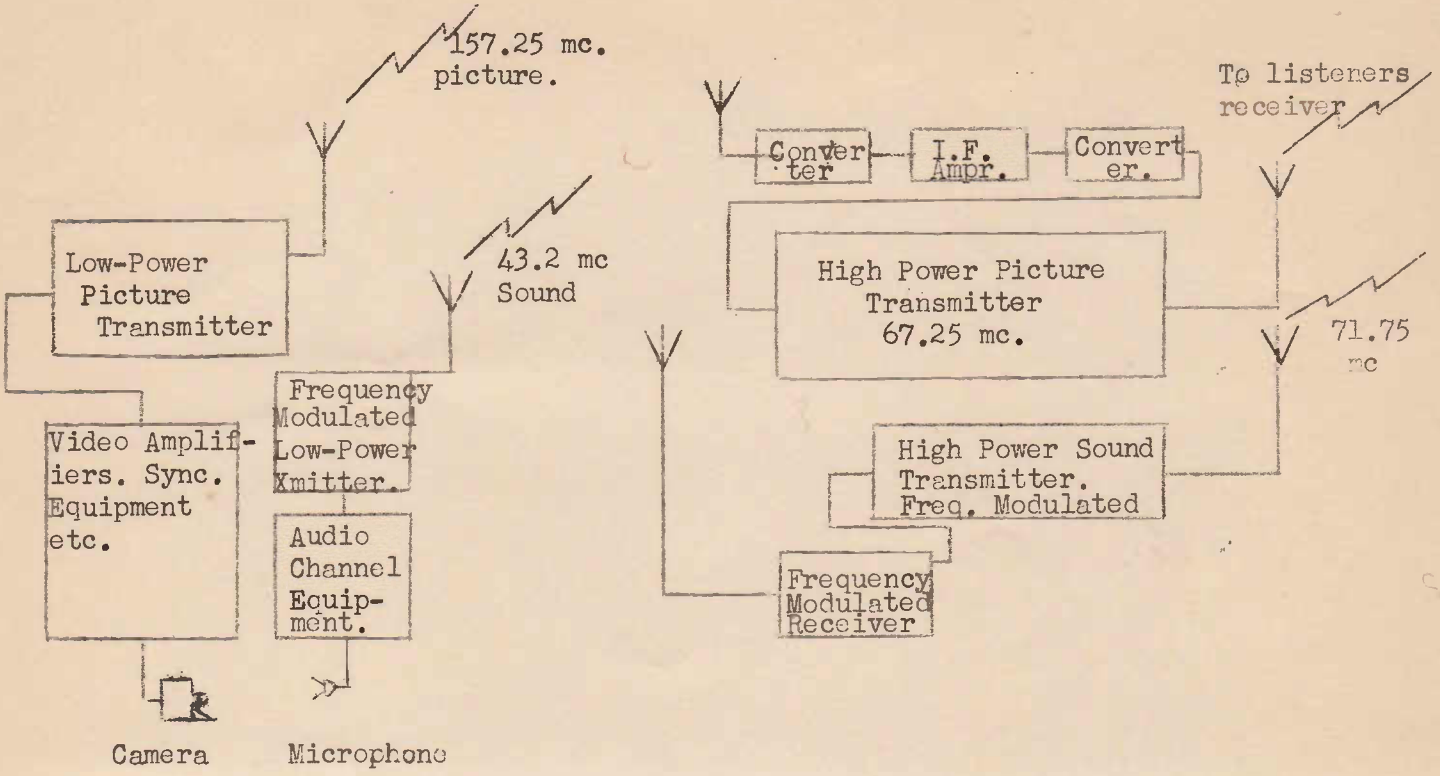
FIGURE 6.

Returning to the question of linking studio with the radiating transmitter, a system which is gaining favour, particularly when considerable distances are involved is the <u>radio link</u>. This system involves the use of a complete low powered transmitters at the studio. The main high powered transmitters, some distance away are provided with receivers to pick up the signal from the studio -- one receiver for the vision signal and the other for the sound. The linking vision transmitter (low powered) is usually operated on a very high frequency -- up to 200 mc/sec. At the main transmitter this frequency is reduced by means of a converter to a comparatively low or intermediate frequency of the order of 20-30 mc/sec. This, of course, is still a "carrier" frequency carrying the video modulation. The intermediate frequency is then amplified, and finally the frequency is stepped up to that of the station's normal channel, usually between 40 and 70 mc/sec. At this frequency it is radiated at high power. Note that the transmitters vision receiver consists only of R.F. and I.F. sections. No detection or demodulation is carried out.

Figure 7 shows a typical radio link as used in one of the New York stations, where the main transmitter is distant 12 miles from the studio. Note, in addition to the points discussed in connection with the vision signal, that the sound signal uses frequency modulation. The transmitter's receiver which picks up the linking signal demodulates the wave, thus re-producing the original audio signal. The latter is used to modulate the high power wave generated at a frequency adjacent to that of the vision signal.

GENERATION OF ULTRA-HIGH FREQUENCY CARRIER.

The generation of stable radio frequencies in excess of about 30 mc/sec. presents considerable difficulty. The reason for this is that, in order to maintain the constancy of frequency required for the allotted channel, crystal control of the oscillation is essential. Now quartz crystals, used for this purpose, cannot be ground for higher frequencies than 30 mc/sec.



STUDIO ← 12 miles → TRANSMITTING STATION.

FIGURE 7.

The system is more or less general use comprises a low-powered oscillator (say 5 to 10 watts) controlled by a crystal ground for a frequency of about 5 mc/sec. Remember, in this connection, that the frequency is determined by the thickness of the crystal, the latter acting as if it were a tuned circuit. The thicker the crystal, the lower the frequency, and vice versa. Although, as stated above, a crystal may be ground thin enough to produce a frequency as high as 30 mc/sec, this comparatively low frequency is preferred to obtain the advantages of greater frequency stability, which the thinner crystal lacks.

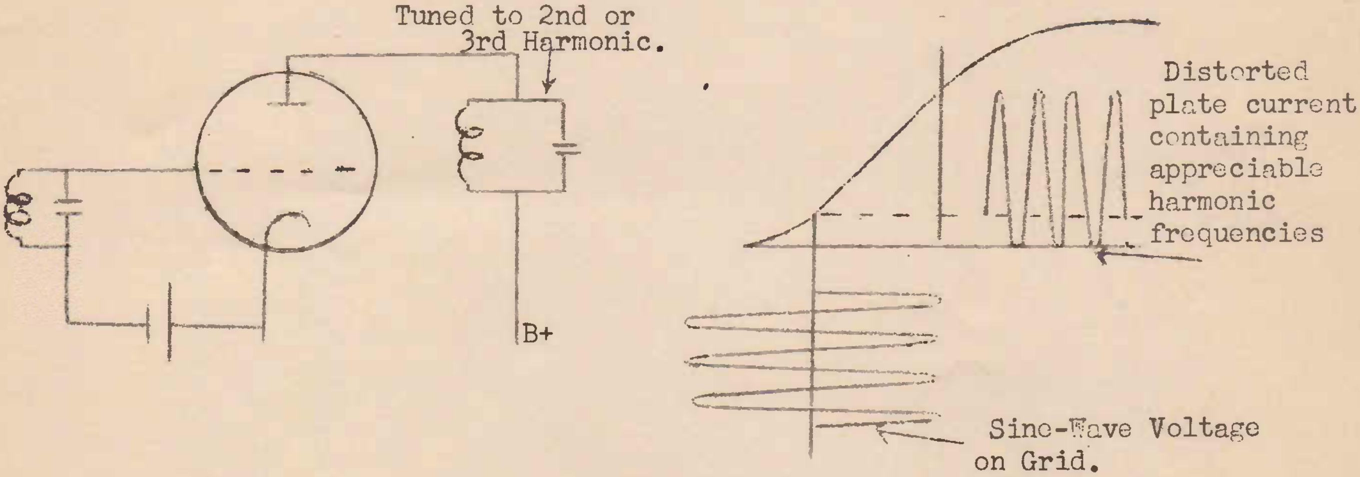
FREQUENCY MULTIPLIERS.

Since it is desired, for reasons already discussed, to radiate the signal in the ultra high frequency region of 40 mc/sec or higher, it is necessary to step-up the frequency of the lower powered oscillator from the 5 mc/sec or so to that of the carrier chosen. This frequency multiplication is achieved by special amplifying stages known as "Frequency Multipliers".

A frequency multiplier is simply an amplifier, operated so as to produce considerable distortion of the input voltage, and with its plate circuit tuned to a harmonic of the original voltage.

Figure 8 illustrates the principle of the circuit. Applied to the grid is an A.C.

sine-wave voltage of, say, frequency 5 mc/sec. The tube is heavily biassed (near cut-off), so that the plate circuit current is greatly distorted compared with the input voltage. As shown at (b) (Fig. 8) the tubes output current



(a) (b)

FIGURE 8.

contains an A.C. current of the same frequency as that of the input, but one having practically all the negative half-cycles cut off. Now, when a sine-wave current is distorted, and the resulting current is analysed, the latter is found to contain a number of harmonics, i.e. currents whose frequencies are multiples (twice, three times etc) the original frequency (called the fundamental). These harmonic currents are all of pure sine-wave form. The greater the distortion, the greater will be the number of harmonics generated, and the stronger they will be.

The plate tuned circuit (Figure 8a) is adjusted to have a resonant frequency tuned either to the second or the third harmonic of the original input frequency. When tuned to the second harmonic the stage is called a Frequency Doubler. When tuned to the third harmonic it is called a Frequency Tripler. The plate tuned circuit will emphasise the harmonic frequency to which it is tuned, and will virtually eliminate all other frequencies (including the fundamental, i.e. the input frequency). In this way, if a voltage of frequency 5 mc/sec is applied to the grid of the tube, the output voltage will be either 10 mc/sec. (Frequency Doubler) or 15 mc/sec. (Frequency Tripler). By using a number of these frequency multiplier amplifying stages the frequency of the low powered 5 mc/sec. oscillation may be stepped up to the final carrier frequency which is usually between 40 and 70 mc/sec.

Figure 9 shows in block-diagram form a typical 7.5 Kilowatt transmitter for the vision signals. The crystal oscillator operates at a frequency of 5.65625 mc/sec. The frequency is then progressively increased by three frequency multiplying stages, producing an over-all frequency multiplication of eight times, yielding finally the carrier frequency of 45.25 mc/sec. The signal, at this final frequency is then handled by three R.F. voltage amplifiers before being passed on to two power amplifiers -- the Intermediate and the Final Power Amplifier. The latter are operated Class C and supply the antenna with the 7.5KW required.

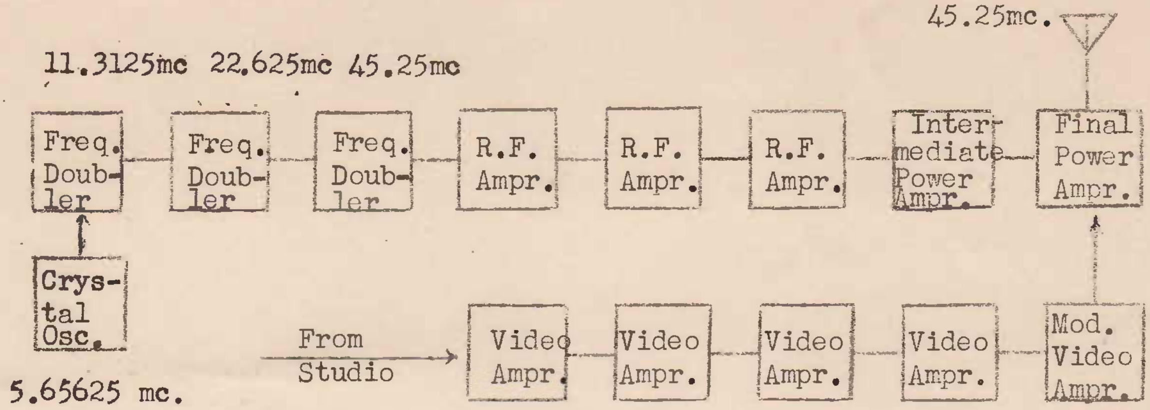


FIGURE 9.

Note that the modulation of the radio-frequency carrier is carried out in the final power amplifying stage. This is called "High-level" modulation, and is the usual, though not universal, practice. The video signal from the studio, consisting of camera signal plus synchronising pulses, at a level of about 1.0 volt (peak to peak) is built up by five video amplifiers to a level of 350 volts which are necessary to modulate the powerful final R.F. amplifier.

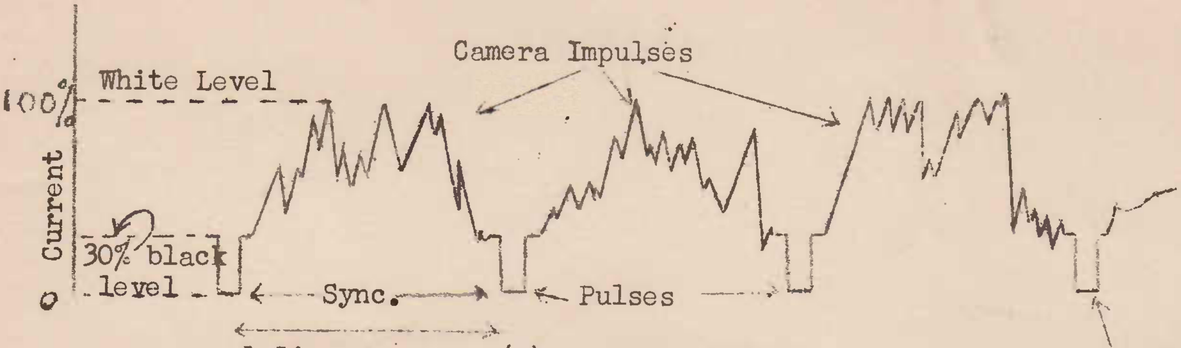
MODULATION OF THE CARRIER WAVE.

Thus far we have discussed in some detail the generation of the video signal and the generation of the radio frequency carrier current. The time has now come when we must consider the problem of how the video signal is superimposed upon the carrier-wave -- that is the problem of modulation.

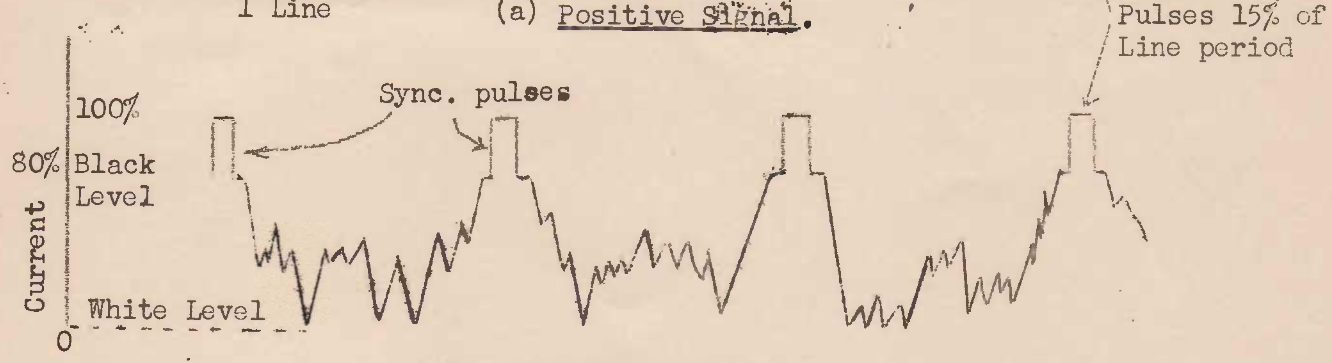
Amplitude modulation of the vision signal is universally adopted -- that is the amplitude, or strength, of the carrier current is made to vary in step with the video modulating current. Two questions now arise. The first of these questions is: shall we cause the amplitude of the carrier to rise or to fall when the picture brightness increases? When we arrange matters so that the carrier strength increases with an increase in picture brightness, and to decrease as the spot traverses a darker area the modulation is called Positive Modulation. When the reverse action occurs, i.e. when the carrier amplitude decreases with an increase in brightness, and increases when the light from the picture decreases, the modulation is said to be negative. The second question is: how will we insert the synchronising pulses (already briefly mentioned in a previous lesson) so that the latter will not interfere with the actual picture signal? To answer both these questions we must examine in more detail the nature of the complete video signal in the modulating stage (see Fig.10) of the transmitter.

THE COMPOSITE VIDEO SIGNAL-POSITIVE AND NEGATIVE SIGNALS.

Figure 10 shows at (a) a positive video modulating signal for three complete scanning lines. Note that the signal is represented by a varying (or pulsating) direct current, and not an alternating current as in the case of an audio modulating signal. The video current is divided into two sections. The upper section



(a) Positive Signal.



(b) Negative Signal

VIDEO SIGNALS.
FIGURE 10.

comprising about 70% (i.e. from 30% to 100%) of the maximum amplitude is devoted to the camera signal. Within this range the variations in current represent the variations in light and shade as the picture is scanned. Note that maximum current represents a pure white portion of the picture, and 30% current represents pure black, i.e. no reflected light from the scene. The lower section of the composite video current, i.e. from zero to 30% maximum is devoted to the synchronising signals. These consist of short duration downward (or "negative") pulses inserted in the gaps between successive lines. During each of the gaps or intervals the scanning beams (at both transmitter and receiver) are returning from the right hand side to the left of the screen, preparatory to commencing a new line. The synchronising pulses, representing sudden or abrupt changes in voltage are utilised in the receiver to regulate the frequency of the saw-tooth oscillator which provides the horizontal movement of the electron beam (i.e. the line scanning). The gaps between the lines represent a time of about 15% of the line interval (i.e. the time taken to scan one complete line). Note that the synchronising pulses occupy a time rather less than the total interval between the lines. This is to avoid any possibility of the pulses interfering with the picture signal.

The effect, then, of the synchronising pulses is to reduce the video signal's amplitude from 30% to zero. Any current less than 30% of the peak represents "blacker-than-black" or, as it is called, infra-black. It is obvious that the sync. pulses could not show up on the receiver screen, since they represent voltages less than that which produces pure black.

At (b) in Fig. 10 a negative video signal is shown. Here picture signals are represented by current variations extending from zero up to about 80% of the maximum amplitude. Zero voltage is utilised to represent pure white, and the 80% level pure black. This means that an increase in voltage represents a decrease in light intensity, and vice versa. Hence the term "negative" signal. In this case voltages ranging from 80% to 100% of the peak represent the "blacker-than-black" or ultra-black region. It is this region that is occupied by the sync. pulses. That is, the sync. pulses are represented by sudden increases in voltage from the 80% peak level up to the max. (100%) peak level. The 80% or black level is sometimes called the "blanking" level, because all picture signals above it are blacked out.

In the case of both positive and negative signals it should be appreciated that the receiver will be able to separate the synchronising pulses from the actual picture signal, because of the difference in amplitude of these two parts of the composite video signal. Just how this is done will be dealt with in the appropriate lesson on receivers.

POSITIVE AND NEGATIVE MODULATION.

The result of utilising each of the two types of video signal to modulate the outgoing wave in the final power amplifier of the transmitter is shown in Fig. 11.

At (a) positive modulation is shown, and at (b) negative modulation. Remember when referring to this diagram that the radio-frequency carrier current is an alternating one with both positive and negative half cycles. The effect of the modulation in either case is to vary the amplitude of this radio-frequency alternating current -- both positive and negative half-cycles being similarly effected. Lines are shown joining the peaks of the r.f. half-cycles and these lines are replicas of the modulating video signal. Such lines represent what is known as the modulation envelope. Note that the envelope for the positive half-cycles is exactly similar to that for the negative half-cycles. Henceforth, for this reason, we shall only show the envelope for the positive half-cycles.

Referring to Figure 11 (a) note that the carrier amplitude is increased to 100% (100% modulation) for a white element of the picutre, and reduced to 30% of peak amplitude for jet black. The sync-pulses, between lines, reduce the carrier strength further, from 30% to zero.

In the case of negative modulation at (b) Fig. 11 pure white is represented by zero carrier amplitude, and jet black by 80% of peak amplitude. The carrier is only increased to 100% by the sync. pulses occuring between lines.

POSITIVE AND NEGATIVE MODULATION COMPARED.

For positive modulation it is claimed that electrical interference is less liable to cause synchronisation troubles. Experiment has shown that such interference causes sudden sharp increases in carrier amplitude, rather than reduction in this amplitude. Since with positive modulation, the sync. pulses cause a reduction of carrier amplitude (from 30% to zero) the latter will be relatively immune from the effects of electrical interference. Such interference, on the other hand,

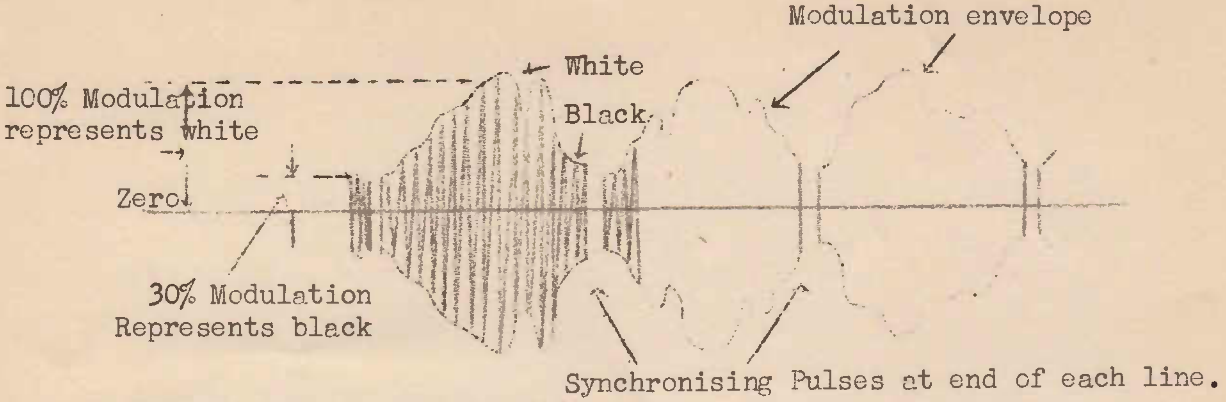


FIGURE 11 (a)

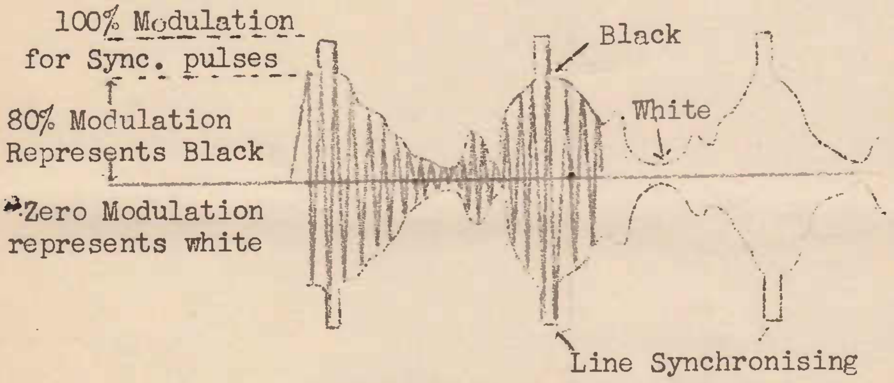


FIGURE 11(b)

causing sudden rises in carrier amplitude, will result in white flashes on the screen, marring the reproduced picture.

If negative modulation is used the interfering impulses may carry the carrier amplitude into the infra-black region of the carrier's modulation, which region is occupied by the sync. pulses. The effect of this is that the receiver could mistake an impulse above the 30% level caused by interference for a true sync. pulse. The result would be that the receiver's scanning would lose syncronisation with that of the receiver.

From the point of view of the picture information, however, negative modulation has the advantage. Interference, resulting mainly in increases in carrier amplitude, would result in dark flashes on the screen. Dark flashes are much less noticeable than bright (white) flashes.

With improvements in sync. equipment experience has shown that synchronisation is not unduly affected by interference when negative modulation is used. It appears, therefore that the advantages of negative as compared with positive, modulation, outweigh the disadvantages. It seems certain that in future negative modulation will be adopted everywhere. It might be mentioned here that, at present, positive modulation is used in England, and negative in America. Henceforth we shall only refer to negative modulation.

ELECTRONIC INTERLACED SCANNING.

To complete our description of the nature of the video signal which modulates the carrier in the transmitter's output stage, we must also discuss the nature of this signal during the frame retrace period, i.e. the interval of time when the scanning beam is returning from the bottom of the picture to the top.

No picture signals, of course, are transmitted during this frame retrace interval, which is utilised for sending special pulses for synchronising the receiver's frame (or vertical saw-tooth oscillator). Since the method known as "Interlaced" scanning is now in universal use, and further since the nature of the vertical or frame sync. pulses are closely bound up with this type of scanning, it will now be necessary to explain briefly how interlacing is achieved electronically.

The student should recall that interlaced scanning involves the tracing of the lines not in a consecutive fashion, but alternately. That is, during any one "frame" every other line is traced out over the whole picture area. Similarly, during the following frame, alternate lines are traced, but these are adjusted to fill in the gaps missed during the first frame. This involves two complete frames per complete picture.

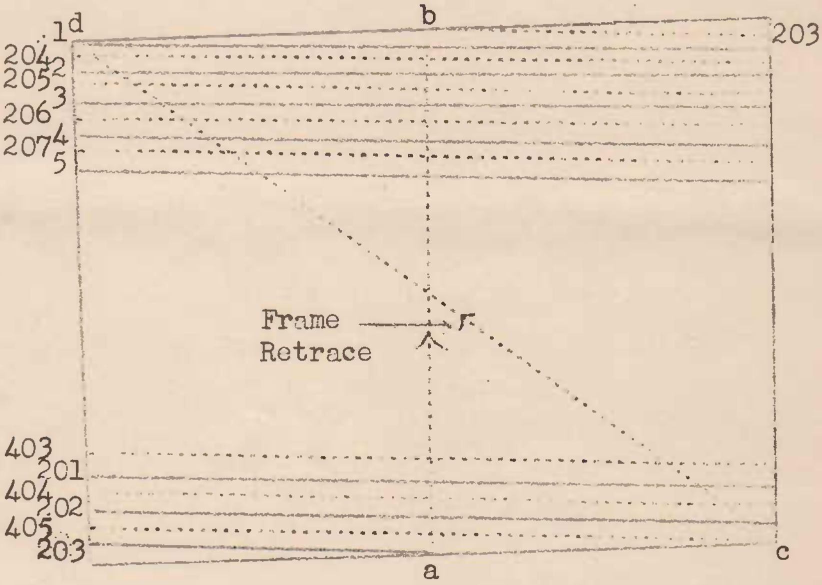


FIGURE 12.

The mode of interlacing the lines for a complete picture is illustrated in Figure 12. We are here supposing that 405 lines per picture are used. The lines traced out during the first frame are shown by continuous black lines in the diagram. Those traced during the next frame are shown by dotted lines. During the first frame lines numbered 1 to 202 are completely covered, and line No. 203 is half covered. This is usually referred to as an "odd" frame. The student should recall that while the horizontal saw-tooth oscillator is moving the electron beam across the picture, the vertical saw-tooth oscillator is simultaneously moving it down the picture, but at a much slower rate. This, of course, is responsible for the fact that the **lines are sloping slightly,** instead of being perfectly horizontal. In the time that one line is scanned from left to right, the vertical saw-tooth oscillator has moved the beam down a distance equal to the width or thickness of <u>two lines</u>. This is achieved by operating the latter oscillator at <u>twice</u> the picture frequency, viz: a frequency of 50 cycles/sec, instead of 25 c/sec. In this way alternate lines are missed.

When the 203rd line has only half traversed the picture, the vertical sync. signal (acting upon the vertical saw-tooth oscillator) suddenly causes the spot to flick back to the top of the picture (see a.b. Fig.12), completing the 203rd line there.

This is the beginning of the next frame. During this frame the lines 204 to 405 are traced out, covering those portions of the picture missed during the first frame. This is called an "Even" frame. At the end of the complete 405th line the vertical oscillator suddenly shifts the beam from the bottom to the top of the picture, and the horizontal (line) oscillator moves it from the left to the right. Hence the beam returns abruptly from c to d., to begin the next odd frame. Note the reason for using an odd number of lines, like 405, for scanning. This gives $202\frac{1}{2}$ lines per frame, and the odd half-line gives the necessary shift to produce the interlacing.

The diagram of Figure 12 represents an idealised case. Here, for simplicity, it was assumed that the beam could return from the bottom of the picture to the top instantaneously, i.e. that the retrace was zero. In practice this time is very short compared with the line taken for uniform downward motion, but still it is sufficient for about 10 line oscillations to occur. This means that at the end of any frame 10 lines (or so) must be "blanked" out, otherwise the frame retrace would show up as a zig-zag path on the screen. Since there are two frames per picture 20 lines (out of the 405) in all will not be used for sending picture information. These are the so-called "inactive" lines. Note that with 405 line scanning only 385 (405 minus 20) are actually used to transmit picture information.

THE VIDEO (MODULATING) SIGNAL BETWEEN FRAMES.

The synchronosing signals for timing the horizontal (frame) saw-tooth generator in the receiver are transmitted, as a modulation of the carrier waves, in the intervals between successive frames, i.e. every $\frac{1}{50}$th second (50 frames/sec.). The student will appreciate that the receiver must be able to distinguish between the frame sync. pulses and the line sync. pulses, these latter recurring every $\frac{1}{10,125}$ of a second (405 X 25 = 10,125 lines/sec). For this reason the frame pulses must differ in some way from the line pulses. Further the intervals between frames will differ, depending upon whether an odd or an even frame has just been completed.

As mentioned above, an appreciable interval of time will elapse between the end of one frame and the beginning of the next. This interval is usually 5% ($\frac{1}{20}$ of $\frac{1}{50}$ sec. = $\frac{1}{1,000}$ sec. or more. The student should recall the method whereby (lesson 3) the beam is moved for scanning purposes. A voltage which rises and falls with a saw-tooth wave-form is applied between a pair of deflector plates in the camera tube or cathode ray tube. These saw-tooth voltages are generated by special oscillators. Figure 13 shows one and a half cycles of a saw-tooth voltage as used for the frame scanning. The frequency here is 50 cycles/sec, so that the time for one cycle (ac) is $\frac{1}{50}$ sec. As the voltage gradually rises from a, b the beam moves at uniform speed down the screen. During the whole of this time, of course, the horizontal saw-tooth generator operating at the much higher frequency of 10,125 c/sec. is moving the beam across the screen for line scanning. When the voltage has risen to (b) Figure 13 the beam has reached the bottom of the picture, and one frame is completed. Now the voltage falls to zero, not instantaneously but along bc.

This moves the beam back to the top of the screen, for the beginning of the next frame. The time represented by dc, during which the beam is returning from bottom to top of the picture is called the "fly-back" time.

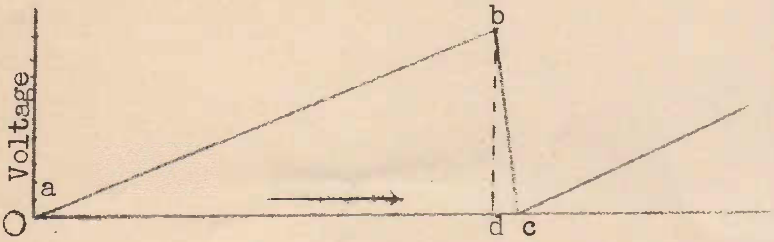


FIGURE 13.

Now the point is, that in designing saw-tooth oscillators of this frequency it is difficult to obtain a fly-back time less than about 5% or $\frac{1}{20}$ of the period of one cycle (a c in Fig. 13). In practice, therefore the fly-back time, d c is, as calculated above, about $\frac{1}{1,000}$ sec. or so. This interval which occurs between frames, gives us ample opportunity to insert the frame sync. pulses. Note also that during this between-frames interval about 10 complete lines will be traced.

The first job then will be to suppress the line signals between frames. This is done by impressing a "blanking" signal on the video signal for the duration of 10 complete lines. The blanking signal simply raises the signal amplitude to the "black" level for the duration of the interval (see (a) Figure 14). This of course will obliterate any camera picture signal (which occurs below the 80% black level).

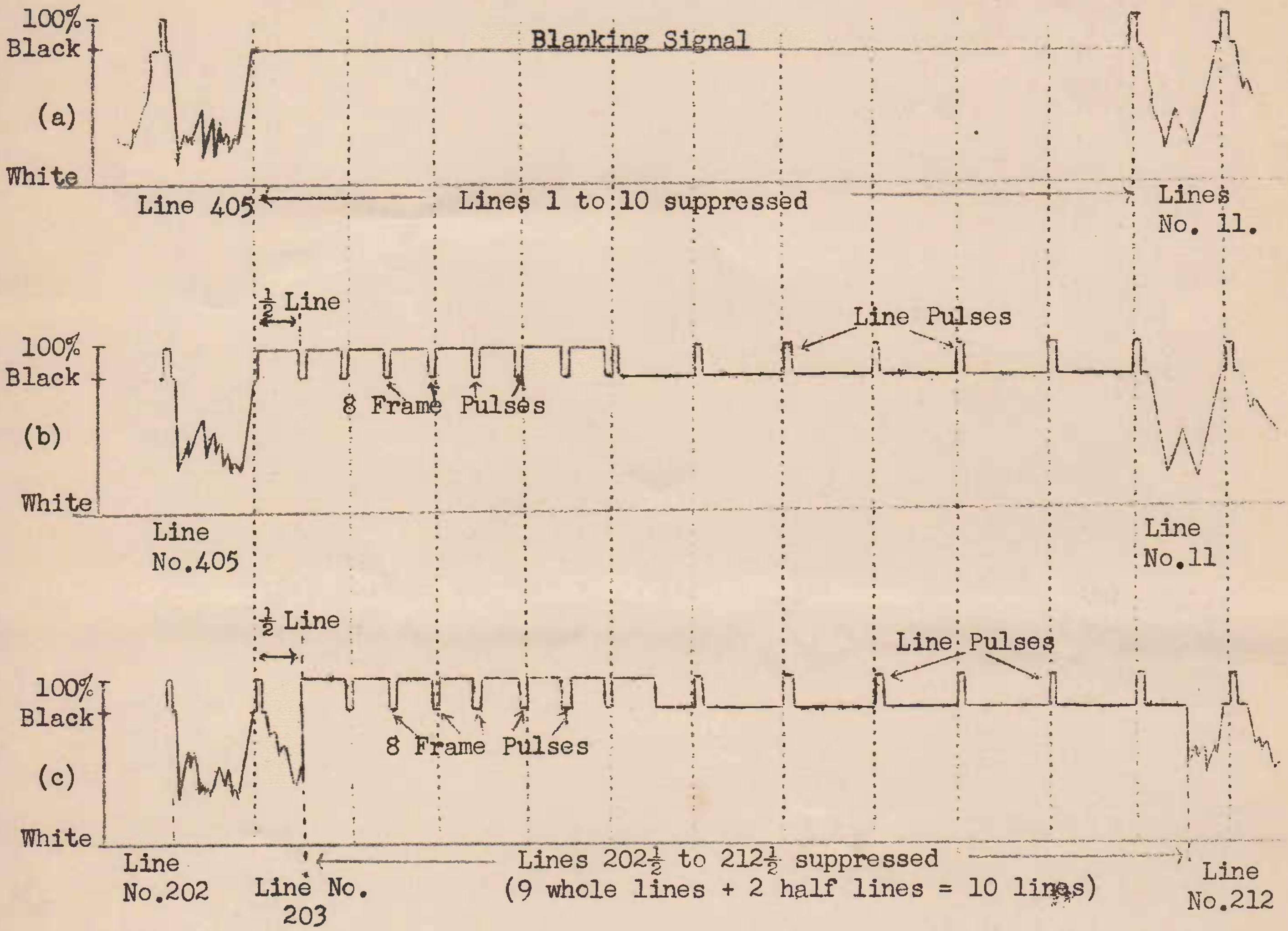
The synchronising pulses are now superimposed on the blanking signal. These pulses of course carry the modulation up to 100%. The interval at the end of even frames is shown at (b) Figure 14. Line 405 has just been completed during the previous even frame.

The camera signal is blanked out at this instant and 8 broad pulses for frame synchronising follow. These eight broad pulses (each having a duration of half a line) form the frame sync. signal. On account of the great difference between the wave-form of this frame sync. signal and the line pulses, it is possible by using special circuits at the receiver to separate the two.

Following the frame sync. pulses there are 6 lines which carry line sync. pulses, but no camera signal. This allows the line synchronisation to settle down, before the next frame commences on line number 11.

The interval at the end of odd frames is somewhat different. This is shown at (c) Figure 14. When line number 203 is half completed the blanking signal cuts out the camera signals and the frame sync. signal commences. This, as before, consists of eight broad pulses covering four complete lines. Note that the blanking signal persists as before for 10 whole lines. The next frame therefore commences at the latter half of line number 212.

The important point to realise is that provided the sync. signals get through to the receiver undistorted, odd frames must commence at the beginning of a line,



(a) and (b) at end of even frames; (c) at end of odd frames.

FIGURE 14.

and end half way through a line, while even frames must commence on the latter half of a line and end at the finish of a complete line. This, as explained in connection with Figure must automatically ensure correct interlacing. Note that the system involves the use of an odd number -- like 405 or 441 -- of scanning lines per complete picture.

THE SOUND CHANNEL.

As explained earlier in the lesson the present system is to transmit the sound on a seperate channel adjacent to that used for the vision. The receiver's aerial tuning may thus, if broad enough, bring in both vision and sound signals simultaneously.

Since the vision channel must, for reasons already discussed, be located within ultra-high frequency range (above 40 mc/sec), this system also involves the choice of an ultra-high frequency for the sound. Now these frequencies are eminently suited for frequency-modulation with its associated advantages of freedom from interference and high fidelity. For this reason the tendency at present is to use amplitude modulation for the vision signal, and frequency modulation, on a separate, but adjacent, channel for the sound. The B.B.C. in England, however, uses amplitude modulation for both.

SINGLE CARRIER FOR VISION AND SOUND.

With the development of a new type of modulation for sound, known as Pulse Modulation, it has been found possible to transmit the sound on the same carrier as is used for the vision signal.

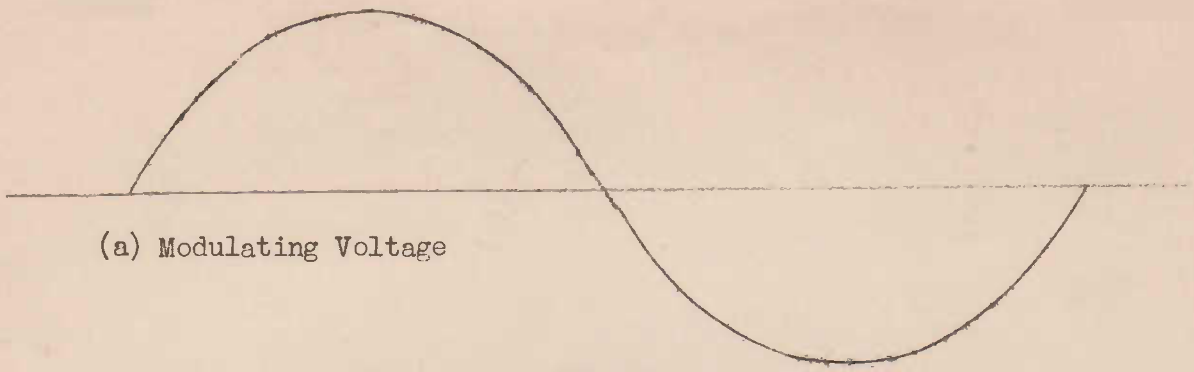
In the case of this system the sound modulates the carrier only during the brief intervals between scanning lines, which interval is also used for the sync. pulses. Instead of transmitting the sound programme continuously it is found to be sufficient to transmit a larger number of "snap-shots" of the sound every second. The receiver may be so designed as to reconstitute the programme from these snap-shots. An analogy may be drawn here to a series of cinematograph "stills" which when passed through a projector at a sufficiently rapid rate will produce the illusion of a moving picture. Similarly a series of sound "stills" when passed through a receiver can reproduce a continuous sound programme. Whereas, however, the eye is satisfied with 24 picture snap-shots per second, the ear requires at least 6,000 sound snap-shots per second if intelligible sound is to be received.

If a 405 line, 25 picture per second system is used, as in England, the line frequency is 10,125 lines per second. This allows us to send 10,125 "snap-shots" of the sound every second, by inserting them during the line intervals.

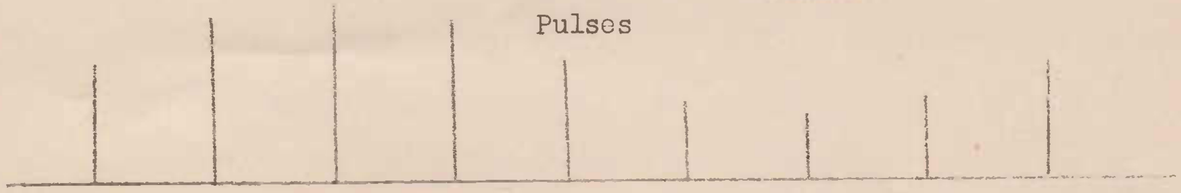
A number of systems of pulse modulation have been developed. The most successful for television purposes, seems to be that whereby the width of special pulses (placed in the line intervals) is made to vary with the instantaneous amplitude of the modulating sound voltage. This is called pulse-width modulation. In pulse-height modulation the height of the pulse is caused to vary with the instantaneous value of the modulating voltage. A third system is to vary the repetition frequency of the pulses with the modulation (pulse-frequency) modulation. Still another arrangement is to vary the position of the sound pulses -- the exact position of any one pulse depending upon the amplitude of the modulating voltage at that instant. This is called pulse-phase modulation.

The idea of pulse-height and pulse-phase modulation is exemplified further in Figure 15. At (a) is shown the modulating (audio) voltage. At (b) the pulses vary about a mean height in accordance with the amplitude of the modulation at that instant. At (c) the pulses have constant repetition frequency, and constant height, but their width varies with the modulation as shown.

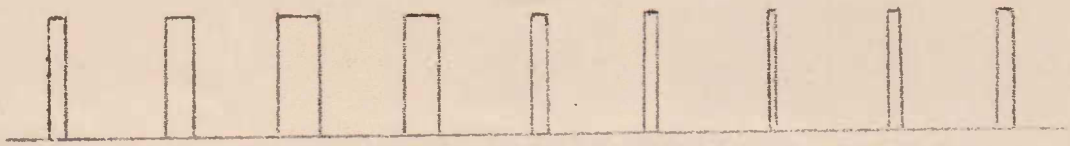
If pulse-width modulation is used, the maximum width of the pulses during the



(a) Modulating Voltage



(b) Pulse height modulation. Pulses constant repetition frequency. Variable height.



(c) Pulse-Width Modulation. Pulses constant repetition - Frequency variable width.

FIGURE 15.

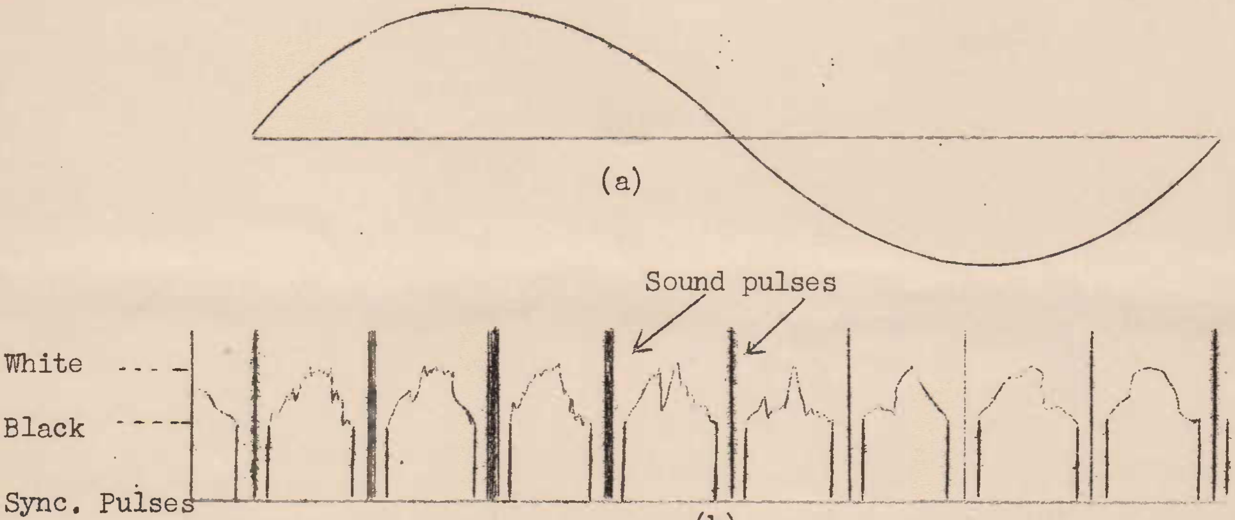
modulation must be somewhat less than the line sync. pulses between lines. When the line frequency is 10,125 sec, the gap between lines is usually about 10% of the line interval, i.e. a time of only about $\frac{1}{101,250}$ of a sec. (i.e. approx. 10 micro-seconds). The widest sound pulses (i.e. those of longest duration) must be considerably less than this, which means that the narrowest pulses are of extremely short duration indeed.

The wave from of a complete video signal together with sound-pulses (width modulation) is shown in Figure 16 at (b). Here positive modulation is used. The sync. pulses therefore, as explained, reduce the signal amplitude to zero (negative pulses). The sound pulses, superimposed upon those sync. pulses, increase the signal amplitude to 100%

A problem is to provide means of separation, at the receiver, of the sound pulses from the vision signal. Earlier it was explained how the sync. pulses could be separated from the vision. This was done, in the case of positive modulation, by limiting the vision signal to the range of 30% to 100% modulation. The sync. pulses then operated in the range 30%—0% modulation. When pulse modulation is used for sound, one method of separation is to further limit the vision signal so that pure white is something less than 100% modulation, say 80%. Then the vision signal occupies the range 30% (black) to 80% (white) of peak modulation. Since the sound pulses extend to 100% modulation their upper 20% may be "sliced off" in the receiver without interfering with the vision signal. In this way separation is achieved.

Advantages claimed for pulse-modulation are many. They include (1) a simplified receiver (2) freedom from interference (3) total band-width of television channel is reduced (4) mutual interference between sound and vision channels is eliminated, (5) installation and maintenance costs of transmitter are reduced, for no separate transmitter is required for the sound programme.

Experiment and theory show that the maximum frequency (audio) of modulation is one-half the frequency of repetition of the pulses. In the case of a 405 line, 25 picture/sec. transmission this repetition frequency is 10,125 per sec. (i.e. the line frequency). Therefore the audio frequency transmitted is limited to about 5,000 cycles/sec. This gives sufficient tonal quality for the average listener, but falls short of high-fidelity transmission. Of course if the number of lines of the scanning system is increased, the repetition frequency of the pulses will be correspondingly increased, thus allowing of a high audio frequency modulation limit. A likely trend seems to be the introduction of very-high definition (600 lines) colour television, operating in the vicinity of 600 mc/sec ($\frac{1}{2}$ metre). The line frequency in this system would be 15,000 per sec., allowing of an audo frequency limit with pulse modulation of 7,500 cycles/second.



Pulse-Width Sound Modulation on Vision Carrier (Positive Modulation).
FIGURE 16.

T. FM & F. No. 6.

EXAMINATION QUESTIONS.

1. State two reasons for the use of ultra-high frequency carriers for television purposes.

2. What is meant by "single side-band" transmission? What is its advantage?

3. In modern television systems why is the sound carrier channel situated adjacent to (either just above or just below) the picture carrier channel.

4. State three characteristics of ultra-high frequency waves compared with medium and low frequency waves.

5. Why is it unsatisfactory to use an ordinary telephone cable or line for the purpose of linking a distant television camera to the studio? Mention <u>briefly</u> the methods in use.

6. What is the function of a frequency multiplier? Explain briefly the reason for using this method to obtain the ultra-high frequency required for the carrier.

7. Explain the difference between positive and negative modulation of a picture-carrier.

8. Explain carefully why, in the case of negative modulation, the picture modulation is limited to 80% of the total signal amplitude.

9. In the case of interlaced scanning why is an <u>odd</u> number of lines used?

10. Why is no separate sound carrier required when pulse modulation is used? State the advantages claimed for this system.

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TELEVISION, FREQUENCY MODULATION & FACSIMILE.

LESSON NO. 7. AERIALS.

The question of aerials is relatively more important in television work than it is in the case of normal radio telephony in the broadcast band. The student well knows the lack of attention usually displayed in the installation of an aerial for the home-radio. Certainly excessive carelessness is often shown in this respect, the performance of a receiver being frequently marred to some degree by failure to observe simple elementary principles. The fact remains however, that the performance of the average broadcast receiver is not critically affected by the aerial installation under the great majority of operating conditions. And in only rare cases is any great knowledge of aerial theory and technique required by the serviceman.

When we are dealing, however, with ultra-short wave communication in general, and in television in particular, the aerial installation looms much larger in the picture. The performance of a television receiver can be made or marred by the type of antenna system provided, and the manner of its installation. The term "antenna system" has been used here purposely to include the so-called "lead-in". The design and adjustment of the latter is of at least equal importance as that of the aerial proper.

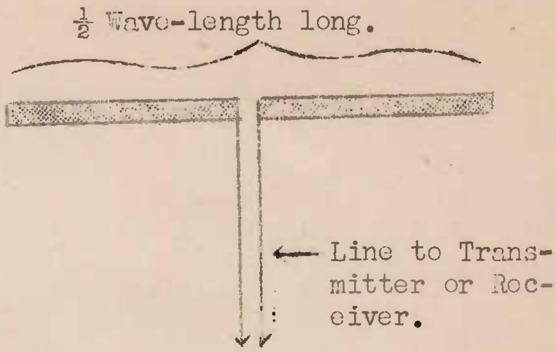
The underlying reasons for this stress on the antenna system of a television receiver are bound up with the ultra-short-wave (high frequency) nature of the carrier wave, and also with the necessity to avoid relative phase-shift (i.e. time delay) in the handling of the different parts of the signal. These points will be explained as the lesson progresses.

RESONANT AND NON-RESONANT AERIALS.

A resonant or tuned aerial is one which, like an ordinary tuned circuit, responds best to one particular frequency. As we shall see the resonant frequency of an aerial depends upon its length. This length, therefore, must bear a definite relationship to the wave-length of the desired signal. In normal broadcast reception the antenna usually shows very little resonant effect, and, in any case, rarely is any attempt made to tune it to the received wave.

THE HALF-WAVE DIPOLE.

The fundamental resonant aerial is that called the Half-Wave Dipole. This consists simply of a straight length of wire, or more usually a rigid rod, having a length approximately equal to one-half of the radiated or received wavelength. In normal television practice the antenna is broken at the centre and each part is connected to one of a pair of wires forming what is known as a transmission line or "feeder". The arrangement is shown in Figure 1.



HALF-WAVE DIPOLE "CENTRE-FED".
FIGURE 1.

The transmission line or feeder serves, in the case of a transmitting antenna, to feed the radio-frequency energy from the transmitter to the aerial for radiation. In the case of reception the line feeds the received signal from the antenna to the receiver's input circuit.

"DISTRIBUTED" CAPACITY AND INDUCTANCE OF A CONDUCTOR.

The student may at first find it difficult to image how a simple straight conductor can act as a tuned or resonant circuit. We commonly regard as the essential components of the latter a coil of wire possessing the electrical property known as inductance, together with a condenser whose electrical property is that known as capacity or capacitance. Inductance, it will be recalled, is that property whereby a circuit opposes or tends to oppose any change (i.e. increase or decrease) in current flowing in the circuit. Capacity is the property of a circuit to store an accumulated electric charge, positive or negative. Now even a straight piece of wire, isolated in space, possesses those two properties to some small degree.

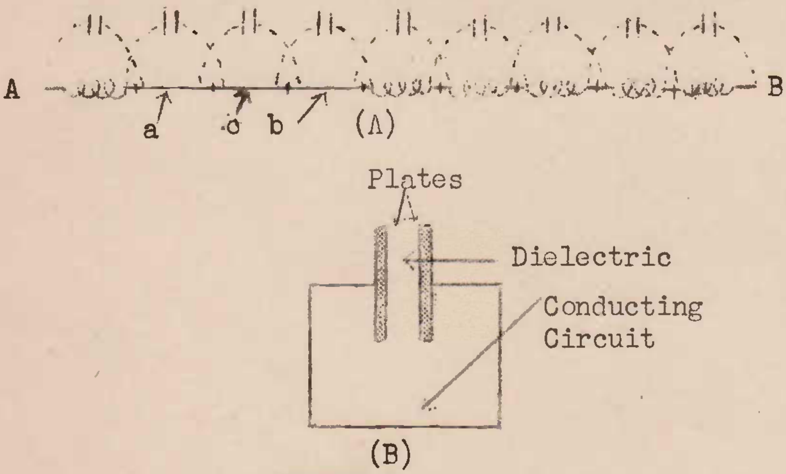


FIGURE 2.

The inductance and capacity, however, of such a simple conductor, are not "lumped", or concentrated, as in the case of a coil and a condenser respectively, but they are distributed over the whole extent of the wire.

To understand this idea of distributed capacity refer to Figure 2 where a straight conductor AB is shown. This wire may be regarded as consisting of a very large number of small sections, or "elements". Two of such elements are shown labelled "a" and "b". These two elements form, in effect, a condenser, since they consist of conducting material and they are separated by the surrounding air which is an insulator, and acts as a dielectric. To be sure the two elements of the wire are also connected by the intervening section of wire c, which is a conductor, but this does not destroy the capacity effect existing between a & b. For comparison purposes a condenser, consisting of two metal plates separated by a dielectric is shown at (b) Figure 2. Although the two plates of this condenser are shown connected by a conducting circuit this in no way affects the value of the capacity formed by them.

Returning to the conductor of Figure 2(a) we can say that between every pair of small elementary lengths of the wire there exists a small capacity effect, and the sum total, or effective value, of all these small capacities is known as the distributed or self capacity of the wire.

Dealing now with the question of the distributed inductance of a straight conductor several fundamental electrical facts and ideas should be recalled. The first of these is that whenever a current flows (i.e. a charge moves) a magnetic field is created around the conductor involved. This field is a circular one, the lines of force forming a series of concentric circles or rings around the conductor. Figure 3 shows the way in which these lines of force are distributed around the current-carrying conductor; a "side-on" view of which is shown at (a). At (b) a cross-sectional, or "end-on", view illustrates clearly the circular nature of the field. Note that some of the lines of magnetic force exist within the conductor, these being mainly due to that part of the current flowing near the centre of the latter. Now if the current is increased extra lines of force are created, and the field expands outwards. Thus we have a moving magnetic field, a part of which will cut across the metal of the conductor inducing an electro-motive-force (e.m.f.) in it. This emf. opposes the direction of current flow, tending to prevent the increase of the latter. Similarly if the current flowing is decreased, the magnetic field is weakened, and lines of force collapse inward into the conductor. This moving field (or part of it) again cuts the conductor and induces the e.m.f., which, however, is in the reverse direction to that of the former case. The induced e.m.f. is now acting in the same direction as the direction of current flow, and tends to prevent the decrease in current, i.e. to maintain it at its original value.

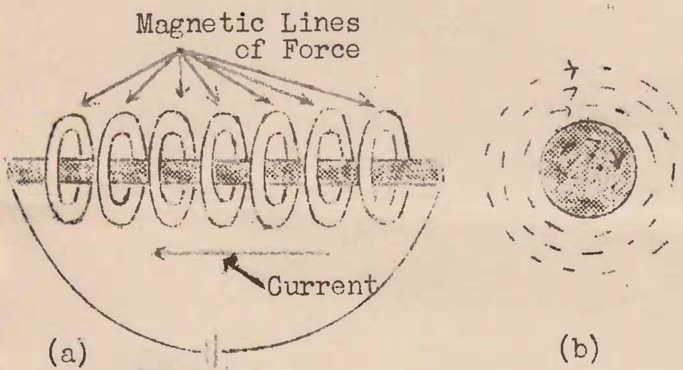
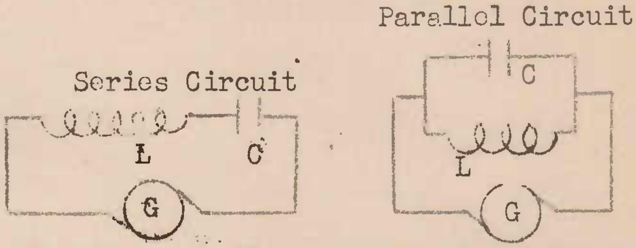


FIGURE 3.

Note that in both cases the self-induced e.m.f. acts in such a direction to oppose any change in the intensity of the current. It is this property of a circuit which is known as its self-inductance. Of course, in the case of a closely wound coil of wire the effect is greatly magnified, due to the more powerful magnetic field produced by the current, and also to the fact that a greater percentage of the total field actually cuts the wire when the current changes in value. But the important point here is that a simple straight conductor possesses some inductance, even though its value, measured say in micro-henrys is small. At low and medium frequencies the effect of the inductance of short lengths of wire is usually so small as to be negligible. Working at ultra-high radio frequencies, however, the current changes are so rapid that the distributed inductance may have quite an appreciable effect.

Thus we have seen that a straight conductor possesses the electrical properties of inductance and capacity. Now the student well knows that any circuit possessing these two properties can act as a resonant or tuned circuit, whereby either a maximum or a minimum impedance is offered to the applied alternating e.m.f, depending upon how the latter is applied to the combination of inductance and capacity.

In Figure 4 we have shown a source of alternating e.m.f. (G) applied across a series tuned circuit at (a) and a parallel tuned circuit at (b). Concentrating on the series case, remember that when the frequency of the applied e.m.f. coincides with the resonant frequency of the circuit, the reactances of the inductance and the capacity are then equal, and instead of adding, as in the case of resistances, they cancel each other. This leaves only the resistance of the wires to oppose the A.C. In other words the impedance of the circuit, at resonance, will be small, and the current correspondingly large. A series tuned circuit may allow a very heavy current to flow, even though the applied e.m.f. is small.



Impedance small
current large.
(a)

Impedance Large
Current small
(b)

FIGURE 4.

In Figure 5 we have shown a straight conductor AB, broken at the centre in order to insert a source of alternating e.m.f., directly applied as at (a) or indirectly applied by means of a transformer as at (b). It is found that an A.C. will flow in the conductor due to the fact that it possesses distributed -- or self-capacity.

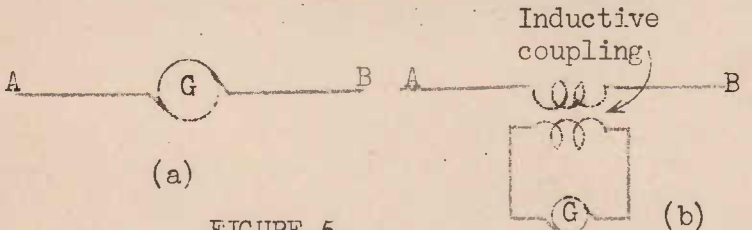


FIGURE 5.

The reactance of this small capacity, however will be very large, and therefore the current may be very small. But remember that the conductor also possesses inductance. If the frequency of the generator is adjusted it will be found that, at some particular frequency (ultra-high) the reactances of the inductance and capacity will cancel out, and a heavy alternating current will flow. Actually the conductor acts like a <u>series</u> resonant circuit. Since the inductance and capacity of the wire are very small, the resonant frequency will be very high (remember that resonant frequency of a tuned circuit is given by the formula.

$$f = \frac{1}{2\pi\sqrt{LC}}$$.

RELATIONSHIP BETWEEN RESONANT FREQUENCY AND LENGTH OF A HALF-WAVE AERIAL.

It is found that the resonant frequency of an aerial of this type is indirectly proportional to its length. That is to say, the longer the aerial, the lower the resonant frequency, and vice versa. The actual thickness of the wire or rod of which the aerial is made has no bearing whatever upon this frequency. In practice the resonant frequency of a half-wave aerial is very easy to calculate. <u>This frequency corresponds to a wavelength approximately double the total length of the aerial</u>. In other words the aerial's length is one-half a wavelength of the radiated wave corresponding to the given frequency. The reason for the name "half-wave" aerial is therefore obvious. To illustrate, let us calculate the resonant frequency of a half-wave dipole 3 metres long (1 metre = 39.32 inch). The frequency will be that corresponding to a wavelength of 6 metres. Now:-

$$\text{Frequency (in cycles/sec.)} = \frac{300,000,000.}{\text{Wavelength (in metres).}}$$

$$= \frac{300,000,000.}{6} = 50,000,000 \text{ c/sec.}$$

$$= 50 \text{ mc/sec.}$$

ALTERNATING CURRENT AND VOLTAGE DISTRIBUTION IN A HALF-WAVE AERIAL.

By utilising our knowledge of a tuned circuit consisting of capacity and inductance, we have seen how it is possible for a straight conductor to resonate at some particular frequency. It will be informative at this stage to consider the nature of current flow and the electrical potential at different points in the conductors when "excited" by a transmitter at its resonant frequency.

First of all it will be necessary for the student to recall that every substance contains a large number of negative electrons and normally, an equal number of positive protons. The charges of these unlike electrical particles therefore cancel each other, and the material is said to be electrically neutral, or uncharged. In the case of a conductor a large proportion of the electrons are free to move at random among the atoms of the material. A net movement in one particular direction of these "free" electrons is called an electric current. If, by means of a battery, or other means extra "free" electrons have been forced into a body, so that the electrons exceed the protons in number, the body is said to be negatively charged. On the other hand if a deficiency of electrons has been created, by removing some of the latter from the body, a positive charge is built up. This positive charge is, of course, due to the minute positive charges of the protons, which are now not completely cancelled by those of the electrons. Remember, however, that the protons are firmly fixed within the atoms, and cannot be moved by ordinary methods.

Consider now the conductor of Figure 6. excited at its resonant frequency by a source of alternating e.m.f. applied at its central point, and acting as a half-wave dipole. Before the voltage begins to act all parts of the conductor will have zero charge as at (a), since the free-electrons are evenly distributed throughout its whole length. If the voltage first begins to act in such a direction that electrons are forced to the left, some of these will flow, or be displaced, in that direction. These displaced electrons will build up a negative potential in the left-hand half of the aerial. The right-hand half will become positively charged, due to the fact that some electrons have moved away from it. This state of affairs is shown at (b) Figure 6. The ability of the conductor to store charges in its various sections is exactly what we meant previously when we said that it possessed distributed self-capacity.

As the applied voltage now falls off to zero, and then reverses, electrons will move along the conductor to the right. The charges shown at (b) will first disappear (c), and then reversed charges will appear as at (d). This process will continue indefinitely.

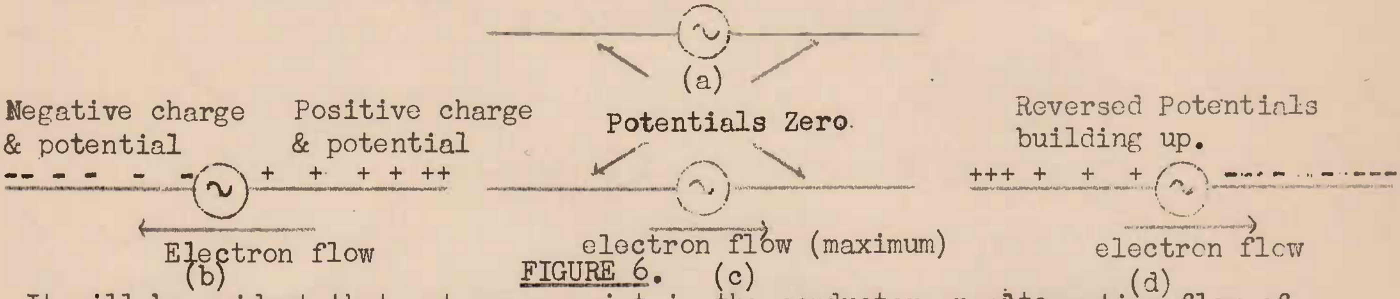


FIGURE 6.

It will be evident that, at every point in the conductor an alternating flow of electrons is taking place at the frequency of the applied e.m.f. The size or amplitude of this current will be a maximum at the centre of the conductor, where the electrons have the greatest freedom of movement (back and forth). Near the ends of the conductor, on the other hand, the current flow will be very small, since electrons cannot leave these ends, and their motion is therefore greatly restricted.

The potential (pressure) distribution is quite different from that of the current. The charges become most concentrated at the ends of the conductor, as shown by the crowding of the + and — signs in Figure 6. The potentials, which are built up by these stored charges will therefore be a maximum at these points. Note that the potential at any point on the aerial is of an alternating character, since it continually changes in value and sign. The potential at the exact centre of the wire will always remain at zero (except for the small voltage of the generator).

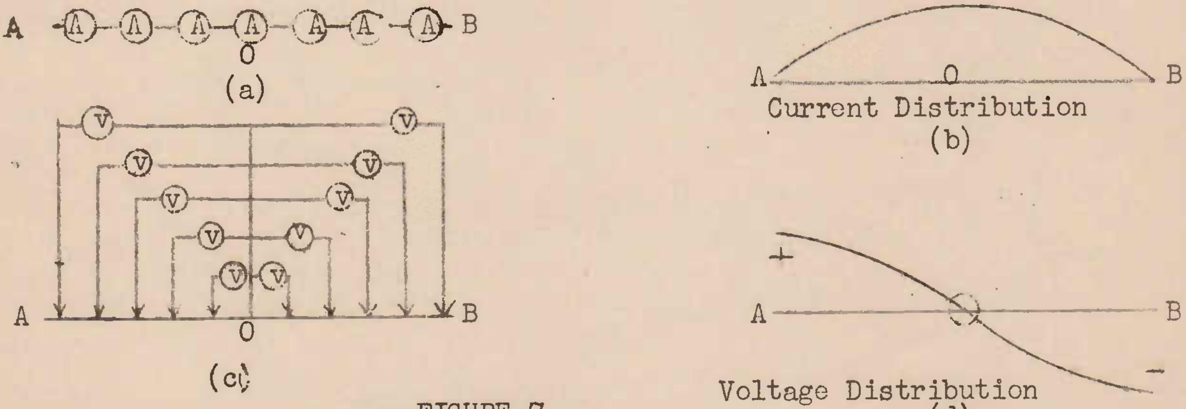


FIGURE 7.
CURRENT AND VOLTAGE CURVES FOR A RESONANT HALF-WAVE AERIAL.

The mode of oscillation of a half-wave dipole may be clearly illustrated by drawing curves showing how the current and voltage vary in magnitude and sign (direction) at all points along it.

In the diagrams of Figure 7. AB represents a conductor excited at its resonant frequency when behaving as a half-wave dipole. The applied exciting voltage is not actually shown in the diagrams.

We could imagine the current at various points along the conductor to be measured by an A.C. ammeter (or series of ammeters) placed as shown at (a) Figure 7. Remember that such a meter shows a steady reading, which is generally the R.M.S. value, or the peak value, (usually the former) of the alternating current. We would find that the meter at the centre (o) of the conductor would show the maximum reading. The deflections on the other meters would gradually fall off as we go from the centre of the wire towards the ends. At (b) Figure 7 we have plotted a curve showing how the current values vary over the length of the conductor.

The diagram at (c), illustrates, at least in a theoretical way, how we may measure the potentials at various points along the aerial, all potentials being measured in respect to the central point (o) of the conductor. (Actually, in practice, it would be extremely difficult to measure the potentials in this way, owing to the fact that the impedance of the voltmeter would not be sufficiently high to avoid "loading" of the aerial).

In the case of these potentials, which, remember are also of an alternating character, we would find that the maximum readings are obtained for the end points of the conductor, with a zero (or minimum) reading for the central point. A reading at any other point would have an intermediate value between the maximum and zero.

The Potential or Voltage distribution curve is plotted at (d). The curve, as drawn, actually conveys more information than the meters would show. It indicates, in addition to the relative magnitudes of the voltages, the fact that, at any given instant the potentials of the two halves of the dipole are of opposite sign. At the instant shown, the left-hand half of the conductor is shown as positive, and the right-hand as negative. Of course, a fraction of a second later, the potentials will reverse, so that the left-hand end would be negative, and the right-hand end positive. The state of affairs illustrated by the potential curve at (d) could be discribed by stating that the potentials of the two halves of the dipole are "out of phase".

In a similar manner the current curve at (b) conveys more information than that relating simply to the magnitudes of the current. The curve is plotted entirely on one side of the zero line to indicate that the currents at all points along the conductor "are in phase". That is the currents, at any given moment, will either be all to the left, or all to the right.

THE IMPEDANCE OF A HALF-WAVE DIPOLE.

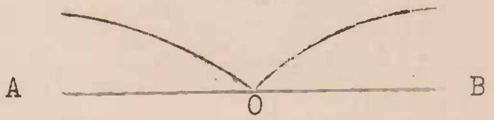
Impedance is a measure of opposition to alternating current flow, and is equal to the ratio : $\frac{\text{alternating voltage}}{\text{alternating current}} = \frac{E}{I}$.

Impedance (Z) is measured in ohms.

By the impedance of an antenna we mean the impedance presented by it to the transmitter (or rather to the feeder-line from the transmitter).

Now since, as illustrated by the curves at (b) and (d) of Figure 7, the values of the current, and voltage vary at different points along the dipole, it is obvious that the impedance will also vary, depending upon the point at which the antenna is "fed". The impdeance, at any point is equal to the ratio of $\frac{E}{I}$ at that point. At the centre, voltage is shown as zero, and current as a maximum. Therefore the impedance at the central point would appear to be zero $\left(\frac{\text{Zero Voltage}}{\text{Max.Current}}\right)$. At either end the voltage is a maximum, and the current zero. Therefore the impedance at these ends appears to be infinite $\left(\frac{\text{Max.Voltage}}{\text{Zero Current}}\right)$. The impedance will thus increase from zero at the centre, to a very large value as we move towards either end.

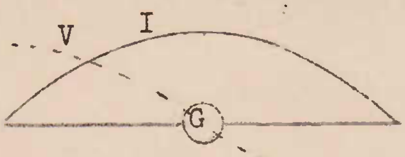
This variation of impedance along the dipole is illustrated by a curve in Figure 8.



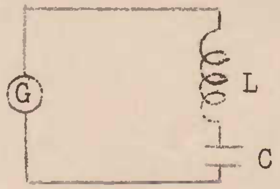
IMPEDANCE CURVE OF HALF-WAVE DIPOLE. FIG. 8.

COMPARISON WITH SERIES FED AND PARALLEL FED RESONANT CIRCUITS.

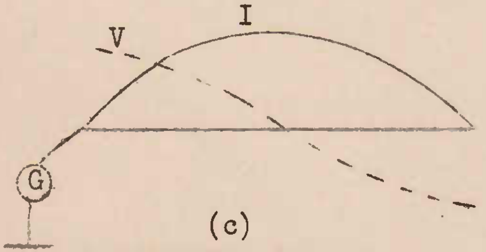
If the source of alternating e.m.f, i.e. generator or transmitter, is inserted in the centre of the dipole, the latter is said to be "centre-fed". This method is illustrated at (a) in Figure 9.



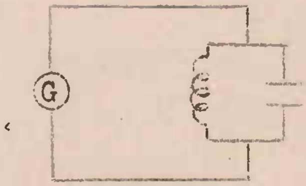
(a)
Centre Fed Dipole.



(b)
Series Fed Resonant Circuit



(c)
End-Fed Dipole.



(d)
Parallel-Fed Resonant Circuit

FIGURE 9.

Here the antenna may be strongly excited by a low-voltage generator, but the current delivered by the latter will be large. The impedance presented to the generator will be zero (or at least small). The conditions obtaining in this case may be compared with those of an ordinary series resonant circuit shown at (b) where the impedance presented to the generator is (in the ideal case i.e. no circuit losses) zero, the current through the generator is large, but the voltage across it is very small.

A very different state of affairs exists if the dipole is end-fed as shown at (c). Here one terminal of the generator is connected to one end of the aerial, the other terminal being earthed. (Note :- the internal impedance of the generator should be large, otherwise the normally large A.C. voltage at the end of the dipole will be grounded, and the normal mode of oscillation of the antenna will be completely modified).

In this case the impedance presented to the generator by the antenna is very large (theoretically infinite). For efficient excitation of the antenna the generator must be of high voltage, but it will be called upon to deliver only a small current, as will be seen from the current and voltage curves. When end-fed the dipole behaves as a parallel tuned circuit (see (d)) where the impedance is high, and the generator current small.

RADIATION RESISTANCE OF AN ANTENNA.

So far we have considered only the properties of inductance and capacity of the aerial conductor. The latter will, of course, also possess resistance. The D. C. resistance is normally negligibly small, but working at the ultra-high frequencies, due to skin-effect, dielectric losses etc. it might amount to several ohms. Even so, this r.f. resistance certainly would never exceed about 10 ohms. Yet we find that the impedance measured at the centre of the dipole (which is theoretically zero if resistance effects are neglected) is in practice around about 80 ohms. Whence comes this extra resistance?

It must be remembered that resistance in a circuit results in the loss of electrical energy in the form of heat energy. Conversely any loss of electrical energy in the form of heat (for example in nearby dielectrics) or other energy losses, causes an increase in the effective resistance of the circuit. Now a transmitting antenna is continuously losing energy in a special way, namely in the form of the radiant energy of the outgoing wave. This continual outpouring or loss, of energy gives rise to an increase in the effective resistance of the antenna. This extra resistance, due to radiation, is known as the Radiation Resistance of the antenna. The radiation resistance of all half-wave resonant dipoles is 73 ohms. Remember this figure.

If the centre-fed half-wave dipole is compared with a series resonant circuit, see Figure 9 (a) and (b), the effect of the radiation resistance will be apparent. If a resistance of 73 ohms were placed in series with the inductance and capacity of the circuit shown at (b) Figure 9. the impedance presented to the generator would be increased from zero to 73 ohms. Similarly the effect of the 73 ohms radiation resistance will be to increase the impedance of the dipole at its central point by this amount. Actually, in practice, the central-point resistance of a dipole is usually taken at about 80 ohms, the extra 7 ohms allowing for ordinary radio-frequency resistance losses.

To understand the effect of the 73 ohms radiation resistance upon the impedance offered by the dipole to the generator when "end-fed" consider the case of the parallel tuned circuit of (d) Figure 9. When the tuned circuit contained no resistance, the impedance measured across it was infinite. If a resistance were inserted in either arm (L or C) of the circuit the result would be to lower the impedance presented to the generator. Similarly the effect of the 73 ohms radiation resistance of the dipole is to lower the end-point impedance from an infinite value to a much lower value. The impedance of a dipole, measured at either end is found to be about 2,000 ohms. Note, however, that this impedance is still much higher than that measured at the centre (80 ohms).

THE "ELECTRICAL LENGTH" OF AN ANTENNA.

In an earlier section of the lesson it was pointed out that a half-wave dipole of given length had a particular frequency at which it would resonate. It was therefore stated that this resonant frequency corresponded to a wavelength approximately double the length of the antenna. In other words the antenna's length is approximately one-half the wavelength of the radiated wave when excited at its resonant frequency.

The reason for this inter-relation of wavelength with physical length of the aerial may now be roughly visualised by reference to the current and voltage distribution curves of figure 7. These curves may be regarded as representing "standing" waves (of current and voltage respectively) upon the wire. The idea of "standing" waves, as distinct from "travelling" waves along a conductor, or radiant, waves in space will be elaborated upon in more detail at a later stage in the lesson, under the heading of transmission lines. At the moment, however, it is sufficient to note that "the standing-wave" (of frequency equal to the resonant frequency of the aerial) gives rise to the electro-magnetic wave radiated into space. Furthermore, as the curves of Figure 7 show, exactly one-half a complete standing wave exists upon the antenna. Consequently the wavelength of these standing waves, and therefore the wavelength of the radiation is twice the length of the wire.

In explaining the current distribution in such an aerial it was assumed that the latter was completely isolated in space. In practice, however, the aerial is in more or less close proximity to surrounding objects. The small capacity effects which exist between such objects and the wire itself modify the form of the standing wave of current, and result in the antenna acting as though it were roughly 5% longer than its actual length. In other words, if the wavelength of the radiation from a half-wave dipole is measured, and the figure divided by 2, the result, instead of corresponding exactly with the length of the wire, will be approximately 5% greater than the latter.

The length $\frac{\text{Wavelength at resonance}}{2}$ is called the "Electrical Length" of the antenna. Summarising, we may state that the "physical" (or actual) length of a dipole is approximately 95% of the "electrical" length. In calculating wavelength and frequency (at resonance), therefore, 5% must be added to the measured length of the wire before applying the calculations illustrated at an earlier point in the lesson.

DIRECTIONAL PROPERTIES OF A HALF-WAVE DIPOLE.

An antenna of this type does not radiate (or receive) equally well in all directions. Referring, at the moment, to a transmitting aerial, the dipole radiates most strongly in directions perpendicular to its length. The radiation in directions parallel to its length is practically zero.

These directional properties of an antenna may best be illustrated by means of a "Polar" Diagram. Such a diagram shows at a glance the <u>relative</u> intensities of the radiated wave (or the received signal) for all directions around the aerial.

The Polar diagram for a half-wave aerial is shown in Figure 10. The diagram takes the form of two circular "lobes", forming an idealised "figure-of eight". Here AB represents the aerial. The signal strength radiated in any given direction is proportional to the length of the line drawn from the point (o) in that direction to the boundary of the polar diagram. For example the radiations in the directions OC and OD (perpendicular to the wire) are proportional to OC and OD, which are equal and are a maximum. The signal strength in the direction OE is proportional to the length of OE which is approximately one-half of OC. Hence the signal radiated in the direction OE will be one-half the strength of that radiated in the direction OC (or OD). Note that the strength of the waves radiated in the directions OB or OA is zero.

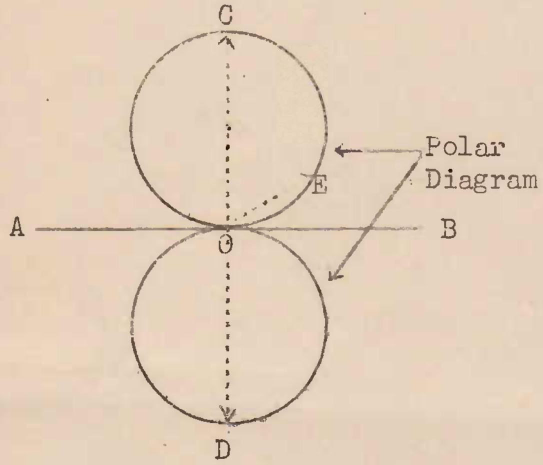


FIGURE 10.

Assuming that the antenna AB of Figure 10 is placed horizontally, (i.e. parallel to the ground,) the polar diagram drawn is described as a "horizontal" polar diagram. If it is imagined that one is observing the antenna from above, i.e. looking <u>down</u> upon it, then the diagram shows the relative signal strengths for all directions taken in a horizontal plane.

If now the antenna, while still placed horizontally, is viewed "end-on" as shown in Figure 11, the relative signal strengths observed in all directions measured outwards from the aerial, in the plane of the paper will be <u>equal</u>. The polar diagram will therefore be simply a circle. This is the "vertical" polar diagram, because the plane taken is perpendicular to the ground. Actually the circular diagram would only be observed if the antenna were well <u>above</u> the ground. When placed horizontally and close to the earth the radiation from a dipole is greatly modified by reflection from the ground of those waves radiated in a downward direction.

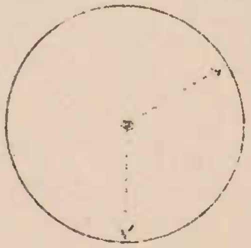


FIGURE 11.
VERTICAL POLAR DIAGRAM
(HORIZONTAL DIPOLE.

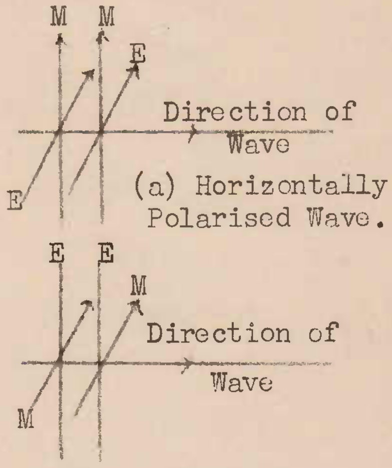
POLARISATION OF THE WAVE.

The "Polarisation" of a wave is determined by the arrangement of the transmitting antenna, and depends upon whether the electric field of the radiation is parallel to the earth (horizontal) or perpendicular to it (vertical).

The nature of an electro-magnetic (radio) wave should be recalled. It consists of two alternating fields -- an electrostatic field and a magnetic field. The lines of force of the electric field are at right angles to those of the magnetic field, Both fields move through space (with the speed of light), in a direction which is perpendicular to both the electric and the magnetic lines of force.

A vertically placed dipole will radiate a wave having the electric field in a vertical plane, and the magnetic field in a horizontal plane. This is called a vertically polarised wave. In the case of a horizontally placed dipole, on the other hand, a horizontally polarised wave is radiated. The electric field will now be in a horizontal plane, with the magnetic field in a vertical plane. Both types of polarised waves are illustrated in Figure 12.

The nature of the polarisation of the wave radiated from a television transmitter is of utmost importance when considering the erection of the receiving antenna. If vertical polaristion is in use, i.e. if the transmitter's radiating conductor or conductors are vertical, the receiver's dipole must also be placed vertically. Conversely for horizontal polarisation and a **receiving** dipole placed parallel to the ground is required.



(a) Horizontally Polarised Wave.

(b) Vertically Polarised Wave.

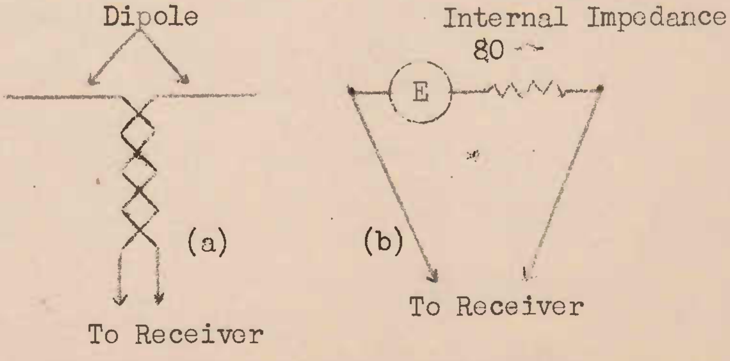
E = electrical field
M = magnetic field.

FIGURE 12.

THE RECIPROCAL RELATIONSHIP BETWEEN A TRANSMITTING AND RECEIVING AERIAL.

Both theory and practice show that, whatever property an antenna exhibits when used for transmitting purposes, then the same property is exhibited in a reciprocal, or inverse, manner, when the aerial is used for reception. For example it has been seen that the half-wave transmitting dipole presents, at its centre, an impedance of about 80 ohms to the exciting generator, this impedance being due mainly to radiation resistance. The aerial was found to act as a series resonant circuit, containing 80 ohms series resistance. Now, when used for reception purposes the aerial acts as a source of e.m.f. ("e"), (which e.m.f. is induced in it by the "received" wave), for application to the receiver. The antenna, still acts as though it possessed an impedance of 80 ohms at its centre. The receiving aerial may now be regarded as a "generator" of "internal impedance" 80 ohms, as illustrated in Figure 13.

As a further example of this reciprocal property, we may cite the case of the antenna's directional characteristics. The polar diagrams of Figure 10 and 11 apply equally well when the aerial is used for reception as it does when used as a radiator. That is, maximum signal strength is received for waves arriving from directions CO and DO (perpendicular to aerial) and zero strength from directions AO and BO ("End-on"). Thus a horizontal television receiving dipole should be placed at right angles to the direction from which the signals will arrive from the transmitter.



Receiving Dipole (a) & its Equivalent Circuit (b).

FIGURE 13.

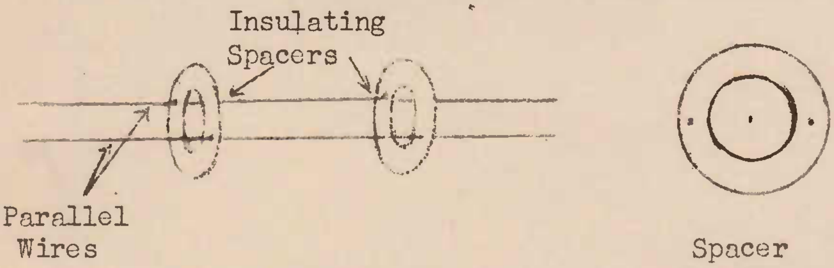
TRANSMISSION LINES.

Transmission lines are used, as far as television is concerned, for transferring r.f. energy from the transmitter to the antenna or from the antenna to the receiver. In both cases the line most be carefully designed and adjusted, if efficient operation is to be ensured. In the case of ordinary broadcast radio reception the receiver is usually fed from the aerial by means of a single wire, known as the "lead-in", possessing no particular electrical properties. In the case, however, of television reception, operating with a resonant aerial, such a casual arrangement would prove quite inefficient. Improper design or adjustment of this important unit of the reception system would result, not only in loss of sensitivity, but even more importantly, in serious distortion of the received image.

PHYSICAL CONSTRUCTION OF A TRANSMISSION LINE.

There are several types of transmission lines in use. These, though differing considerably in physical construction, all possess similar electrical properties.

The first type is that known as the parallel -- or twin-wire. This consists, usually, of a pair of parallel wires, of fairly heavy gauge (e.g. 14 S.W.G.), separated and held in place by "spacers" of insulating material placed at regular intervals, as shown in Figure 14. The spacers may be circular, as shown or simply flat strips of insulating material to hold the wires the required distance apart and parallel to one another.



Spacer End-View

FIGURE 14.

A second, and very common type of transmission line in television receiver installations is that known as the "twisted-pair", consisting of two rubber covered wires twisted together an enclosed by a covering of cotton braid or other material similar to ordinary power flex.

A third type, used mainly in transmitting equipment, is the "coaxial" or concentric line, illustration in Figure 15. Here one conductor, in the form of a wire, is run centrally through the other conductor, the latter consisting of a cylindrical tube. The two are separated by means of low-loss insulating material.

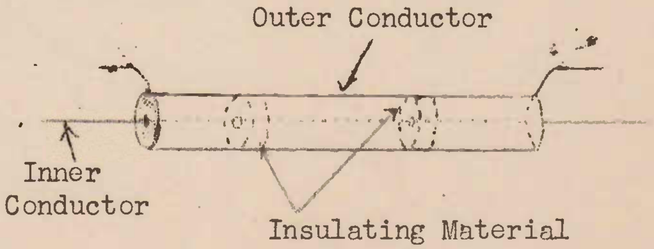


FIGURE 15.

ELECTRICAL PROPERTIES OF TRANSMISSION LINES.

In order to explain the operation of transmission lines a simple twin parallel wire line will be considered. It will be understood, however, that the following explanation will unless otherwise stated, refer to all types of line.

ELECTRICAL WAVES ALONG A LINE.

Suppose we have a line consisting of a pair of 12 S.W.G. wires mounted upon poles, as shown in Figure 16, and extending away an infinite distance. The near end of this transmission line is shown leading into a building which is supposed to contain a radio-frequency generator or oscillator feeding the line with an alternating voltage of constant amplitude. The R.F. generator is provided with a vacuum tube voltmeter to measure the sending potential, and a thermo-ammeter indicating the current passing into the line, as shown in Figure 17.

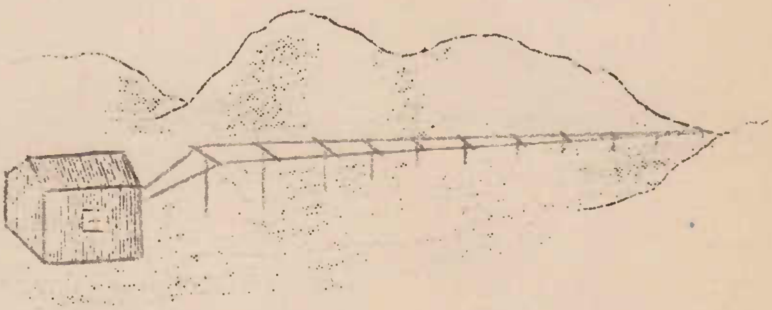


FIGURE 16.

Now suppose the voltmeter reads 600 V (R.M.S.) and the ammeter 1A (R.M.S.). When the output is connected (by means of the double pole-double throw switch shown) to an unkown resistor R. The value of this resistor must by, by Ohm's Law, $R = \frac{E}{I} = \frac{600}{1} =$ 600 ohms. Further suppose that the test engineer, by throwing the switch applies the output to the line, and the meters register the same readings as before, Viz: 600V and 1A. It is obvious that the line must present an impedance to the generator exactly equal to the resistance of the resistor, that is 600V.

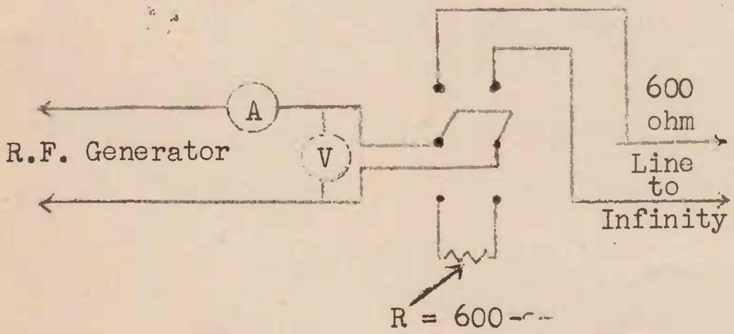


FIGURE 17.

There is one important difference, however, between the case of the resistor and that of the line. The energy output from the generator when connected to the resistor is being all dissipated in the latter (in the form of heat). The transmission line possesses comparatively little resistance, and therefore the energy from the generator is not immediately dissipated as heat, but must pass continuously along the line. This energy is transferred down the line in the form of electrical waves, which will, theoretically in this ideal case, travel for an infinite distance.

The nature of these "guided" waves, and the manner of energy transfer may be understood more clearly by reference to Figure 18 where the distributed self-inductance of the wires is indicated by small coils, and the capacities between small sections, or elements, of the adjacent wires are shown by small condensers. We may state the inductance and capacity per unit length (e.g. per foot) of the twin-wire line in micro-henrys and micro-farads or (micro-micro farads) respectively.

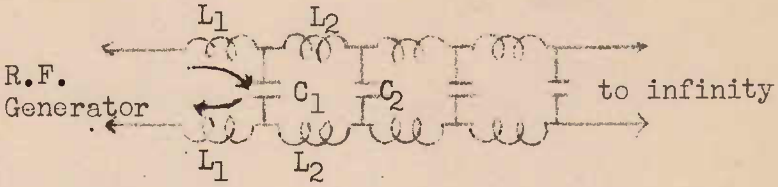


FIGURE 18.

If a potential is suppled to the input end of the line the first condenser C_1 will charge up through the first set of inductances L_1 until the voltage across its plates equals that of the generator. C_1 then discharges through L_2, charging C_2, which in turn discharges through the next set of inductances to the next capacity and so on. In this way each part of the line is, in turn, subjected to voltage and current surges, which passes down the line with a velocity equal to a radio wave in space, viz: 186,000 miles per second.

In actual practice, of course, the inductance capacity effects of the line are not "lumped" as illustrated in Figure 18, but are evenly distribued over its whole length.

If the line is fed by a generator supplying continuous r.f. voltage, the "wave" motion will also be continuous, each capacity being, in turn subject to a continuous charge and discharge of an alternating character.

An important point to notice is that the currents in the two wires at any given point on the line will, at any given instant, be in opposite directions. Consider, for example the case where C_1 (Figure 18) is charging through the two halves of L_1. The direction of the charging current is shown in the diagram, and it is clearly seen that the current in the upper wire is opposite to that in the lower wire. Of course a fraction of a second later, during the next half-cycle of the r.f. voltage, both currents will reverse, as C_1 charges in the other sense.

The fact that the currents in opposite wires are opposed to each other at all points of the line, means that there is very little electro-magnetic (radio) wave radiated into space from it. The reason for the latter statement is that the electric and magnetic fields produced by the current in one wire will be practically cancelled by the opposing fields set up by the current in the other wire. This desirable condition will only be realised, of course, if the spacing between the wires is comparatively small (small, that is compared with the length of the wave).

THE CHARACTERISTIC OR SURGE-IMPEDANCE OF A TRANSMISSION LINE.

We have seen in connection with Figure 17 that a given line of infinite length will present a characteristic impedance to a generator connected to it. In the case cited this was 600 ohms when the line consisted of twin-wires of 12 S.W.G. separated by 8". If either the thickness of the conductors (i.e. the gauge of the wires), or the spacing between them, or both, were altered it would be found that this impedance would have a different value. It appears, then, that a line constructed with a given gauge of wire, and a given spacing will have a "characteristic" impedance. This characteristic impedance is sometimes called the "surge" impedance of the line. It should be noted that a line presents its characteristic impedance to alternating voltages of all frequencies. In other words the line show no resonant effect. The only stipulation we have made is that the line in each case, is regarded as of infinite length, or at least, in a practical case, of very great length compared with a wavelength. A little later we shall see how this stipulation may be modified.

Factors Controlling the Characteristic Impedance of a Line.

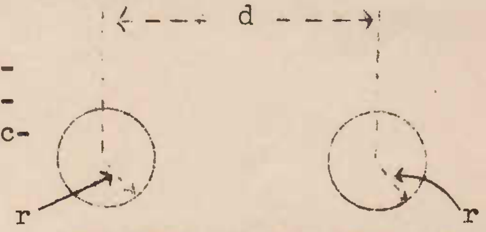
As stated above the characteristic impedance, which we shall henceforth designate by Zo depends only on the thickness of the conductors and the spacing of the wires. It is obvious that these factors will determine the distributed inductance and capacity per unit of length of the line.

If the spacing of the wire is increased Zo will be increased, (but not proportionately) and vice versa. If the thickness of the wire, on the other hand, is increased, Zo is decreased, and vice versa. For the sake of those students who are familiar with logarithms, the following formula for Zo is given:-

$$Zo = 276 \log \left(\frac{d}{r}\right) \text{ Ohms.}$$

Where d = spacing between conductors, r = radius of each conductor, (see Fig.19).

In any actual case "d" may be measured directly, and "r" may be obtained, for any given gauge, by referring to standard wire tables.



END VIEW OF TWIN-WIRE LINE.
FIGURE 19.

In the case of a coaxial or concentric line, Zo depends upon the inner radius of the outer tube or cylinder, and upon the outer radius of the inner conductor or tube. The formula is:-

$$Zo = 138 \log \left(\frac{r_2}{r_1}\right) \text{ Ohms.}$$

Where r_2 = inner radius of outer conductor
r_1 = outer radius of inner conductor.
(See figure 20)

In the case of the "twisted-pair" type of line, the Zo is not easily calculated, for the spacing between the wires is not uniform. In this case, however, the characteristic impedance may be taken as in the vicinity of 80 - 140 ohms.

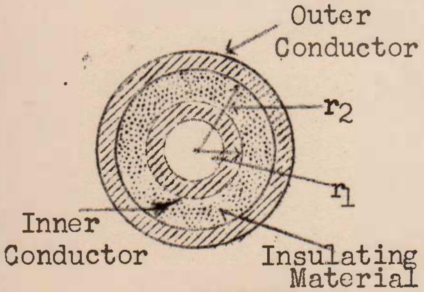


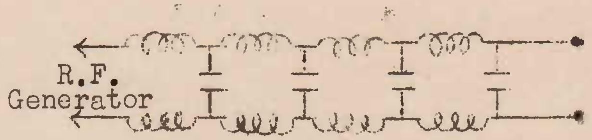
FIGURE 20.

For comparison purposes the Zo of the parallel twin-wire type is usually found to be in the range 200 - 600 ohms. It is difficult to reduce Zo below 200 ohms in this type, because the spacing between the wires becomes too small for practical convenience. For the coaxial type, Zo is, in practice, usually found to be in the vicinity of 70 ohms.

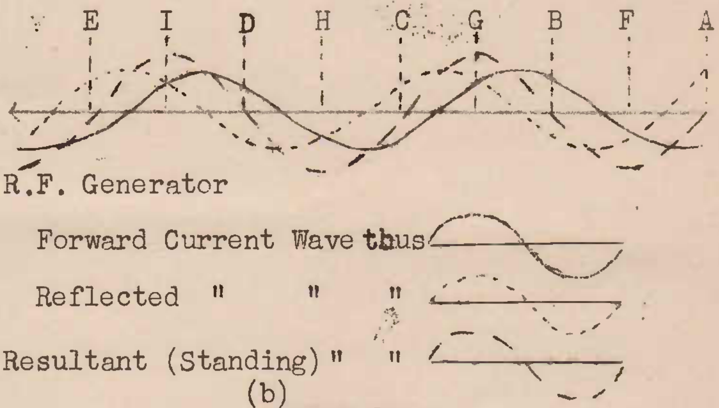
TRANSMISSION LINE OF FINITE LENGTH-LOAD MATCHING.

In considering the operation of the transmission line earlier, the line was considered to be of infinite length, so that the energy from the generator could pass down the line continuously in one direction. This energy transfer was considered as a wave motion of current and voltage. Its transmission was seen to be due to each "elementary" condenser becoming charged through the inductance of the corresponding "element" of the line, and then discharging through the inductance of the next adjacent element of the line. In this way the capacities of succeeding sections progressively become charged, at the speed of an electromagnetic wave, viz: 186,000 miles/second.

Suppose now we consider the case of a piece of transmission line of definite length, open-circuited at the end remote from the generator. Such a line is represented as consisting of small inductance and capacity effects in Figure 21 at (a). When the generator is switched on, a wave passed down the line from left to right, as described; the final condenser becoming charged up. This condenser cannot pass its charge further to the right on account of the open-circuit. In discharging, therefore, it sends a current back along the line. In this way a wave is initiated from the right-hand end of the line, and travels back as a reflected wave. We now have two waves, one passing from generator to the right and the other (reflected wave) in the opposite direction.



Open-Circuited Finite Line.
(a)



(b)
FIGURE 21.

The net A.C. current and voltage at the sending terminals may be greatly modified, due to the reflected wave either adding to (if in phase) or substracting from (if out of phase) the initial generator voltage and current. The result is that the ratio of $\frac{E}{I}$ at the generator, and therefore the impedance presented to the latter, may be considerably different from the characteristic impedance of the line, as measured when the line is of infinite length.

Another important effect caused by the reflected wave is that, if the current is measured at different points along the line, at some points it will be very large, and at other points it will be zero! (or at least very small). This is due to the reflected wave reinforcing the forward wave at certain points, and cancelling it at others. The forward current wave, the reflected current wave, and the resultant (or net) current wave are illustrated at (b) in Figure 21 (b). The waves are shown for one wire only. Those on the other wire will be similar but opposite in phase. The important thing to notice is that at certain points (A,B,C,D and E) on the line the current is always zero, due to the forward and backward waves always cancelling at these points. Ammeters inserted at A, B, C, D, and E would never show any reading of current. Meters inserted at points F, G, H, I, on the other hand would record maximum readings, because the forward and reflected waves reinforce each other at these points. The resultant wave obtained is called a Standing Wave.

The idea of standing waves may be illustrated by citing the case of a wave motion along a rope. Imagine a boy shaking the end of a rope which extends to infinity, as in Figure 22 at (a). A wave motion will travel continuously down the rope from left to right. All points of the rope will be affected by the motion. This is a travelling wave, and is analogous to the case of the infinite transmission line. Now consider a finite length of rope tied to a wall as at (b). If the rope is continuously shaken a standing wave will be created, whereby certain points on the rope (A,B,C) will remain (comparatively) at rest. Other points, (D,E, F) will be in a state of continuous oscillation or agitation. The motions of the points B and C due to the forward wave are cancelled by the wave reflected from the wall, at all instants.

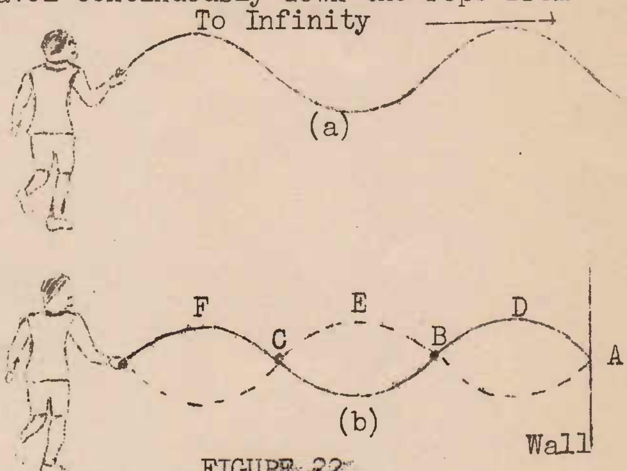


FIGURE 22.

The above description is for the case of an open-circuited line. If the line is short-circuited as in Figure 23 a reflected wave will also be found, resulting in the formation of standing-waves as before.

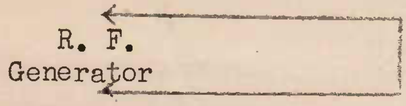


FIGURE 23.

MATCHING A LINE TO A LOAD.

Consider now an infinite line of characteristic impedance Zo, fed by an R.F. generator (Fig 24 (a)). The actual impedance experienced or "seen" by the generator will be Zo. Imagine a wave reaching the point A on the line. This wave will "see" ahead of it an impedance of Zo (for the line is still of infinite length measured from A). Suppose now the same line is broken at A, and the remainder of it replaced by a resistor of value Zo, as shown at (b) Figure 24. The wave on reaching A will still "see" an impedance of Zo. (viz: the resistance Zo of RL) as if the remainder of the line extending to infinity were still there. Hence the energy of the wave will pass into the resistance, without reflection. As far as the generator is concerned the line in case (b) will appear exactly as at (a), i.e. of infinite length. Therefore the actual impedance "seen" by the generator will be the characteristic impedance of the line.

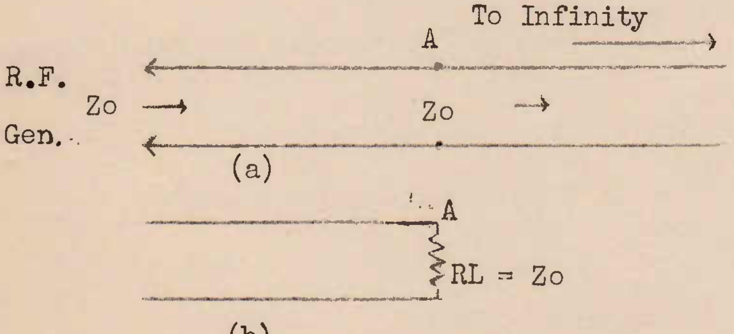


FIGURE 24.

The reason no reflection occurs at A is that the resistance of RL (= Zo) is just right for the normal discharge of the capcity of the last element of the line preceeding the point A. The result is that the wave will therefore proceed to the right as in the case of the infinite line at (a). Where the line is terminated by resistance equal to Zo, however, the energy of the wave, instead of travelling on forever, is quickly dissipated in the form of heat in RL. This is just what we require. All the energy passed into the line by the generator, travels down the line and is received by the load.

If RL is greater or less than Zo, reflected waves will be set up. The strength of these reflected waves will depend upon the amount of mis-matching. The reflected wave will reinforce the forward wave at certain points, and oppose it at others, resulting in the formation of standing waves. If a meter is moved along the line points of minimum current and others of maximum current will be found. The current will never by zero, however, as in the case of an open-circuited or short-circuited line, because the reflected wave will be weaker than the forward, so that complete cancellation can never occur. The ratio:-

$$\frac{\text{Max. current at points of reinforcement.}}{\text{Min. current at points of cancellation.}}$$

is called the "standing-wave ratio".

This ratio may be measured in practice and is an indication of the amount of mis-matching. If the standing wave ratio is 1 it indicates that the current is the same for all points on the line. This means no reflected wave is sent back by the load, and the line is correctly matched (Rl = Zo).

The current (or voltage) at different points along the line may be observed in practice by using one of the devices as shown in Figure 25. These are called Standing Wave indicators. The indication may be moved along the line, maximum and minimum readings being noted. No variation in reading as the indication is moved down the line indicates correct load matching.

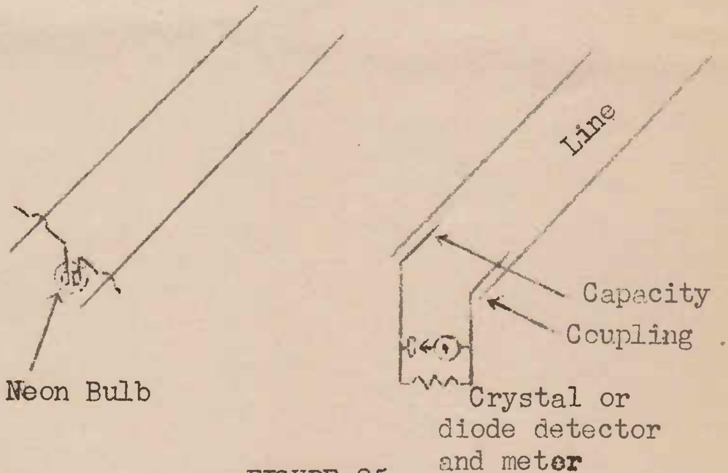


FIGURE 25.

LOAD MATCHING OF A TRANSMISSION LINE AT THE SENDING END.

It is a well known fact that if an A.C. generator is to deliver maximum power into a load, then the load impedance must equal the internal impedance of the generator. In the case of a transmission line, therefore, it is important to ensure correct load matching at the "sending" end as well as at the receiving end. The load imposed on the generator is, of course, the characteristic impedance (Zo) of the line (assuming the line is correctly terminated by an impedance of value Zo). For correct matching at the sending-end, therefore, the internal impedance of the latter should equal Zo ohms. Mis-matching at the sending end will mean that the maximum amount of power is not accepted by the line, and passed by it to the final "load" at the receiving end. An important (undesirable) effect occurs if both ends are incorrectly matched. The energy of a wave reaching B (Figure 26) is partially absorbed by the load RL. The rest of the energy is reflected from B back along the line to A, where some of the reflected energy is again reflected down the line. In this way a reflected wave may pass backwards and forwards along the line until it is all absorbed partly by RL and Ri (internal impedance of generator) and partly by the losses of the line itself. Such a state of affairs means that of the total energy fed into the line at A at any given moment only a fraction will be received in the load RL when the wave first passes the length of the line. A small interval of time later, after the reflected wave has had time to pass back along the line and down again, RL will receive a little more of this energy, and so on. This effect as explained later causes serious distortion in the case of a transmission line coupling a receiving aerial to a television receiver.

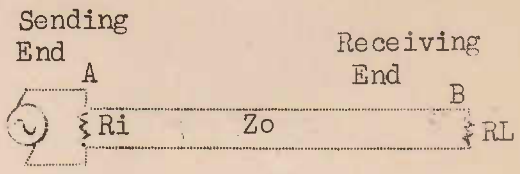
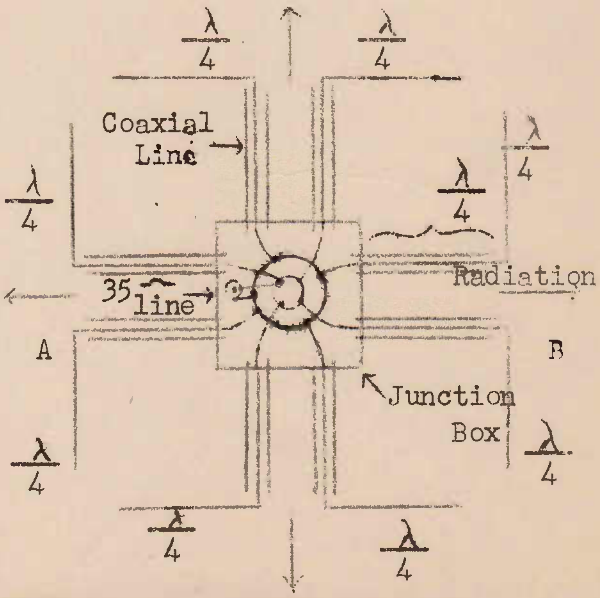


FIGURE 26.

TRANSMISSION ANTENNAE.

In the problem of transmission of television signals there are two important considerations to be dealt with. The first concerns the directivity of the radiation. It is desirable to direct as large a proportion as possible of the radiated energy towards the area of population to be covered, and to prevent radiation in the direction of the sky, where it serves no useful purpose. If vertical polarisation is used, a single dipole has desirable properties, in that it radiates no energy vertically upwards, and a maximum of energy in the direction of the horizon. On the other hand it radiates equally well in all horizontal directions, and cannot be used, therefore, to concentrate the horizontal radiation towards a particular city. If horizontal polarisation is used, the dipole radiates no energy in the horizontal line which coincides with the length of the dipole, and maximum energy in a direction perpendicular to that line, both horizontally and vertically upwards. Hence, by placing the dipole broadside on to the direction of the area of population, maximum signal strength will be directed there. The sky-ward radiation, however, is wasted in this case, but it may be suppressed by employing special multi-element radiators.

A system of "crossed" dipoles, designed for more or less uniform radiation in all horizontal directions, but which suppresses sky-ward radiation, is shown when viewed from above, in Figure 27. Here 4 dipoles forming the sides of a square are fed from a central "junction box", via short-lengths of coaxial cable. The dipoles are fed so that the current in any one is of opposite phase to the current in its opposite fellow. If a point in space above the system be considered, the wave arriving from any dipole will be cancelled by the equal and oppositely phased wave from the opposite dipole. Note that such a point in space is equidistant from all the dipoles, so that out-of-phase waves setting out from a pair of dipoles will still be out of phase when they reach the given point. This means that the net radiation upwards is zero. In other words the vertically radiated wave is entirely suppressed.



TELEVISION TRANSMITTER RADIATOR - "CROSSED" DIPOLES AND COAXIAL LINES. HORIZONTALLY POLARISED WAVE. FIG. 27.

In the case of a wave radiated horizontally the situation is different. Consider a point in the same horizontal plane as the dipoles, say to the right of them. At any instant the waves radiated by dipoles A and B are 180° out of phase. A fraction of a second later the wave radiated to the right by dipole A will have reached dipole B. Now the distance between the dipoles is exactly one-half a wavelength. Hence in this time the wave from A will have changed its phase by an amount equal to $\frac{1}{2}$ wavelength, i.e. 180°. The result is that the wave radiated from A at the <u>original instant</u> will be exactly in phase with the radiation from A <u>as it passes the latter dipole</u>. This means that the two waves will reinforce each other at all points to the right of A. Figure 28 will show clearly how this additive effect occurs. Here the plane of the paper is supposed to represent a vertical plane, the dipoles being viewed "end-on".

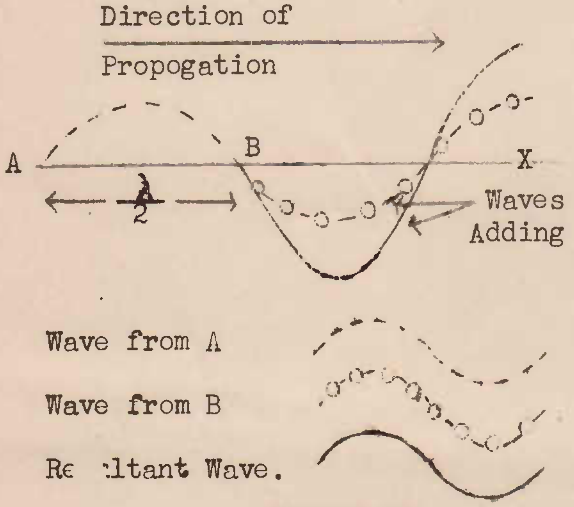
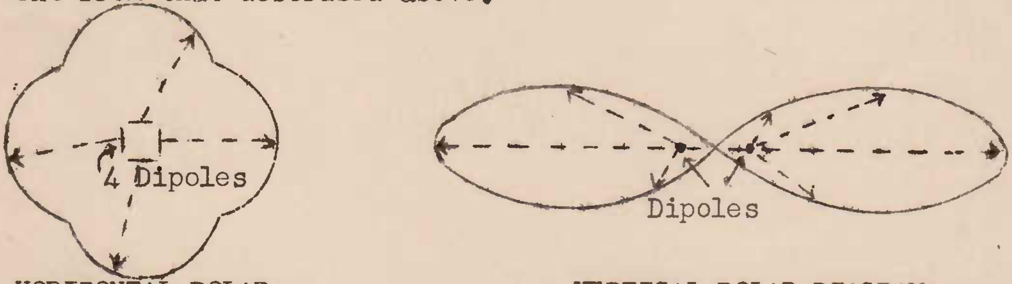


FIGURE 28.

Figure 29 shows the horizontal polar diagram of the system at (a). Note that radiation is roughly uniform in all horizontal directions. Such a radiator would be used when the transmitter is situated near the centre of a populated area to be covered. At (b) is shown the vertical polar diagram. Note that the energy is concentrated into a horizontal radiation pattern, the skyward wave being reduced to a minimum.

The dipoles of this type of radiator are sometimes curved, so that the four of them form the circumference of a circle. The appearance of such an arrangement is shown by the upper radiator on the mast depicted in Figure 30. Actually in this figure the electrical arrangement is that known as the "folded" dipole system, which is somewhat different from that described above.



HORIZONTAL POLAR DIAGRAM.
(a)

VERTICAL POLAR DIAGRAM.
(b)

FIGURE 29.

The second problem to be considered in transmitting antennae concerns the antenna impedance over the frequency band of the transmission. This band, as we have seen in an earlier lesson is usually wide; up to 6 mc./sec. for the video carrier. As explained in this lesson a dipole is resonant at one frequency only, when its impedance (measured at the centre of the radiator) is a minimum and purely resistive. At frequencies on either side of this resonant frequency the impedance rises and becomes partly reactive. In this respect the dipole behaves exactly like a series resonant circuit. If the sidebands are not to be appreciably weakened or distorted this de-tuning effect must be made negligible over the width of the transmission channel. The problem is solved in practice by heavily "loading" the radiator elements with resistors, and by special shaping of them. The lower radiator of Figure 30 shows one system. Here four radiators protrude from a curved collar-like conductor. The radiators themselves, instead of being simple straight conductors, are of an ellipsoidal shape. In the figure the upper radiation (previously referred to) is used for sound transmission (ultra-high frequency F.M.), while the lower, just described, is used for the picture transmission.

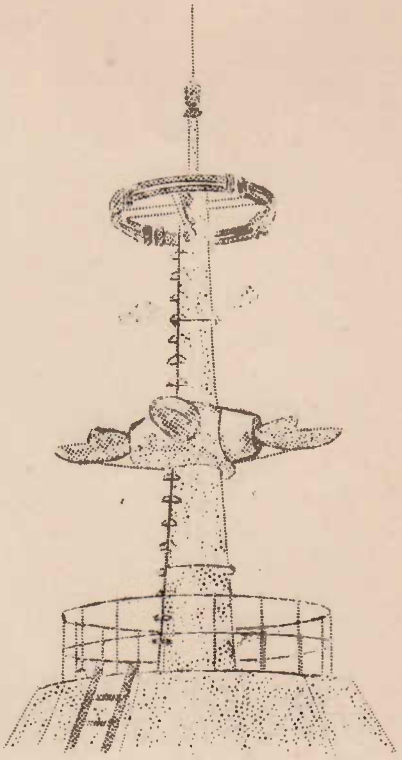


FIGURE 30.
TELEVISION TRANSMITTING ANTENNAE.

RECEIVING ANTENNAE.

The antenna system of a television receiver requires to be much more critical than that of a broadcast receiver. This applies equally as much to the lead-in arrangement as it does to the actual aerial itself.

In the first place it should be made clear that usual practice is to use a single receiving aerial for both the picture signal and the sound. The two signals, lying in adjacent frequency channels, are "sorted out" in the early stages of the receiver.

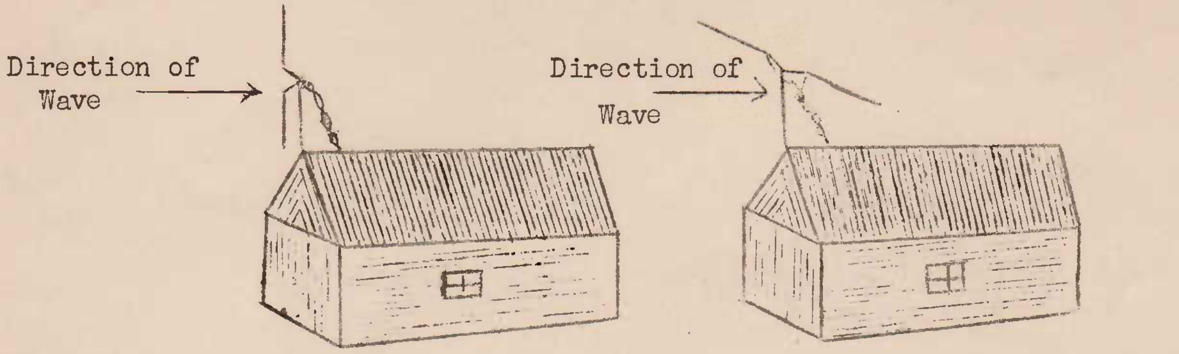
Television receiving antennae are usually of the simple dipole type. Sometimes special arrangements of several dipoles (multi-element "arrays") are used, when special directional properties are desired.
In erecting an antenna the first point to consider is the polarisation characteristics of the transmitted wave. In England vertical polarisation has been in favour, and in this case the receiver dipole must be placed so that its length is perpendicular to the ground. If the wave is horizontally polarised, as in America the dipole is erected parallel with the ground.

Secondly, the direction from which the signal arrives must be considered. Remember the dipole has directional properties such that maximum signal strength is absorbed when the dipole length is at right-angles to the direction of the wave. In other words, the dipole must be placed "broadside-on" to the line joining transmitter to receiver. If it is desired to operate upon more than one transmission, a compromise must be decided upon in this respect.

Figure 31 shows the necessary orientation of antennae for vertically polarised wave at (a) and horizontally polarised wave at (b).

DISTORTION DUE TO REFLECTIONS.

Ultra-high frequency waves are particularly susceptible to reflection from large objects such as city buildings. In this way waves from a transmitter may arrive at a receiver from different directions, and having covered paths of different lengths. Figure 32 shows a receiver antenna R receiving a "direct" wave from the transmitter T along the path TR. A wave is also received having travelled the path



Reception of Vertically Polarised Wave.
(b)

Reception of Horizontally Polarised Wave.
(a)

FIGURE 31.

TOR, due to reflection from the building B. The effect is to produce a blurred image on the receiver screen due to the reproduction, twice, of each picture element. The reproduction of a particular picture element due to the reflected wave will not appear on the screen in exactly the same spot as that produced by the direct wave. To understand this remember that the picture elements are superimposed on the r.f. wave in succession, and in the form of modulation. Now imagine that at the present moment a particular picture element appears as modulation on the wave just leaving T. This picture element will be reproduced on the receiver screen a short time later -- the time the direct wave takes to pass directly from T to R. The same picture element will be reproduced a second time -- a little later still -- by the wave travelling the route TOR. This path is longer than TR, and hence the time taken will be longer. The result will be that two identical picture elements will appear on the screen side by side, since the scanning beam is continuously moving, at high velocity, over the screen. A blurred image will result.

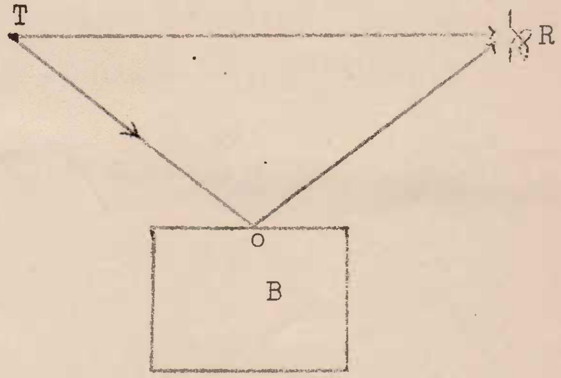


FIGURE 32.

Such reflections can be discriminated against by turning the dipole until it is more ore less end-on to the direction from which the reflected wave is arriving. Of course this may involve orientating the dipole so that it is not square-on to the direct wave, with a resultant loss in signal strength. In practice a compromise in this respect must be effected.

LENGTH OF RECEIVER DIPOLE.

As previously discussed, the dipole, to be resonant, must have an electrical length equal to one-half of the wavelength of the desired signal. (Remember that the physical length is only about 95% of the electrical length). If a single transmission only is to be considered the problem, then, is simple. Suppose, however, a number of stations, with a frequency band of, say, 44 mc/sec. to 108 mc/sec. are to be received. Once again a compromise must be resorted to. It is usual to design the antenna in this case so that it is resonant at a frequency known as the "<u>geometric centre</u>" of the range. This is calculated by multiplying the two extreme frequencies and taking the square root, thus:-

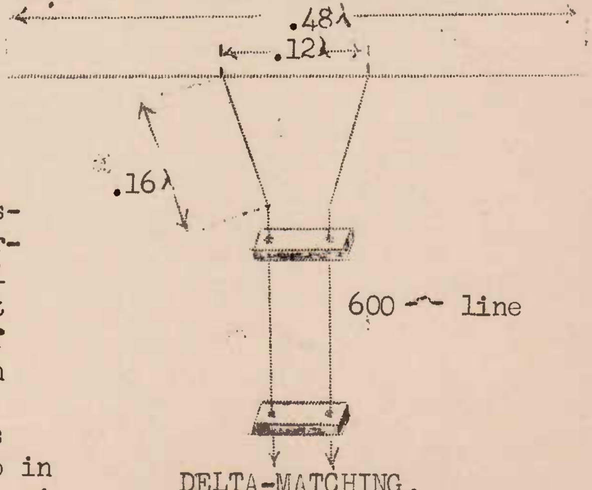
$$\text{geometric centre} = \sqrt{44 \text{ X } 108} = 70 \text{ mc/sec.}$$

The dipole is designed so that it is $\frac{1}{2}$ wave-length long at 70 mc/sec. A certain amount of de-tuning effect will be experienced for frequencies on either side of this, but since the losses in the antenna system are usually fairly heavy, the antenna, considered as a tuned circuit, is very <u>broadly</u> tuned, and it is found in practice that the band of frequencies can adequately be conered by a single aerial.

FEEDING THE SIGNAL FROM DIPOLE TO RECEIVER.

The "lead-in" is almost invariably a transmission line, properly "matched" at both ends. It should be noted that here the dipole itself may be regarded as an A.C. generator supplying the input to the line. The internal impedance of this "generator" is about 80 ohms (the "radiation" resistance and ordinary resistance of a dipole). Hence the line must be matched to this 80 ohms impedance, if maximum energy is to be transferred to it from the antenna. Again, if the receiver input (aerial circuit) is to absorb maximum energy from the line, <u>and if reflections in the line are to be avoided</u>, the load imposed upon the line by this input circuit must be equal to its characteristic impedance (Zo).

Transmission lines used in practice are of the parallel (twin) wire, coaxial cable, or twisted-pair types. The parallel-wire type usually has a higher impedance (Zo) (usually hundreds of ohms) and therefore requires special matching devices at the centre of the dipole (impedance 80 ohms). One matching method is that known as the Delta-match illustrated in Figure 33. The dipole is unbroken at the centre, and the transmission line is flared out, the dimensions being shown for a 600 ohm line. The theory of this matching method is rather complicated and will not be discussed in detail here.



DELTA-MATCHING.
(λ = 1 Wavelength)
FIGURE 33.

The effective load on the other end of the line must also be equal to its characteristic impedance -- 600 ohms in this case. The transformer effect is usually used for matching purposes here. The load imposed on the line will depend upon the natural impedance of the input circuit of the receiver and the turns ratio of the transformer. The arrangement is shown in Figure 34. Note that the centre point of the primary coil is grounded. The reason for this is to cause cancellation of any signal pick-up in the two wires of the transmission line. These signals will cancel out in the two halves of the primary coil, so that all signal fed to the receiver comes from that absorbed in the dipole itself. This precaution is called "balancing" the line.

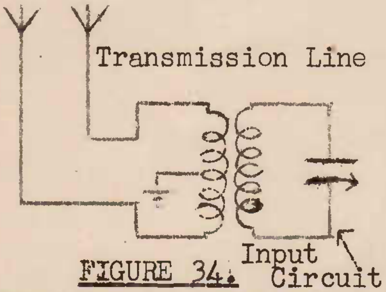


FIGURE 34.

The twisted-pair type line has a lower characteristic impedance -- usually 50 to 150 ohms -- so that direct coupling to the dipole (Z_o = 80 ohms) is in most cases satisfactory (See Fig. 35). The attenuation, due to r.f. losses, of the twisted-pair is, however, high. Although this results in loss of signal strength, the high attenuation is actually an advantage in damping out reflections, due to imperfect load matching, as discussed below. For these reasons the twisted-pair is usually to be favoured above all other types for ordinary household reception purposes.

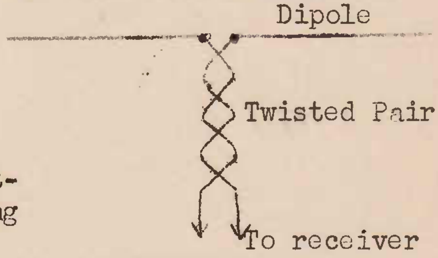


FIGURE 35.

DISTORTION DUE TO LINE REFLECTIONS.

If the transmission line from the dipole is not correctly matched at both ends, reflections, producing standing waves are set up, as previously discussed. These line reflections cause exactly the same type of screen distortion as occurs when the antenna receives a wave reflected from an object, as shown in Figure 32. If the line is not accurately matched to the load of the input circuit, a part of the energy, instead of being absorbed by the receiver, is reflected back along the line. If imperfect matching also occurs at the antenna end, the wave is again reflected towards the receiver. The reflected wave may pass back and forth several times along the line. Each time it strikes the receiver end, a part of it is passed to the receiver screen. In this way a picture element may be "laid down", at adjacent points, several times on the screen, with consequent blurring of the image. If the line is short, the time taken for the reflected wave to travel twice its length will be extremely short, and in this case, the distortion will be negligible, since the picture elements will fall practically on top of each other. If a long line is used, however, the distortion can be very serious.

The fault is largely avoided if a high loss twisted-pair line is used, because the reflected wave is virtually wiped out, by attenuation, in travelling the double-length of the line. Obviously, however, the best method of preventing the trouble is to design the antenna system, together with the receiver input circuit, so that correct matching at both ends of the line is obtained.

T. FM & F. LESSON NO. 7.

EXAMINATION QUESTIONS.

1. Explain with the aid of a diagram the meaning of the terms distributed self capacity and inductance of a straight conductor.

2. Draw a diagram showing a half-wave dipole. Insert curves to show how the magnitudes of the current and voltage vary over the antenna length when it is operating on its resonant frequency.

3. What is meant by the radiation resistance of an antenna? What is the value of the radiation resistance of a half-wave dipole measured at its centre?

4. What is the correct physical length of a half-wave dipole to be operated on 90 mc/sec?

5. What is a polar diagram? Sketch a horizontal and vertical polar diagram for a half-wave dipole placed horizontally.

6. Give and explain one reciprocal property of a dipole when used for reception and transmission.

7. What factors determine the characteristic impedance of a twin-wire transmission line? Under what conditions would the input impedance of the line equal its characteristic impedance?

8. What effects may be encountered if a receiver's transmission line is not correctly matched at both antenna end and receiver end?

9. Explain the meaning of the term "polarisation of a wave". Should a receiver's dipole be vertical or horizontal to receive a vertically polarised wave?

10. Why may the presence of large buildings near a receiver aerial result in a blurred picture?

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T.F.M. & F. LESSON No. 8.

TELEVISION RECEIVERS.

The broad general principles underlying the reception of television signals are identical with those you have learned about in your earlier lessons on ordinary sound broadcast receivers. For this reason we shall concentrate here on elucidating the special problems which are characteristic of the reception, amplification, and detection of the high frequency, wide-band wave which constitutes the television signal. A great deal of this explanation can be illustrated by block diagrams to replace full circuit diagrams. Whenever this is done the student should be ever ready to apply, in his own mind, the knowledge of electronic technique already acquired in the study of broadcast reception. He should understand that, unless the contrary is stated, a "block", representing a stage, or section, of the receiver, operates in the same general manner as its counterpart in the more humble broadcast set.

THE SPECIAL PROBLEMS OF TELEVISION RECEPTION.

As has been pointed out in an earlier lesson of this series the complete television signal as broadcast from the transmitter is rather a complicated affair. In the first place it consists, in the case of the system at present in general use, of two separate waves -- one carrying the vision signal, the other the sound -- lying in adjacent frequency channels. The first problem will therefore be that of picking up and tuning in this "dual" signal, and thence separating the two in order that each finally reaches its proper destination, viz: the cathode ray tube in the one case, and the loudspeaker in the other.

Then again, as will be recalled the vision signal itself consists of two parts, the true picture or video signal, and the synchronising pulses. These must, by special methods, be separated one from the other, and made to perform their allotted tasks.

A third special problem is that of handling the ultra-high radio frequencies which we have seen are characteristic of television signals. For efficient tuning and amplification of these frequencies, extending up to many scores of megacycles, requires somewhat special design for the amplifying circuits.

Finally, but of great importance, is the problem of handling the <u>wide-band</u> signals which are characteristic of modern high-definition signals. It will be recalled that these band widths run up to 3 or 4 megacycles, as against several kilocycles in sound broadcast transmissions. The problem in this connection is mainly one of the correct design of the I.F. amplifiers, and also, of course, any stages of video amplification employed after detection.

In addition to the above mentioned problems of tuning, separation of vision and sound, and wide-band amplification, there is of course the important function of operating the cathode-ray tube to build up, from a series of picture-elements, a re-creation of the original moving scene. This part of the receiver incorporates, such as "saw-tooth" oscillators which have no counterpart in the ordinary broadcast model. The operation of the cathode-ray tube, together with its associated circuits will be deferred until the next lesson. Here we shall deal with the sound and video tuning, mixing, amplifying (R.F. I.F. and video), and detection circuits.

<u>TYPES OF RECEIVERS</u>.

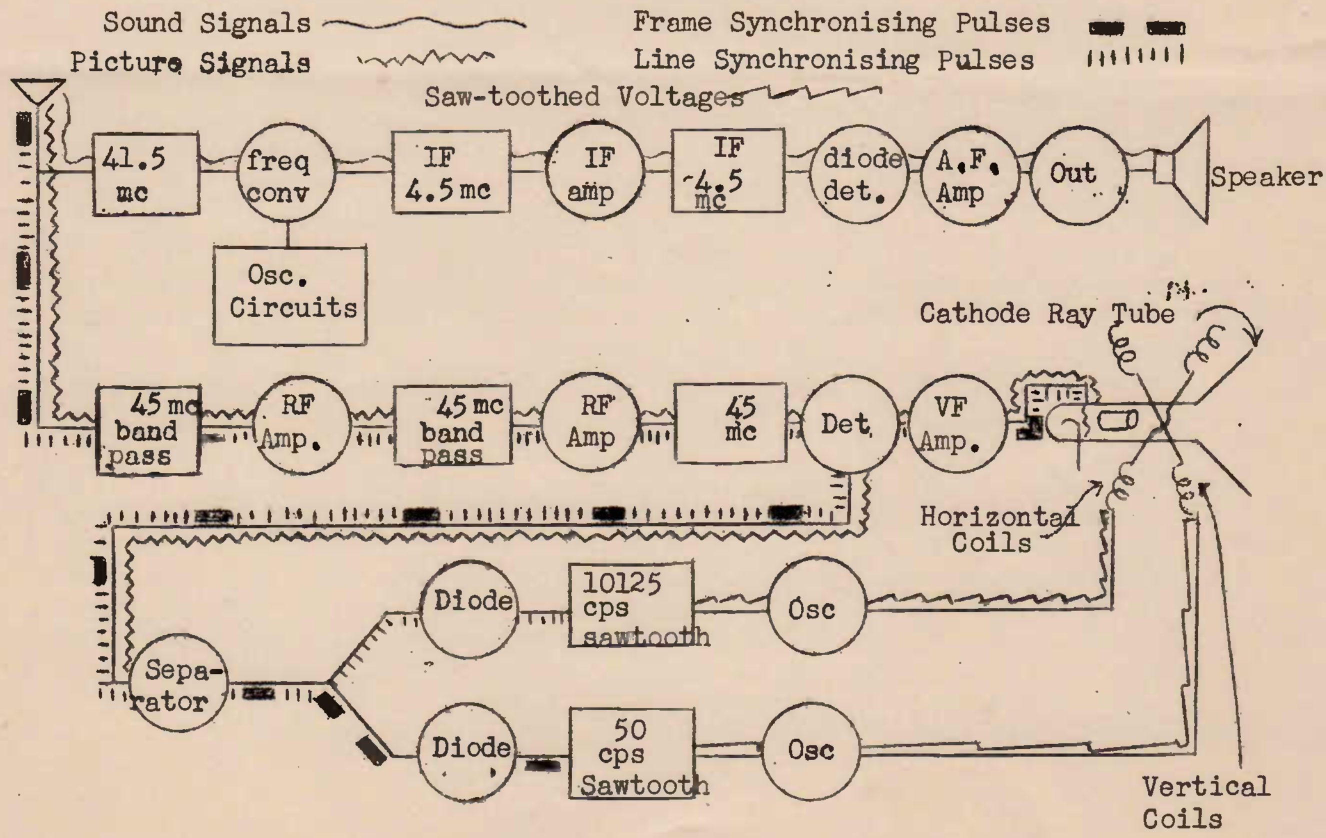


FIGURE 1.

Just as it is possible to use a straightforward TRF receiver or a superheterodyne for the reception of signals from broadcasting stations, so it is possible to use either a T.R.F. or superheterodyne circuit for receiving either or both the vision signal and the sound signal. Some receivers have employed superhet circuits for both vision and sound signals. Others have used a superhet circuit for sound and a TRF circuit for vision. Still others have used a TRF circuit for sound and a superhet circuit for vision, while it is also possible to use a T.R.F. circuit for both. Regardless of the type of reception adopted, the general principles are exactly the same as those you have learned about in your earlier lesson papers.

Figure 1 is a "block" diagram of a television receiver employing a superhet section for the sound signal, and a TRF circuit for the vision. The two sections represent two entirely separate receivers except that they operate from a single dipole. Although this antenna is "resonant", its tuning is broad and will, due to various "losses", amply cover the entire sound and vision channels.

In the diagram (Figure 1) the circles represent valves, while the rectangles are tuning circuits. The receiver is supposed to be operating upon a television signal consisting of a sound carrier of 41.5 mc/sec, and a vision channel of carrier frequency 45 mc/sec, with side-bands extending from, say 43.5 mc to 46.5 mc. The sound signal, picture signal, and sync. pulses are shown as per the key at the top of the diagram. Remember that the sync. pulses are superimposed, as modulation on the 45 mc. vision carrier.

The sound carrier is separated from the vision carrier by a sharply tuned r.f. circuit adjusted to 41.5 mc. This signal is then reduced to the I.F. of 4.5 mc. by means of the frequency **converter** (1st detector). Compare this I.F. with that commonly used in broadcast reception (455 kilo-cycles).

The remainder of the sound receiver corresponds in principle exactly with any conventional superhet-receiver.

The picture carrier, which contains the vertical (frame) and horizontal (line) sync. pulses is fed into tuned circuits designed and adjusted to pass the band of frequencies comprising the 45 mc. carrier itself together with its necessary side-bands. This band-pass "filter" cuts off rather sharply frequencies above and below the vision channel. In particular it eliminates, or greatly reduces the sound signal which must be prevented from reaching the picture screen, where it would cause interference to the reproduced scene. In the case of the receiver illustrated, the vision section is T.R.F. consisting of 2 stages of r.f. amplification. Each stage is tuned to the picture signal, so that by the time the latter has reached the detector, the last traces of the sound signal have been suppressed.

The detector may be of any of the usual types employed in a T.R.F. receiver. In this stage, of course, the signal is de-modulated, i.e. the video signal is separated from its carrier. This video signal, representing the picture elements, is then amplified by one or more stages of wide-band amplificiation. Video amplifiers were discussed in detail in Lesson 5. The video signal is then applied to the control grid, or modulating electrode, of the cathode-ray tube.

It will be observed that the two sync. signals, which were also separated from the carrier by the detector, are "side-tracked" at this stage into that section of the receiver which produces the saw-tooth voltages (or currents) for beam deflection. The discussion of this part of the receiver will require considerable space, and is therefore deferred until the next lesson, where it will be treated in detail.

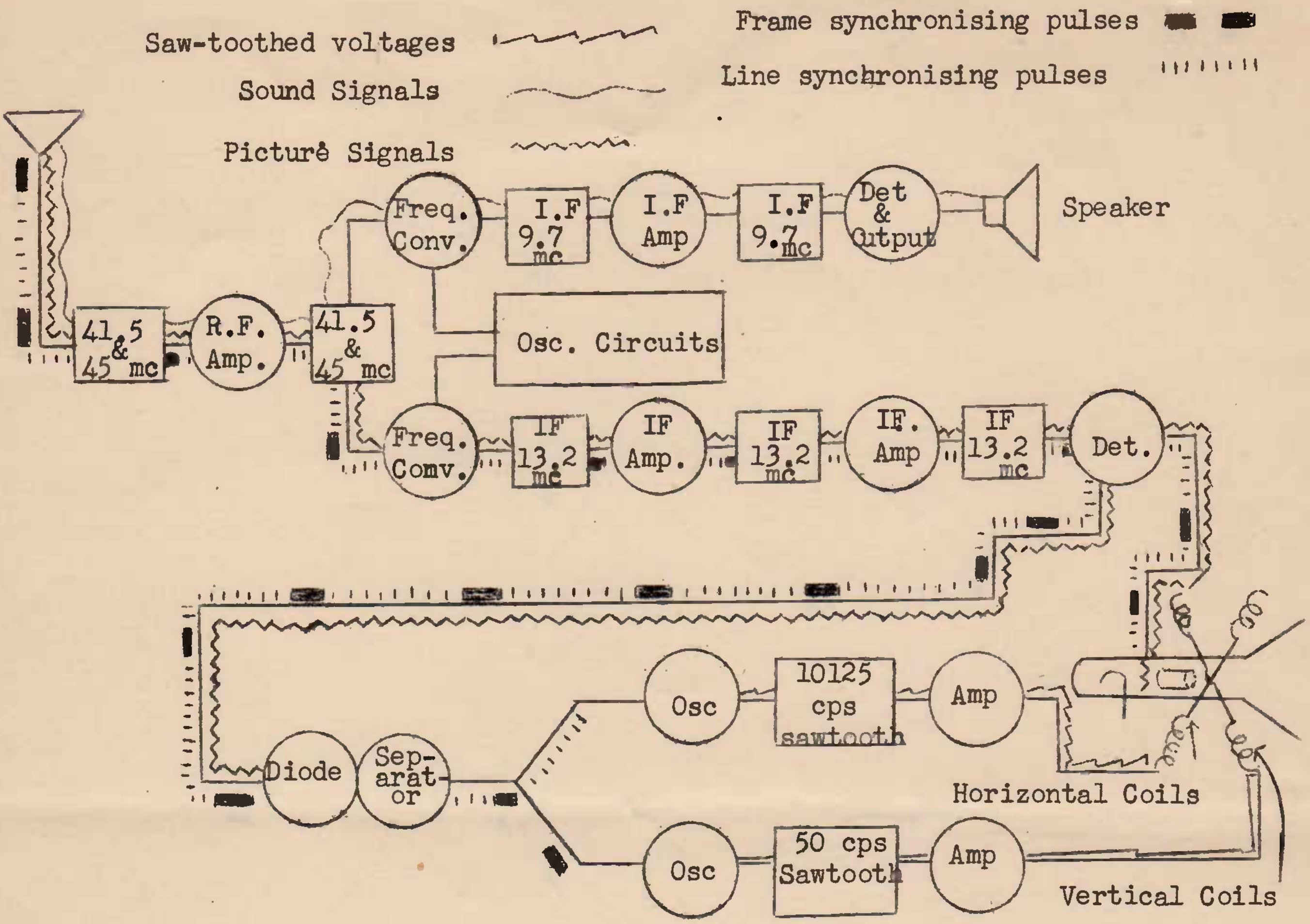


FIGURE 2.

Figure 2 shows another typical receiver layout, in which both sound and vision sections employ the super-heterodyne principle. In this case both signals are passed through the one R.F. amplifier, which is sufficiently broadly tuned to cover the entire television band. For the channel cited, this will extend approximately from 41.5 mc. to 46.5 mc. The two signals are then separated by more sharply tuned circuits, and passed into their respective frequency converter stages. These reduce the frequencies to the I.F's of 9.7 mc. and 13.2 mc. respectively. The sound section then follows, in principle, the conventional superhet. layout. The picture signal passes through two stages of I.F. amplification, where the tuned circuits have broad characteristics to accomodate the wide band of side-frequencies (e.g. 3 mc.).

The detector is normally of the diode type. Such a detector if sufficient amplification is obtained from the previous R.F. and I.F. stages, will produce a video signal strong enough to operate the cathode-ray tube directly. Hence, as shown in Figure 2, some receivers do not contain any stages of video amplification.

As in the first receiver described, the sync. pulses are diverted, at the detector stage, into those cathode-ray tube auxiliary circuits which provide the beam scanning. It will be observed that no attempt is made to suppress the sync. signals from the modulating electrode. Such suppression is unnecessary; for, as will be shown clearly in the next lesson, these signals, although serving no useful purpose at this electrode, cannot cause any undesirable interference with the picture formation.

The diagrams of Figures 1 and 2 will give the student some idea of the functions to be performed by a television receiver, and of the number of valves and components required. It would be as well to mention now that it is practically universal practice to utilise the superhetodyne principle in both sound and vision sections of the receiver as in Figure 2. We shall now proceed with a more detailed discussion of the particular problems associated with the aerial, mixer, I.F. and detector stages of such a typical receiver.

THE INPUT (AERIAL) STAGE.

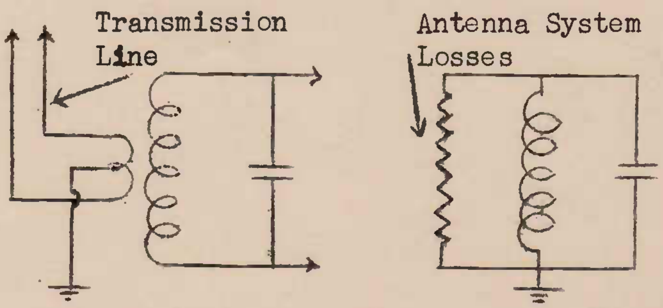
The function of this stage is to accept the composite (sound and vision) signal from the antenna (to which it must be matched -- see previous lesson), and to transfer these two carriers either directly to the converter valve or valves, or firstly to an R.F. amplifier.

The use of an R.F. amplifier has the advantage of improving the signal-to-mask ratio (in the same way as it improves the signal-to-noise ratio in an ordinary superhet). It also results in a slightly improved over-all amplification and selectivity. The more usual practice, however, is to omit an R.F. amplifier, as the number of valves in a typical television receiver is comparatively large. Another reason for omitting this stage is that a considerable simplification in the tuned (input) circuits is thereby achieved.

The input or aerial stage consists of a tuned circuit or circuits sufficiently broadly tuned to cover the entire television channel, which, including the vision and sound carriers (with sidebands) may be as wide as 5 mc. If a single circuit is used this broad tuning is mainly achieved as a result of the "loading" of the circuit due to the antenna and transmission line circuits which are coupled across it. These losses have the same effect as a resistance connected in parallel across the tuned circuit (See Figure 3).

The input circuit or circuits are usually inductively tuned, i.e. they employ coils with adjustable iron cores. The tuning capacities then consist of the stray wiring and valve input capacities.

If the receiver is designed to be tuned to a large number of television channels it is usual to employ a separate circuit for each channel. The stations are then selected by a suitable switching arrangement



Aerial Circuit

Equivalent Circuit showing effect of Transmission Line losses.

FIGURE 3.

as shown in Figure 4. Notice here that five channels are provided for. The primary of each coupling coil consists of a metal strap, stamped from sheet, and

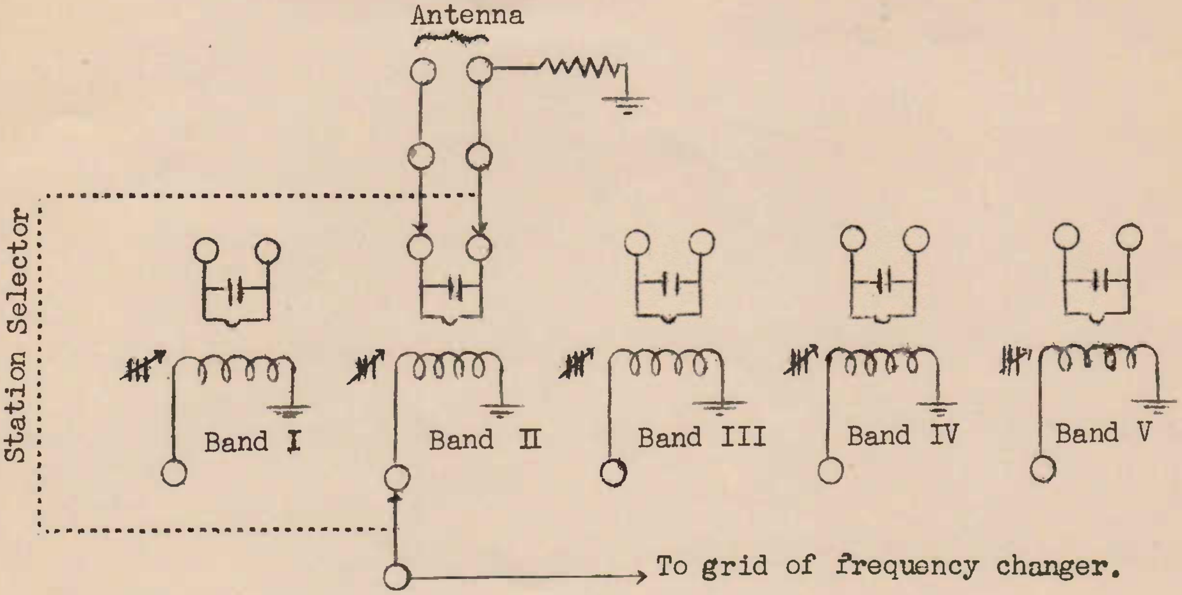
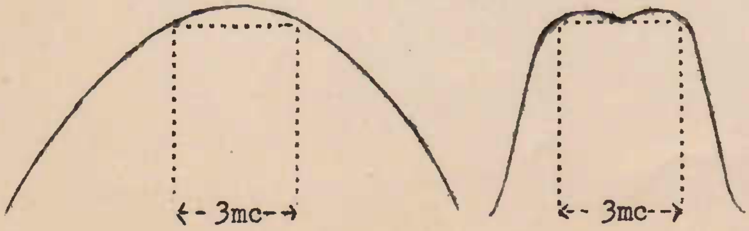


FIGURE 4.

consisting of but a single turn, intended to match the impedance of a 75 ohm transmission line. The secondaries are tuned by means of powdered iron cores which fit within the coils. The five channels provided for are 44 to 50, 50 to 56, 66 to 72, 78 to 84 and 84 to 90 mc.

Coupled circuits, to produce a band-pass effect, are often used in preference to a single circuit. The idea here is not to increase the selectivity of the receiver (the over-all selectivity of a typical receiver is due almost entirely to the I.F. stages), but to improve the ratio of signal-to-mask (noise) ratio. When a single circuit is sufficiently broadly tuned to cover a band of several megacycles it has a very low "Q", and produces no voltage amplification of the signal. On the other hand it passes to the converter a maximum amount of "thermal agitation" voltages. Briefly it may be stated that the sharper the tuning of a circuit (i.e. the higher its "Q" value) the greater will be its signal-to-random voltage ratio. The requirement of wide tuning range to cover the whole television signal, together with the advantages of comparatively high "Q" circuits may be obtained by using several circuits designed to produce a band-pass or "filter" effect.



(a) (b)

FIGURE 5.

A comparison between the characteristics of a single broadly tuned circuit (at a) and a "band-pass" arrangement (at b), consisting of several tuned circuits is shown in Figure 5. In each diagram the dotted line represents the "ideal" selectivity curve required for a 3 mc. channel. At (a) it is shown that in order to cover approximately this band using a single circuit, the tuning has to be broadened (by resistance loading) to such an extent that frequencies well outside the channel are not greatly attenuated. Even so there is some attenuation of the upper side-band frequencies of the signal. The curve obtained at (b) is that of a band pass "filter" arrangement. Here the signal channel is adequately covered, yet frequencies outside the band are sharply cut off.

When a receiver is designed to operate on a single station only (i.e. when no provision is desired for selecting one of a number of television channels) the input circuit may be constructed to yield sharp resonance for the comparatively very narrow sound channel. In the case of the simple input circuits so far described the sound signal, occupying a band of perhaps only 10 Kc. in width, is passed to the converter grid through the common input circuit which will accept a band of frequencies extending over several megacycles. This results in a lowered over-all amplification and signal-to-noise ratio as far as the sound section of the receiver is concerned.

In Figure 6 is shown an input circuit which provides selective resonance for the sound signal. Separate converter valves are used for video and sound channels.

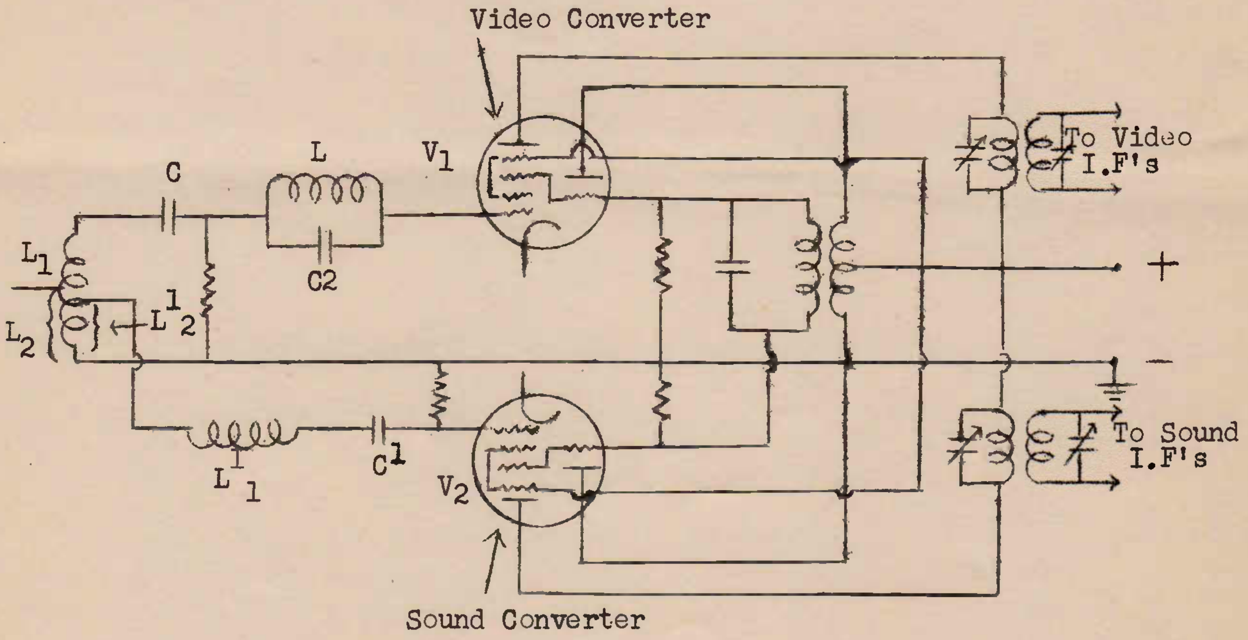


FIGURE 6.

The input circuit which accepts the broad band representing the composite signal consists of coils L1 and L2 and condenser C. Coils L^1_2, L^1_1, and condenser C^1 form a sharply tuned circuit of the band-pass type, adjusted to the frequency of the sound carrier. It allows only the comparatively narrow band of frequencies, representing the sound signal, to pass to the grid of the lower converter. Circuit LC^2 forms a parallel resonant circuit, tuned sharply to the sound carrier. This circuit offers a large impedance to the sound frequencies, but passes comparatively freely the wide band of frequencies representing the picture signal to the video converter.

THE CONVERTER STAGES.

The function of the converter stage is, as in the case of an ordinary broadcast receiver, to produce lower frequencies, viz: "intermediate" frequencies, which may then be more efficiently amplified and separated. Note, however, that in the case of television work, there are two separate carriers (vision and sound) to consider, and two separate intermediate frequencies to produce. Systems which have been, and still are, used to generate the two I.F.'s are several in number:-

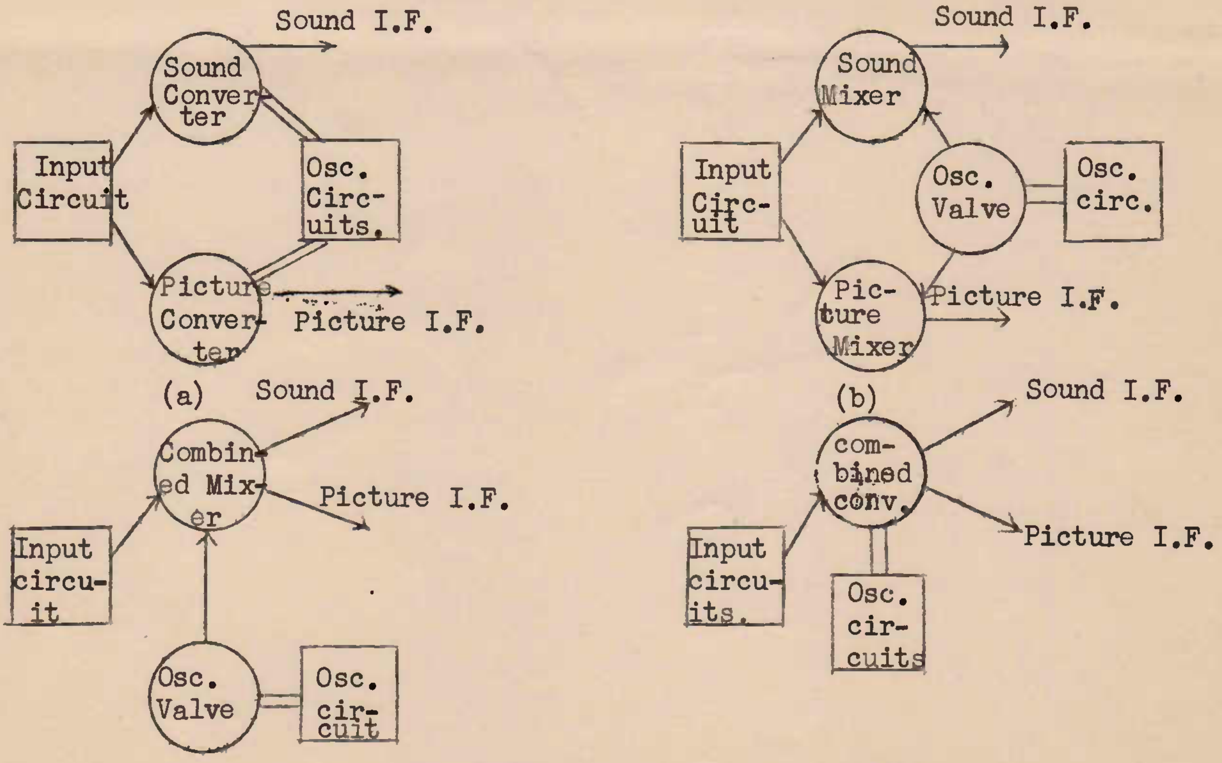
(1) Separate converter valve for each channel, each valve functioning as both oscillator and mixer for its own channel.

(2) Separate mixer valves for each channel, but using a separate valve for producing the local oscillations for both channels.

(3) A single mixer valve for both carriers, but employing a separate valve for producing oscillations, and

(4) A single converter valve which acts as both oscillator or mixer for both channels.

(NOTE:- We are here using the term "converter" when a valve performs the dual function of producing the locally generated oscillation and "mixing" it with the incoming carriers. The term "mixer" is used when the valve is relieved of the job of generating the local oscillations, by the employment of a separate valve for this purpose.)



(c) (d)

FIGURE 7.

The four systems are illustrated diagrammatically in Figure 7. In the case of systems (1) and (4), at (a) and (d) respectively, the valves perform the double function of mixer and oscillator. Systems (2) and (3), (at (b) and (c)) employ separate valves for oscillator and mixer functions. From another point of view

(a) and (b) are similar -- in that the mixing of sound and picture carriers (with oscillator frequency) is carried out in separate valves. By the same token (c) and (d) may be compared, for in both these arrangements mixing for sound and picture signals is achieved within a single valve, the two I.F's being then separated by selective circuits.

COMPARISON OF CONVERTER SYSTEMS.

Whether or not a separate oscillator valve is used depends mainly upon the television frequency or frequencies the receiver is designed for. It is found that for carrier frequencies above about 70 Mc. it is virtually necessary to use a separate oscillator valve. Working at these high frequencies (which are common in the U.S.A.) it is very difficult to maintain a stable oscillator frequency, independent of the signal frequencies, when a single converter type valve is used. This is due to coupling effects occuring within the valve, between the different frequencies involved. In addition, a considerable loss of power in the oscillator frequency is involved.

When operation is on the lower frequencies, however, as in the case of the B.B.C. transmissions on 40 odd M.C, the use of combined converter type valve is quite satisfactory(See Fig 7 (a) and (d)), and has the advantage of reducing the number of valves in the set.

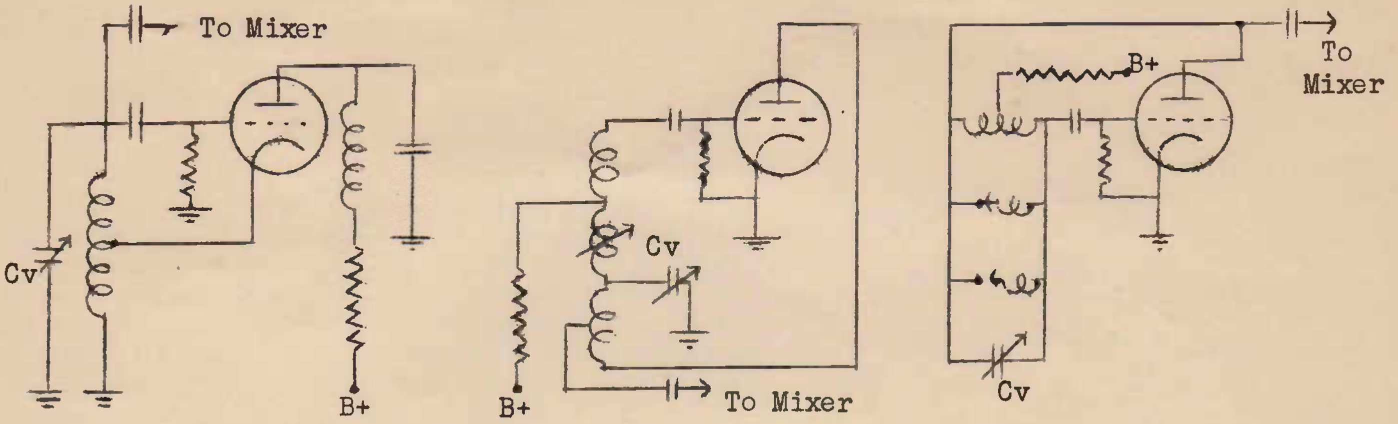
With regard to the question of the mixing of the sound and picture signals within separate valves (as at (a) and (b) -- Fig. 7), or within a single valve (as at (c) and (d)), the problem again depends largely upon the intended purpose of the receiver. If operation is to be confined to a single television transmission advantage may be taken of separating the sound and picture carriers in the input circuits, whereby selective resonance, particularly for the sound signal, may be employed, as described earlier in this lesson. This plan necessitates the use of separate mixer valves. When, however, the receiver is designed for switching to different television channels, as is commonly done in America, it is virtually impossible to carry out any separation of sound and picture carriers in the input (aerial) circuits. In this case, as explained each input circuit (for each television channel) is a simple tuned circuit, and separation of sound and picture signals is carred out after the single mixing stage, by means of the circuits tuned to the separate Intermediate Frequencies.

Summarising, we may state briefly that in America the arrangement at (c) Figure (System 3) is most favoured. English receivers, on the other hand seem to prefer the arrangement illustrated at (a) in this diagram.

SOME OSCILLATOR AND MIXER CIRCUITS.

The oscillator tuning is one of the most critical adjustments in the entire receiver. The oscillator must therefore be designed to operate at a very stable frequency, i.e. the latter must not vary appreciably with supply voltage or temperature changes. Two circuits which seem to show the highest degree of freedom from frequency instability are the "floating-cathode" type shown at A in Figure 8 and the tuned plate circuit, two versions of which are illustrated at B and C in the same figure. All these circuits are really modified versions of the Hartley oscillator.

The condenser Cv in each case is used as a trimmer.



(A) (B) (C)

FIGURE 8.

Simple tuned-grid oscillators, as found in broadcast receivers are rarely used.

A Push-pull type of oscillator, with grid-tuning may be used when the receiver operates with separate converter tubes for each channel. An example of this arrangement was given back in Figure 6. Here the triode sections of the two converter tubes, acting in push-pull maintain in oscillation the single tuned circuit which is connected in their grid circuits.

With reference to this circuit note that the function of the hexode section of V1 is limited to the generation of the video I.F, the hexode section of V2 being used for the sound I.F. Observe also that the picture I.F. which occupies a broad frequency band, is transferred to the following stages by means of an untuned (r.f.) transformer. The sound I.F. on the other hand, is amplified selectively by means of tuned coupled circuits, as is common practice in broadcast receiver design.

An example of a complete converter stage employing a single mixer valve for both picture and sound channels, together with a separate oscillator is shown in Fig. 9.

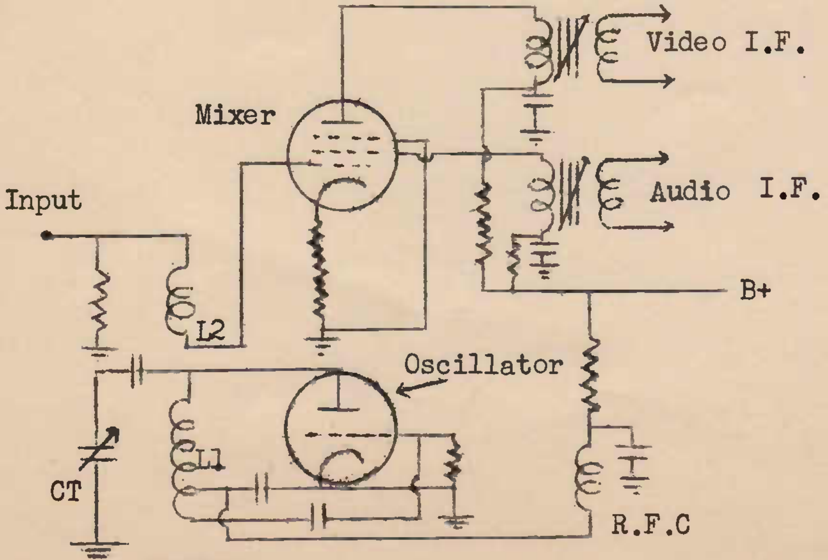


FIGURE 9.

Here the oscillator consists of the Hartley circuit with a triode valve. The oscillator's tuned circuit consists of the tapped coil L_1, and trimmer condenser CT. The mixer value is a pentode of high mutual conductance. The oscillator frequency is injected directly into the grid by means of the coupling coil L_2. This arrangement gives the highest sensitivity.

An interesting point

about this circuit is that while the picture I.F. signal is taken, as usual, from the plate of the mixer, the sound I.F. is taken from the screen-grid, which is not by-passed.

THE TWO INTERMEDIATE FREQUENCIES.

At this stage it should be clearly understood how the two I.F's are produced from a single oscillation with the receiver. Suppose the sound carrier has a frequency of 49.5 mc. and the picture carrier is of 45 mc. If an oscillator frequency of 58 mc. is "mixed" with both these carriers a number of frequencies will emerge. One of these is the difference between 58 Mc and 49.5 Mc., viz: 8.5 Mc., and this is the sound I.F. Another frequency produced is the difference between the oscillator frequency and the picture carrier frequency, viz. 58 - 45 = 13 Mc. This is the video I.F. As will be explained fully a little later it is always desirable to arrange matters so that the sound I.F. is below the picture I.F., as in the case cited.

Now if the transmission is such that the sound carrier is below the picture carrier, then the oscillator frequency must be adjusted to a value below both carriers if sound I.F. is to be below picture I.F. (Read this once again!) The student should, at this juncture consider a number of hypothetical cases for carrier frequencies and oscillator frequency, and on each occasion figure out for himself what the I.F's will be. If this is done the following points should be clear. Assuming that it is desired to produce a sound I.F. below the picture I.F, then

(1) If sound carrier is above picture carrier, oscillation frequency should be above both.

(2) If sound carrier is below picture carrier, oscillator frequency should be below both.

(3) In all cases the separation between the I.F. channels is equal to the separation in the carriers. It follows, therefore that while the frequencies of the two I.F's may be varied by adjustment to the receiver's oscillator circuit, the difference between the two is fixed for any given transmission.

With reference to points (1) and (2) above, it is desirable, from the transmitter's point of view to generate the picture carrier at the lower frequency. The reason for this is that, when operating in the region of U.H.F's. the lower the actual frequency the greater the efficiency and power which may be obtained. Greater difficulty is experience in generating sufficient power to override interference in the case of the picture signal than in the case of the sound.

From the point of view of receiver design however it is better to have picture-carrier above sound carrier, since this results in a lower receiver oscillator frequency. The point here is that it is much easier to design a converter oscillator of sufficient frequency-stability and power when the frequency is kept to a minimum.

So it appears to be six of one and half-a-dozen of the other! In the English B.B.C. transmissions it has been the practice to operate on the picture carrier-above-sound-carrier-system, involving an oscillator frequency below both. The opposite system is in use in America.

REASON FOR THE HIGH INTERMEDIATE FREQUENCIES.

The Intermediate Frequencies used in Television are of a much higher order than those with which you are familiar. In an example given above the Figures 13 Mc (for picture) and 8.5 Mc.(for sound) were quoted. Note that these are still high radio-frequencies — in fact they approach in value the carrier frequencies used in the communication short-wave band. The question may well be asked: why not "convert" the television carriers to much lower frequencies, where amplification may be effected with greater efficiency?

The answer to this question is, in the main, bound up with the great width of the band necessary to incorporate all the video components in the picture signal. As we have seen previously this band is usually several megacycles in width. Remember that when the converter reduces the carrier signal to the lower intermediate frequency, the width of the band should in no way be reduced. If such a narrowing of the band were introduced in the converter or I.F. stages, it would mean a loss of the higher video frequencies in the picture signal, with a resultant deterioration in picture detail and sharpness.

Suppose then our picture channel extends over a frequency range of 3 m.c. It would be clearly impossible to design tuned circuits having a "centre" frequency of less than 3 mc, and yet still pass this frequency band. Even with an I.F. of 13 mc. the band pass required is nearly one-quarter of the centre frequency of the I.F. circuits, Figure 10 illustrates the problem here.

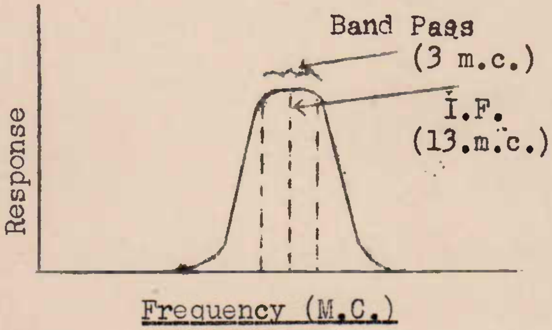


FIGURE 10.

A second reason for choosing frequencies like 8 - 13 mc for the television I.F's, is that this particular section of the electro-magnetic frequency spectrum is in very little demand for other services. If an I.F. corresponding to the carrier frequency of some other broadcast were selected, the television receiver would suffer from serious interference; for its I.F. circuits would readily pass the interfering signal from direct pick-up and insufficient selectivity in the R.F. stages of the receiver.

The student may still be wondering why the sound I.F. is not operated on something like, say 465 K.C, since the band-width argument does not apply to it. The point here is that, as explained earlier the separation between picture and sound <u>I.F's</u>. must, of necessity, be equal to that existing between picture and sound <u>carriers</u>, as radiated from the transmitter. And remember that picture and sound are transmitted on adjacent carriers, separated by something like 4.5 m.c. in the u.h.f. range. Hence, if 13 m.c. is the lowest practicable picture I.F, the sound I.F. <u>must</u> be either 13 + 4.5 = 17.5 mc. or 13 — 4.5 = 8.5 mc. As has been stated earlier the sound I.F. is always fixed at a value <u>lower</u> than the picture I.F. The reason for this arrangement now emerges. In the interests of sound I.F. amplifier gain, the latter I.F. might as well be as low as possible, since only a narrow band of audio frequencies is carried by it.

THE SOUND I.F. CHANNEL.

The I.F. stages for amplification of the sound signal follow very closely along conventional lines, i.e. the inter-stage coupling consists of a pair of coupled tuned circuits. The operating frequency is, of course, much higher, as has been explained. This will necessitate coils and condensers having considerably lower values of inductance and capacity respectively.

There is one point of interest, however, in respect to these I.F. stages. They are designed to pass a band of frequencies having a width several times that of the audio modulated I.F. Whereas the audio frequencies extend only to a maximum of 15 K.C. per sec., the tuned circuits are designed for a band-pass of anything between 40 to 100 K.C. per sec. This, of course, will ensure high quality in the sound reproduction since there will be no possibility of "cutting" the higher side-bands of the modulated signal. The main reason, however, for this apparently excessive band-pass in the I.F. stages, is not connected with fidelity, so much as with oscillator design and adjustment. The oscillator signal, which is used to produce both the picture and sound I.F, has a frequency in the ultra-high-frequency range, say, for example 50 m.c. Any variation in this frequency will cause an equal variation in I.F. An oscillator designed to operate so that its frequency does not vary more than 0.1% represents a high degree of precision both from the point of view of initial adjustment and that of frequency stability. Now 0.1% of 50 M.C. is 50,000 C. or 50 Kc. Hence, if the oscillation frequency "drifts" by this amount, the sound (and picture) I.F. will also change by 50 Kc. It is obvious, therefore, that if the sound I.F. stages were designed to pass a band of frequencies only 10 or 20 Kc. in width, it would be impossible to maintain the I.F. signal accurately in the centre of this pass-band. The result would be that oscillator adjustment would be much too critical to get the sound signal through the I.F. stages; and even if the correct initial adjustment could be made, the sound would continuously come and go, due to "drift" in the oscillator frequency.

This point will be appreciated more clearly, perhaps, by reference to Figure 11, where the selectivity characteristic of an 8.5 m.c. I.F. stage is illustrated. Here the band-pass is 50 Kc. The audio I.F. signal, of say width 10 Kc. is shown in two "positions" in respect to the circuit's characteristic. The figure shows how the actual I.F. may vary by approximately 25 Kc. below or above its correct value without any loss in signal strength or cutting of side-bands.

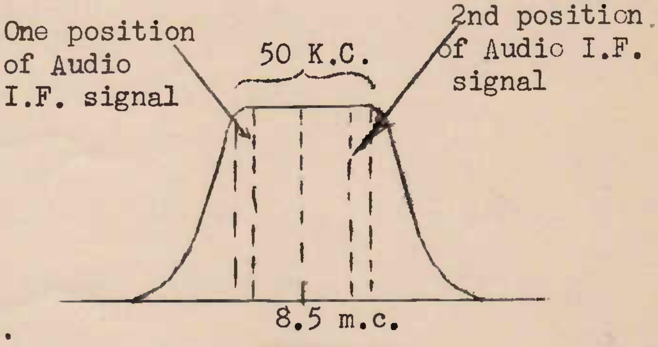


FIGURE 11.

USE OF THE DOUBLE-SUPERHETERODYNE PRINCIPLE.

A sound I.F. of the order of 455 Kc. may be obtained by the use of a second converter for the sound signal above. The first converter lowers the signal frequency to, say, 8.5 m.c. The second converter, producing an oscillation differing in frequency by 460 K.c. above or below 8.5 m.c, causes a further reduction in frequency.

The use of the double super-het. is not, however, in favour. Due to interaction between the two oscillators numerous whistles and "ghost-signals" are produced, and only extreme care in design and shielding will prevent this. In any case the use of a second frequency converter stage to reduce the I.F. to 455 Kc. would not overcome the problem of oscillator frequency drift because any drift would pass through the second frequency conveter and would be present in the new I.F. A drift of 25 Kc. in 455 Kc. would be an impossibly large amount for ordinary I.F. transformers.

THE PICTURE I.F. CHANNEL.

Here we are referring to those stages (usually two or more) whose function is to selectively amplify the modulated picture (video) signal passed on from the converter. This section of the receiver is, from our point of view one of the most interesting and important in the whole circuit. Interesting, because the inter-stage coupling circuits may appear quite unfamiliar to the ordinary radio serviceman. Important, because these stages have to meet such stringent design conditions that the over-all performance of the receiver may be made or marred by them.

First of all the student should have a clear picture of the job the picture I.F. stages are to perform. They are required to amplify an extremely wide range of frequencies, all of which are higher than the radio-frequencies to which the broadcast technician is accustomed. The amplification must be uniform over this wide band, i.e. the "response" characteristics of the circuits must be flat over the given range. Moreover, the circuits must "cut-off" sharply frequencies outside the lower and upper limits of the picture I.F. band. For example a typical case for a modern receiver would be a picture I.F. band extending from 8.75 mc. to 12.75 mc. -- a width of 4 m.c! Amplification over this band must be flat. Now, in the case cited the <u>sound</u> I.F. would be on 8.25 mc. and this -- only .5 mc. below the lower limit of the picture I.F. band -- must be totally eliminated by the picture "band-pass" circuits. This means a high degree of selectivity (see Figure 12).

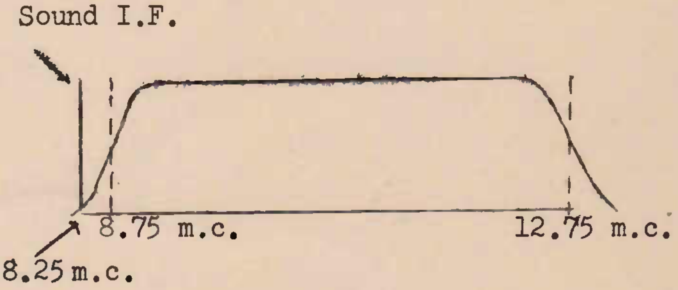


FIGURE 12.

And all this wide band uniform amplification sharp selectivity must be achieved despite the fact that the band-width to be passed forms a very large fraction ($\frac{2}{5}$) of the central frequency.

The student should, at this stage, have observed an important point, namely that selectivity is an essential even though the receiver has to cope with but a single television transmission. The reason for this is, of course, that each transmission employs two carriers. The sound carrier must not be able to pass through the picture I.F. carrier, for otherwise serious interference to the picture formation on the screen would result. Of course if the receiver is located within the coverage area of two or more transmitters the question of selectivity becomes of even greater importance.

BAND-PASS COUPLING CIRCUITS.

The response characteristics required (as described above) for the inter-stage coupling of the video amplifiers may be obtained by two general methods:-

A. Over-coupled circuits loaded with resistances.

B. Circuits based on band-pass "filter" design.

Actually there is no sharp distinction between the two types, but for our purposes we shall discuss them separately.

OVER-COUPLED CIRCUITS, RESISTANCE "LOADED".

The student should already be familiar with the general theory involved under this heading, but we shall quickly review the subject.

Briefly the main points are as follows. Suppose we have two tuned circuits, tuned to the same frequency (fo), and loosely coupled by mutual induction (m) between the coils (see A Figure 13). The response curve will be like curve "a" Figure 13(D). If the coupling is now increased the peak of the curve will rise, until at a certain value of coupling known as "critical coupling" or "optimum coupling", a maximum peak is reached (curve b), still at frequency fo. Further increases in coupling (m) will lead to the formation of two peaks, one below, the other above the frequency fo. This is known as "double-peaking" or "double-humping". See curve "c" Figure 13(D). Still greater degrees of coupling would cause the peaks to move further apart and to become more distinct.

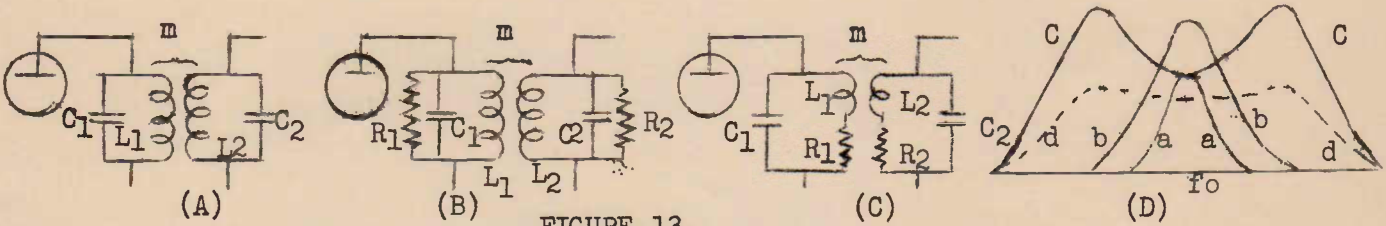


FIGURE 13.

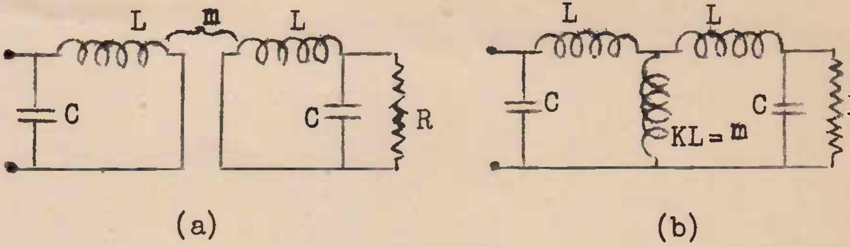
Suppose now we connect resistors R1 and R2 either across (in shunt with) the tuned circuits, as at B, or in series with them, as at C. The effect is to lower the peaks, without appreciably reducing the response in the region between them. A curve similar to "d" results. Note that the amplification for frequencies between the peaks is substantially uniform, but for frequencies outside them considerable attenuation is experienced. This is the band-pass effect desired.

The width of the band passed depends upon the frequency-separation of the "peaks"; and this in turn depends on the degree of coupling. But if the band-pass is further increased by tightening the coupling the hollow between peaks becomes more pronounced. To "flatten-up" the curve again we must increase the loading or clamping of the circuits by means of the resistors R1 and R2. The increased loading lowers the over-all "Q" and dynamic impedance of the coupled circuits. Since this dynamic impedance forms the plate-load of the valve it will be seen that a loss in stage gain will be suffered.

Summarising, we may say that the wider the pass band for which the circuits are designed, the lower will be the stage gain achieved. With the modern tendency towards wider band (higher definition) transmissions it appears that the loaded over-coupled circuit method is proving inadequate. For this reason the use of more complicated coupling systems, designed upon the "filter" theory, and employing perhaps 3 or 4 resonant circuits per stage, is becoming more and more common.

INTER-STAGE COUPLING CIRCUITS BASED ON "FILTER" THEORY.

The circuits referred to now usually dispense with mutual induction coupling between the two tuned circuits, and employ instead an impedance which may be either inductive or capacitive in nature.



(a) (b)

FIGURE 14.

Figure 14 shows at (a) a pair of tuned circuits, coupled by the mutual inductance (m) existing between the two coils L. This is the arrangement already discussed. At (b) is shown a band-pass "filter" in which the mutual inductance (m) is replaced by a self-inductance (KL) equal in value to m. The A.C. current in the first LC tuned circuit flowing through the inductance KL develops an A.C. voltage across it. This voltage is then transferred into the second L.C. tuned circuit. KL acts as a "common coupling impedance", and serves the same purpose as the mutual inductance (m) in circuit (a).

Actually, the two circuits of Figure 14 are identical in performance. Circuit (b), however, has the advantage over (a) in that the mutual inductance (m) of the latter is too difficult to adjust and control with sufficient accuracy, in production. The constants (L,C. and K)of circuit (b) may be precisely designed, using the "filter" theory, starting from a known value of R, for any desired bandwidth.

The circuit of Figure 15 shows a typical band-pass filter for inter-stage coupling. The two identical tuned circuits consisting of the component L1 and C1 are coupled by means of the series resonant circuit L2 C2. The type of characteristic obtained is also shown in the figure. Here f1 and f2 are the upper and lower frequency limits of the video I.F. band, and fr is some frequency which it is desired to reject completely. At any frequency lying between f1 and f2 (i.e. the video I.F. band) the coupling circuit L2 C2 is <u>not</u> at resonance, and therefore offer an impedance across which a voltage is developed for application to the second tuned unit L1, L2. This is impedance coupling. An advantage of this type of circuit is that, by proper choice of the components L1,C1, L2 and C2 practically 100% rejection of one particular frequency (fr) may be achieved. This frequency is usually chosen to be that of the <u>audio</u> carrier.

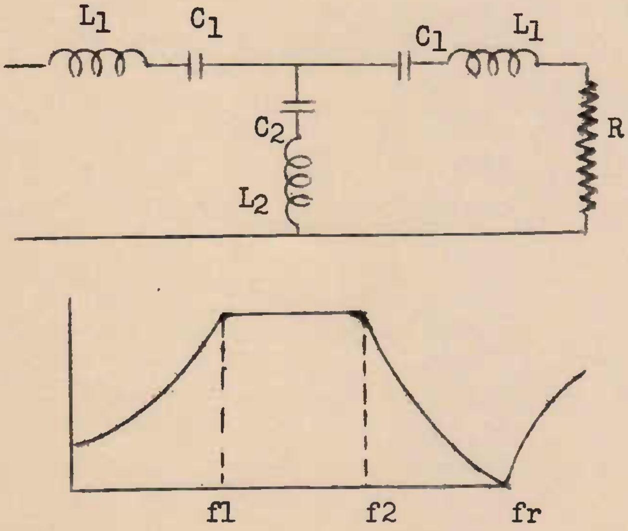


FIGURE 15.

A combination of capacitive and tuned circuit coupling is shown in Figure 16. By choosing L1 and Co to resonate at the adjacent audio carrier frequency the latter may be entirely eliminated. Note that L1 and Co form a <u>series</u> tuned circuit, which at resonance has practically zero impedance. At any video I.F.

frequency there is considerable impedance across the coupling branch (L1,C1,Co) and the overall characteristic of the circuit is such that uniform response is obtained over the desired range.

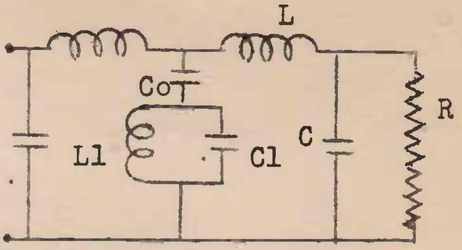


FIGURE 16.

TYPES OF VALVES FOR VIDEO AMPLIFICATION.

In the discussion on loaded over-coupled circuits for interstage video I.F. coupling it was pointed out that the heavy resistive loading lowered the "dynamic" impedance of the circuits. The wider the band-pass required, the lower this impedance had to be. The same general principle applies to all the circuits just described.

Now the gain of a stage using a pentode valve is given by:-

Gain = Gm X Rd.
(Gm = mutual conductance of valve, Rd = dynamic impedance of plate load.

The load in the plate circuit of a video I.F. amplifier is, of course, the overall impedance of the coupling circuits used. If ordinary pentodes were employed the stage gain, on account of the low value of this impedance, might quite well be negligible or even non-existant.

To compensate for the low value of Rd, valves having very high values of Gm have been developed. One such type has been mentioned in the lesson on Video Amplification, viz: the 6AC7 (1852), having a normal plate current of 10 m.a. and a Gm of 9.6 m.a. per volt or 9600 micromhos. Actually, in practice the same types of valves are used for r.f. and I.F. amplification as for video amplification (after detection).

A recent development in the way of valves for I.F. amplification is the "secondary emission" tube. In this type the secondary emission within the tube is used to augment the electron flow liberated by thermionic emission from the cathode. In this way a greatly increased plate current is obtained, resulting in unusually high values of Gm -- e.g. 13,000 micromhos. The use of these amplifier valves has made it possible to reduce the number of stages of I.F. amplification to two where three were used before.

THE SECOND DETECTOR (VIDEO) STAGE.

This stage serves a similar purpose to the corresponding stage in audio work. It demodulates the modulated I.F. (or R.F.) signal. The output of the detector should be substantially the same as the input of the modulator in the transmitter, In other words this output is the real video signal, consisting of voltage changes representing both picture signals and synchronising pulses.

Although plate detection has been used, the only common type is the familiar diode detector, and we shall here confine ourselves only to the latter.

LOSS OF DETECTOR OUTPUT FOR HIGH VIDEO FREQUENCIES.

In Figure 17 is shown a simple diode detector. The rectified (detector) video voltage is developed across the diode load Rc just as in audio work. In video detection, however, we are faced with an additional problem due to the high value of those frequencies representing the fine detail in the picture. Across Rc exists various stray capacities consisting of wiring capacities to earth and cathode-earth capacity. These are represented by Cs in Figure 17, and appear in parallel with the load Rc. The reactance of Cs is high at low and medium frequencies, and therefore the "shunting" effect on Rc is negligible. However, at the higher video frequencies (which may extend up to 4 m.c., Cs seriously shunts Rc. The problem here is identical with the shunting effect of stray capacities across the plate load in video <u>amplifiers</u>. The effect of the shunting is to reduce the total impedance across which the video voltage is developed, with a consequent loss in high frequency output. This effect is countered in practice in exactly the same manner as was used for "high-frequency compensation" in amplifiers, i.e. by "peaking" coils and/or tuned circuits. The result is that instead of finding a simple resistor, by-passed by a condenser for the diode load, we find instead all manner of complicated circuits consisting of L, C and R.

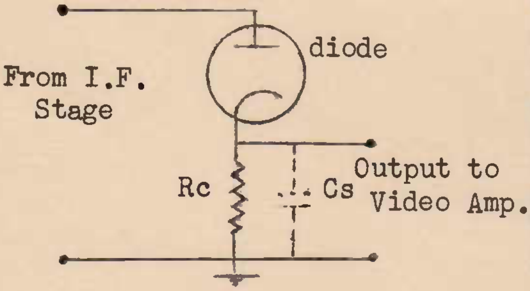


FIGURE 17.

Figure 18 shows one such arrangement. In addition to the diode load resistor R, we have coils L1,L2 and condenser C, in addition, of course, to the unavoidable stray capacity Cs. The network of components is so designed that its impedance, between points A and B, remains practically constant over the entire video range from, say 50 c/sec up to 4 mc/sec.

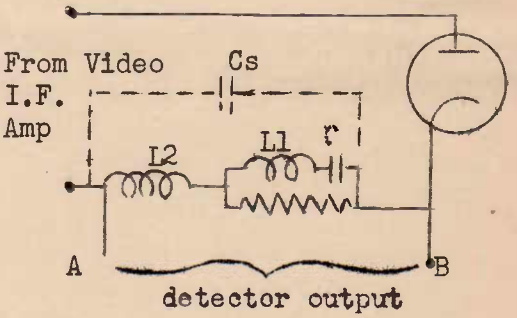


FIGURE 18.

Another problem not so easily overcome in video detection is the elimination of the r.f. or I.F. component from the video amplifiers. It will be remembered that the r.f. or I.F. is kept out of <u>audio</u> amplifiers from the detector's output by the simple expedient of connecting an r.f. by-pass condenser, of small capacity, from plate of the 1st A.F. amplifier tube to earth. In audio work this method is satisfactory since the I.F. is of the order of 455 Kc/sec. compared with, say 10 Kc/sec. for the highest audio frequency. Hence it is easy to choose a capacity which will effectively eliminate the I.F, without attenuating the highest A.F.

In the case of video detection, on the other hand the I.F. (say 12 mc/sec) may be only 3 times as high as the highest video frequency. A simple by-pass condenser of sufficient capacity to eliminate the I.F. would also seriously reduce these higher video frequencies.

The problem is usually solved simultaneously with that of the loss of high video frequencies due to stray capacities shunting the diode load. Actually the "load circuit" shown in Figure 18 may be adjusted to have a constant impedance from zero up to the highest video frequency, but an impedance which drops suddenly above that.

The I.F. may be very effectively eliminated by use of a "filter" circuit of the type shown in Figure 19. The filter consists of coils L, condensers C and 2C and the load resistor Rc, "terminating" the filter. This circuit may be designed to have an impedance characteristic as shown -- constant from zero frequency up to 4 m.c, and cutting off sharply at 8 m.c. Thus it is seen that the video range is covered without high frequency loss, but the I.F. (12 m.c.) is entirely eliminated.

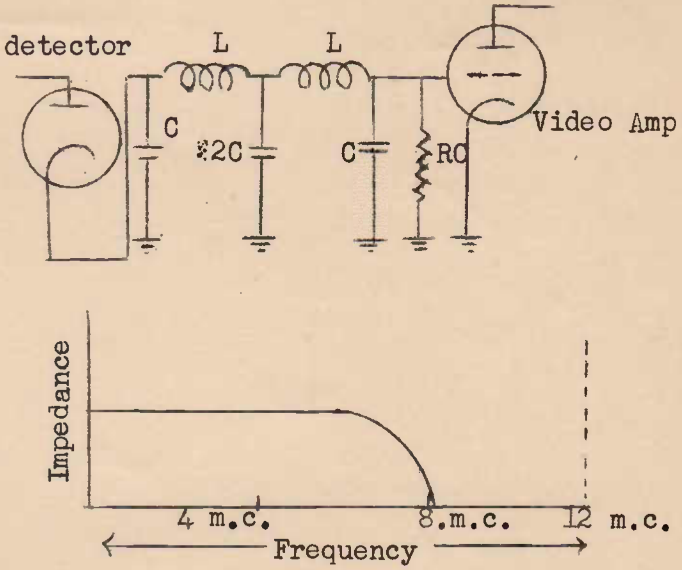


FIGURE 19.

AUTOMATIC GAIN CONTROL.

A.V.C. or A.G.C. is not extremely necessary, in television receivers, since very little "fading" is experienced on the u.h.f's. However, variations in supply voltage will affect the receivers gain. Any variation in the video output level to the cathode-ray-tube has the effect of varying the picture contrast. The eye is very sensitive to such changes. Hence some receivers employ an a.g.c. circuit in their picture sections.

An a.g.c. circuit in the picture I.F. amplifier is quite different from the a.v.c. system for audio work. This is because the a.g.c. voltage must not vary with the average level of the picture r.f. signal. The reason for this is that this average level of signal is determined by the brightness of the scene being televised, and it would not do for the a.g.c. to counteract the variations in picture brightness.

Now assuming negative modulation at the transmitter the peaks of modulation, (representing the sync. pulses) remain constant at the transmitter. Hence any variation in the peaks of modulation at the receiver's detector would mean either a fading of the signal or a change (unintentional) in receiver gain. For these reasons the a.g.c. voltage for application to the I.F. valves grid's is determined by the peak amplitude of the signal.

To achieve this a peak-voltmeter arrangement is used as shown in Figure 20. The peak voltmeter is an over-biassed triode, with a load resistor in the cathode circuit. This triode normally carries no current. On the signal peaks, the positive voltage developed across the diode load (Rc), and applied to the triode's grid causes the latter valve to conduct. This charges the condenser C1, which is so large that it cannot discharge appreciably through the resistors. Thus C1 charges up to a voltage whose steady value depends upon the amplitude of the peaks of the signal. This a.g.c. voltage is amplified by means of a direct-coupled amplifier, and thence applied to the grids of the picture I.F. amplifier. Note that the a.g.c. amplifier inverts the voltage to give correct polarity.

VIDEO AMPLIFICATION.

The video signal obtained, after detection, is similar to that produced by the television camera at the transmitter. In some receivers no provision is made for amplification of this signal, the detector's output being applied directly to the grid of the cathode-ray-tube. When amplification of the video signal is considered necessary, one, two or even three stages may be used. These video amplifiers have been described and explained in detail in Lesson 5.

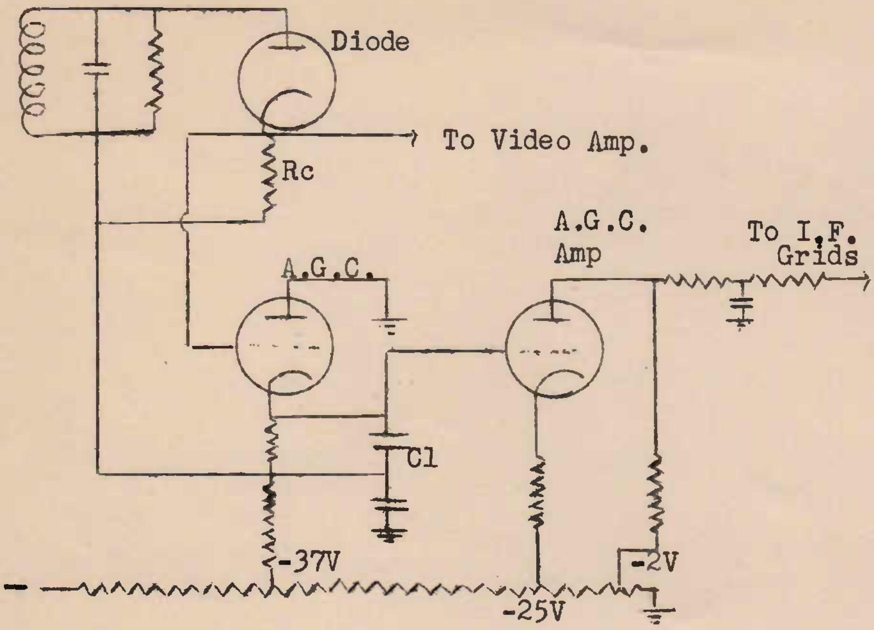


FIGURE 20.

T.F.M. & F. LESSON NO. 8.

EXAMINATION QUESTIONS.

1. Why is it that the aerial input circuit of a television receiver usually has a low value of "Q" and poor selectivity?

2. What explanation could you give for the fact that "ganged" condensers are not used for oscillator and aerial tuning in a television receiver?

3. A television signal consists of a 45.25 m.c. picture carrier and a 49.75 m.c. sound carrier. What should be the oscillator frequency for I.F.'s of 12.75 M.C. (picture) and 8.25 m.c. (sound)?

4. Why does the use of a separate oscillator valve become virtually essential when operating on carrier frequencies above about 70 m.c?

5. Explain why considerable selectivity is required in the design of both picture and sound I.F. stages, even though the receiver is within range of but a single transmitter.

6. What is the main reason for not using a picture intermediate frequency below about 8. m.c?

7. Explain briefly the effect of over-coupling a pair of tuned circuits, and then "loading" them with resistors.

8. Why must valves having a high value of "Gm" be used in a picture I.F. Amplifier?

9. The diode load of a picture detector usually consists of one or more inductance coils, as well as a resistor. What is the purpose of these?

10. Referring to picture I.F. amplifier automatic gain control, what would be the (undesired) effect of utilising a control voltage proportional to the <u>average</u> value of detector output?

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T.FM & F. 9 LESSON NO. 9.

IMAGE REPRODUCTION.

APPLYING THE VIDEO SIGNAL TO THE CATHODE RAY TUBE.

In Lesson 4 we studied the methods used to produce an electric current which varied in sympathy with light variations as the picture was scanned. Lesson 5 explained how this video current could be used to modulate an R.F. carrier wave. In the last lesson (Lesson 8) we arrived at the stage where the modulated wave was "detected", and a replica of the original video signal was re-created across the diode load. We shall now, in logical sequence, proceed to explain the methods and techniques involved in reproducing, on a cathode-ray tube's screen, variations in light corresponding to those original variations as the scene was scanned at the transmitter.

At this stage Lesson 3 on Cathode-Ray Tubes should be revised, paying particular attention to the use of the control electrode for varying beam current and spot brightness. The idea of moving the beam for "scanning" purposes should also be fully grasped, although the details of the "auxiliary" circuits used in a television receiver for this job will be deferred until the following lesson.

POLARITY OF DETECTOR OUTPUT.

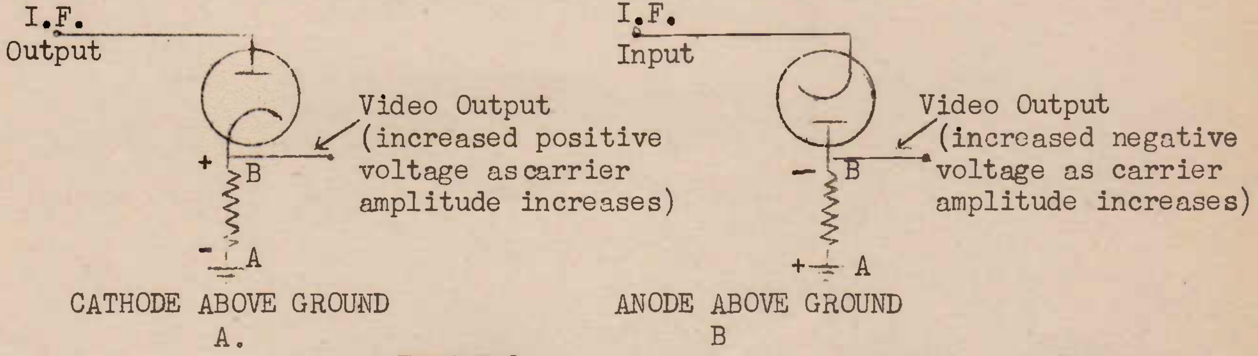
In applying the detector output to the control electrode of the C.R.T. (Cathode Ray Tube) care must be taken to ensure that the polarity of the video voltage on this electrode is correct. If correct precautions are not taken in the design of the detector and any video amlification stages used, a "negative" picture may result. The effect is shown in Figure 1. where at B a negative picture is illustrated. Comparing this with the picture at A it

FIGURE 1.

is seen that light portions have become black and vice-versa. The result may be exactly compared with the negative (i.e. the originally exposed film) of a photograph.

To obtain a correct "positive" picture the video voltage <u>on the C.R.T. control electrode</u> must be going positive as the transmitter scanner moves from a darker to a lighter portion of the scene (and vice-versa). Remember, in this connection, that a more positive voltage on the C.R.T. control electrode will increase the electron stream, and brighten the light spot on the screen. Conversely a negative going voltage will reduce the electron stream, and the spot will become dimmer.

Now, when using a diode as detector there are two possible methods of connection -- the conventional connection, known as "cathode-above-ground" connection shown at A (Figure 2) and the "anode-above-ground" connection as shown at B.



<u>FIGURE 2</u>.

Referring first to the cathode-above-ground connection (Figure "2A") any increase in carrier voltage applied to the anode will result in an increased electron flow upwards through the load resistor, i.e. in the direction from A. to B. This results in the voltage at B (detector output) going more positive. Now if the transmitter were using positive modulation of its signal, an increase in carrier amplitude represents an increase in light intensity. Hence in this case the detector output would be correct for direct application to the C.R.T. However, if a single stage of video amplification were used between detector and C.R.T. a negative picture would result (since the output of an amplifier stage is reversed in polarity compared with its input). If two stages of amplification were inserted the polarity would again be correct. Summarising we may state that, using a cathode-above-ground diode on a <u>positively</u>-modulated signal, either <u>no</u> stages or an <u>even</u> number of stages of video amplification are required.

Referring still to the cathode-above-ground connection (Figure 2A), but considering now a <u>negatively-modulated</u> signal, any increase in <u>carrier</u> amplitude applied to the detector anode would represent a <u>decrease</u> in light intensity. But, as before, the detector output voltage, at B, would go more positive. If this were applied <u>directly</u> to the control electrode of the C.R.T. the spot would become <u>brighter</u>. The polarity is now incorrect. A negative picture would result. To obtain a positive picture the polarity of the detector's output voltage must be reversed before applying the latter to the C.R.T. This may be done by using <u>one</u> or <u>three</u> stages of video amplification, i.e. an <u>odd</u> number of stages.

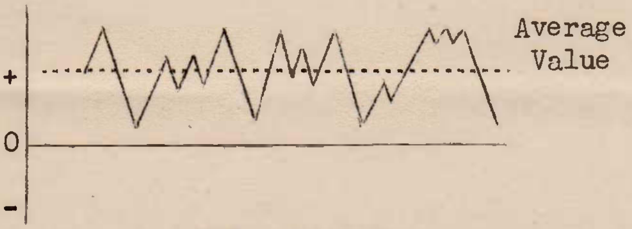
In the case of the anode-above-ground connection of Figure 2B, any increase in carrier amplitude again results in an increased electron flow through the tube, but this time, the electrons, in flowing from cathode to anode, flow downwards through the load resistor from B to A. This increases the voltage drop across the load resistor with the result that point B (output) becomes more negative than before. The following results will be left to the student to figure out for himself:-

For correct picture polarity anode-above-ground connection --
A. Positive Modulation -- an <u>odd</u> number of video stages required.
B. Negative Modulation -- <u>no</u> stages or an <u>even</u> number of video stages required.

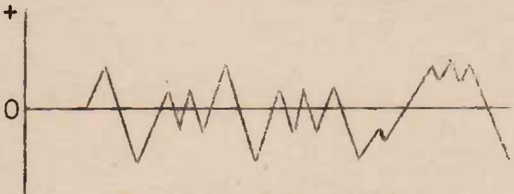
It should be noted here that with improved I.F. amplification, the tendency has been to eliminate all video amplification, applying the detector output directly to the control electrode of the C.R.T. This means that when receiving negatively-modulated signals (as is universal in the U.S.A.) the anode-above-ground connection, as shown in Figure 2B must be used.

THE DIRECT-CURRENT COMPONENT IN VIDEO SIGNAL.

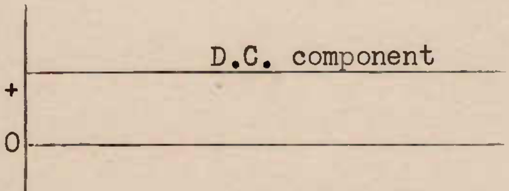
The D.C. component of the video signal refers to the average value of the current (or voltage) about which the variations (representing the picture elements) occur. The video signal consists of a pulsating direct-current or voltage as shown in Figure 3 at A. The variations in current are caused by the variations in light intensity as the scanning beam moves across the scene, and they represent the elements or detail of the picture. A direct-current as at Figure 3A may be considered as consisting of an alternating current (positive and negative half-cycles), shown at B, superimposed upon a <u>steady</u> direct-current as shown at C (Figure 3). This direct-current component has the same value as the <u>average</u> value of the pulsating D.C. representing the complete video signal. The average value of this signal is shown by the dotted line in Figure 3A.



A. Video Signal



B. A.C. Component



C. D.C. Component

FIGURE 3.

Now suppose we consider two video signals as represented on the same graph in Figure 4. Both signals have identical A.C. components, but the D.C. component of signal A is greater than that of signal B. Now what has caused the difference between those two signals? Since they have identical A.C. components they represent the same picture elements, but the average value of A is greater than the average value of B. This means that the average amount of light on the scene resulting in signal A is greater than the

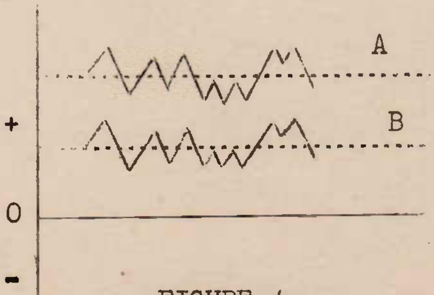
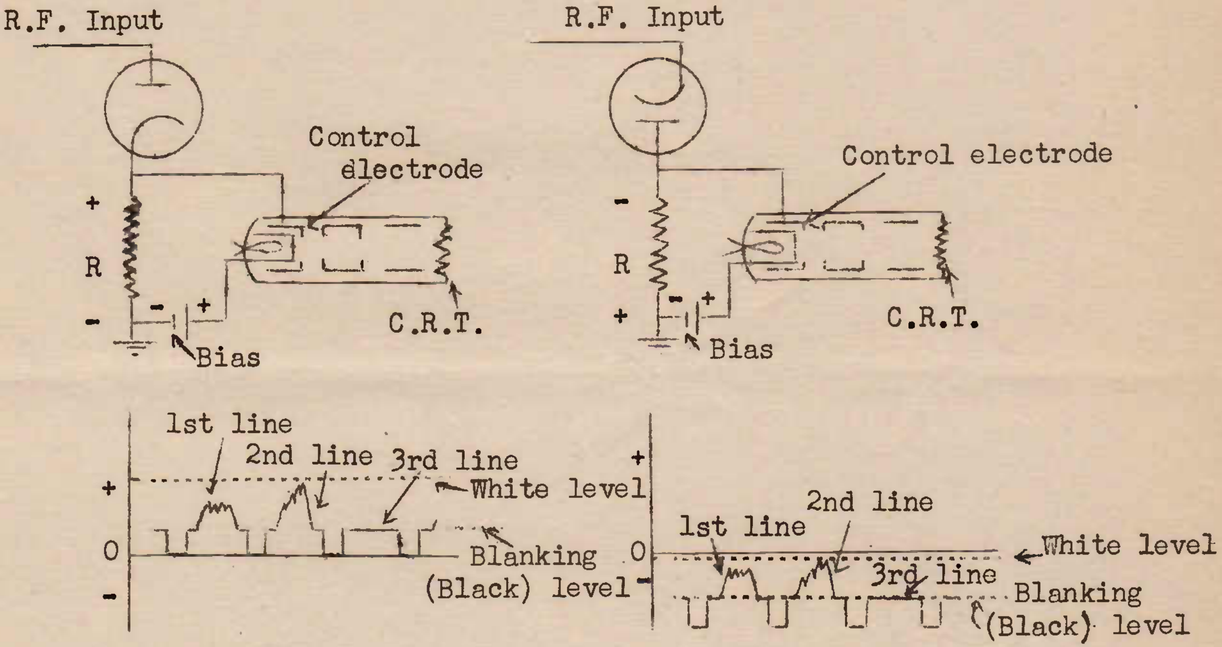


FIGURE 4.

average amount on the scene producing signal B. For example signal A might have been obtained from a scene bathed in bright sunlight, while signal B might have been caused by the <u>same scene</u> when the sky was over-cast.

When at a cinema, we are able to appreciate how the brilliance portrayed on the acreen varies. Bright sunshine, twilight, semi-darnkess etc, each has its place, and in this way complete entertainment is obtained. The importance, then, of applying the D.C. component of the video signal, as well as the A.C. component, to the C.R.T. control electrode will be realised.

The video signal first re-appears in the receiver across the diode load, after de-modulation. This voltage will be a D.C. one, varying about an average level as the picture elements are scanned.



A. Positive Modulation - Detector Cathode above ground. Detector Output Shown Below.

B. Negative Modulation - Detector Anode Above Ground. Detector Output Shown Below.

<u>FIGURE 5</u>.

In Figure 5 the two possible cases are shown. At A we have a detector connected with cathode above ground, operating on a positively modulated R.F. (or I.F.) signal. At B is shown a diode with anode above ground for reception of a negatively modulated signal when no stages of video amplification are used. In either case it is seen that the video voltage developed across the diode load is a <u>positive</u> video signal (i;e. a positive-going voltage corresponds to an increase in light intensity, and vice versa). But note that in case A the average value (i.e. D.C. component) of the output voltage is positive; while in case B this D.C. component is negative.

In both cases the detector outputs are shown for three scanning lines. The second line has a higher average value than the first, representing a greater average value

in illumination. The signal voltage for line 3 remains at the black (blanking) level for the whole duration of the line. This line corresponds to an entirely black strip of the scene.

APPLYING DETECTOR OUTPUT TO C.R.T.

It will be remembered that the control electrode of a C.R.T. functions in a very similar manner to the control grid of an ordinary amplifying valve. If given a negative voltage in respect to cathode the electron beam (anode current) is reduced, resulting in reduced brightness of the light spot on the screen. If this control electrode voltage is made sufficiently negative "cut-off" occurs, as in an amplifying tube. This condition corresponds to black in a picture on the screen.

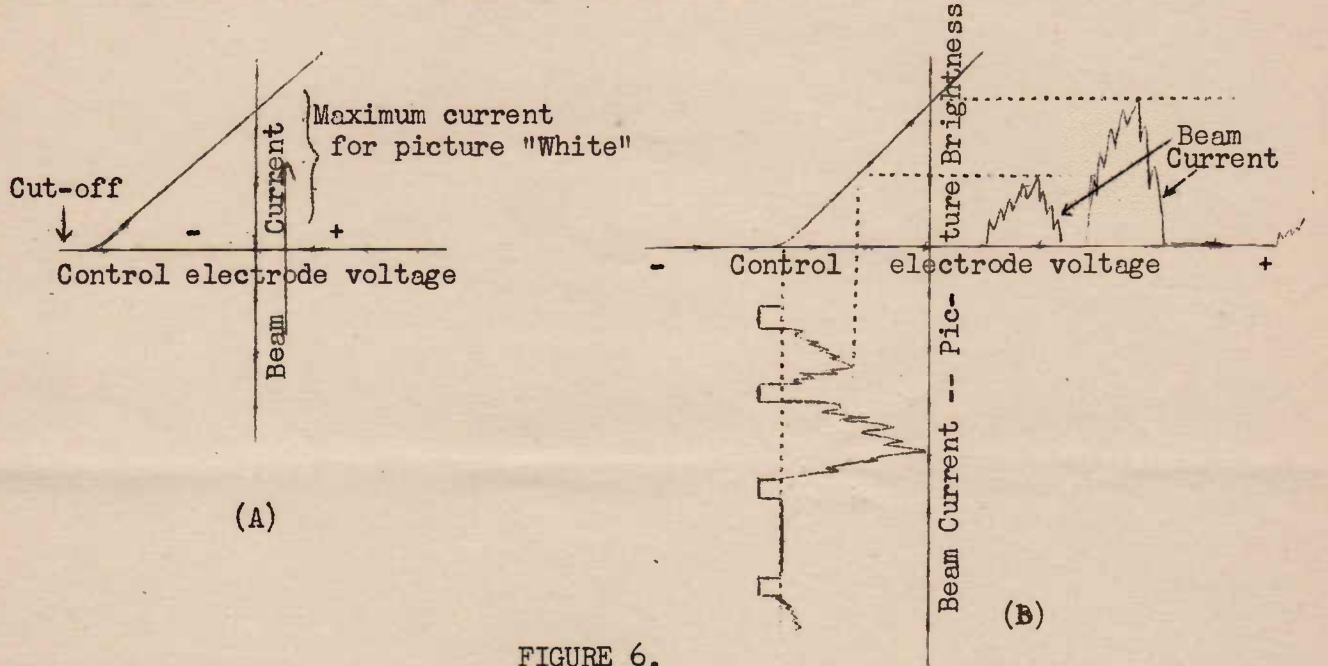


FIGURE 6.

Figure 6A represents a control electrode-beam current characteristic for a typical tube. In practice control-electrode voltage is always maintained negative, by the application of a bias voltage (as in the case of class A amplification using triodes, pentodes etc).

The video signal from the detector is applied between control-electrode and cathode of the C.R.T. so that its black ("blanking") level corresponds to the C.R.T's negative control electrode cut-off bias. Now referring back to the detector output, shown in Figure 5, it is seen that this black level is a <u>positive</u> voltage in case A, and a negative voltage,(though not necessarily the cut-off value) in case B. These voltages must therefore be adjusted by the application of the correct values of bias voltage in either case. In Figure 5 the bias voltages are represented for simplicity by simple batteries. Figure 6B illustrates in a graphical way the net result. The bias voltage places the signal black level at the tube's cut-off voltage. Note that the sync. pulses carry the control-electrode voltage even more negative, and therefore for the duration of these pulses the screen will remain black. During line scanning a beam current proportional to the signal voltage flows. The screen illumination is, of course proportional to this current. Note that during the scanning of any line, not only is the picture detail portrayed (by the current variations) but the average illumination of the picture is brought out also.

LOSS OF D.C. COMPONENT OF VIDEO SIGNAL.

When employing one or more stages of video amplification between detector and C.R.T. the D.C. component of the video signal is lost. This is due to the capacitive coupling normally used between stages.

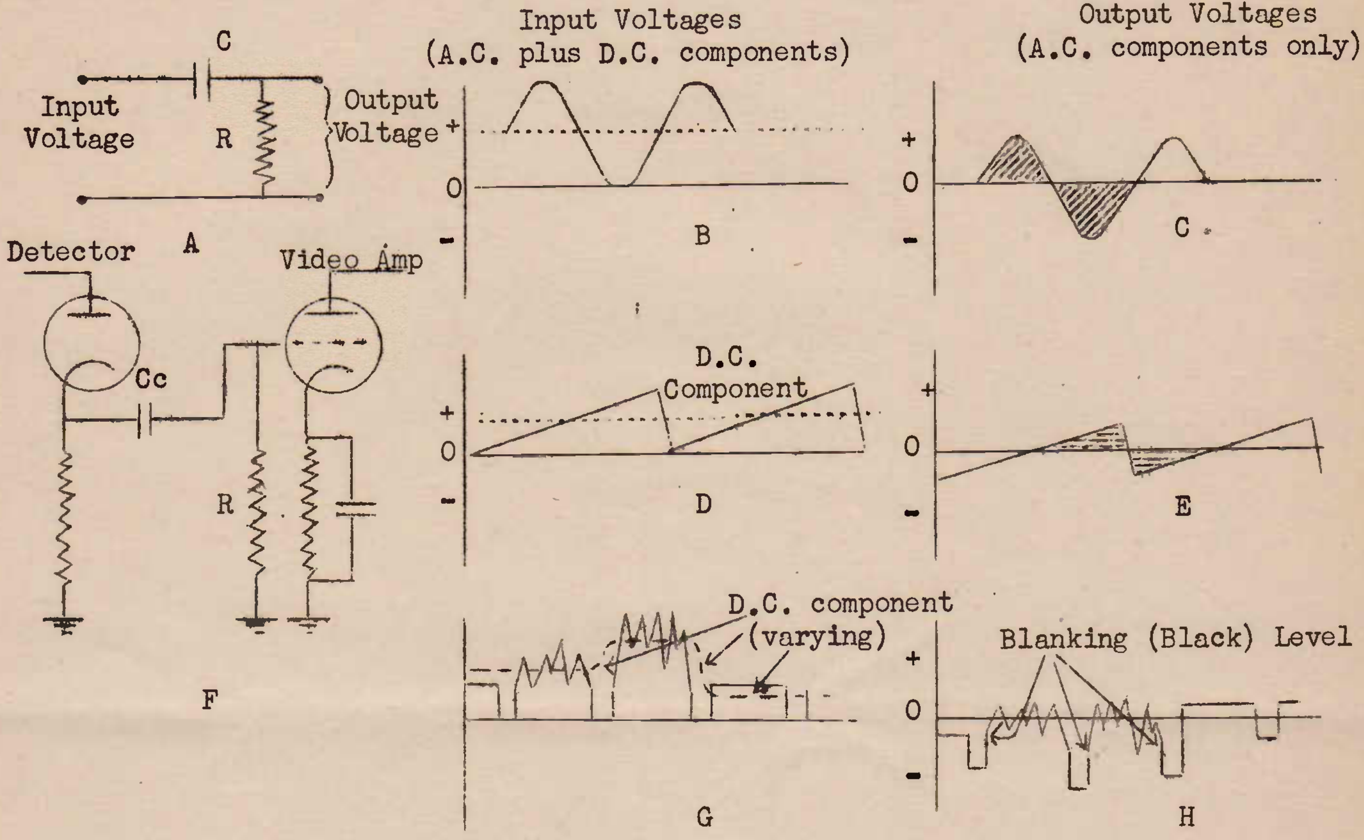


FIGURE 7.

It is important to understand clearly what happens when a voltage consisting of an A.C. and D.C. component is passed through a network involving a condenser as in Figure 7A. The condenser blocks the D.C. component, passing only the A.C.

At B and D are shown two examples of voltages containing D.C. components. The corresponding output voltages obtained across R (Figure 7A) are shown at C and E respectively. These are pure A.C. voltages. Note that the voltages adjust themselves so that the areas contained by the positive half-cycles are equal to the areas contained by the negative half-cycles.

At F (Figure 7) is shown a diode detector resistance-capacity coupled to a video amplifier. The detector output voltage, containing both A.C. and D.C. components, is graphed at G. Note that the D.C. component varies for the three scanning lines shown, as the average illumination changes. Since this D.C. component is completely lost after passing through the coupling condenser Cc, the voltage on the grid of the video amplifier is as at H. The average illuminations of all the lines are now the same. Hence a true portrayal of the picture will not be obtained. Another important point to note is that the voltage level corresponding to black varies as the average illumination changes. This will be seen by carefully examining graph H of Figure 7. Summarising then, we may say that loss of the D.C. signal component: (1) Results in a flat, drab picture having no contrasts in over-all illumination, and (2) Renders it impossible to maintain the signal blanking (black) level at the cut-off value of control electrode potential. The seriousness of this latter point will be realised later when dealing with scanning generators.

D.C. RESTORATION.

The loss of the signal D.C. component, when using video amplifiers after detection, is remedied by utilising a special circuit known as a D.C. Restorer. Such a circuit creates a D.C. voltage, proportional to the original voltage, representing the average picture illumination, and varying with it. This D.C. voltage is then applied, together with the A.C. signal voltage from the plate of the last video amplifier, to the control electrode of the C.R.T. The process is sometimes also called D.C. reinsertion.

CHARGE AND DISCHARGE OF A CONDENSER THROUGH A RESISTOR.

Before explaining the operation of a D.C. Restorer Circuit it will be necessary to discuss the exact manner in which a condenser charges through a resistor when a D.C. voltage is suddenly applied across the circuit, and also the nature of the discharge of the condenser through the resistor. We shall go into this subject in some detail, because the ideas developed will be necessary to explain, not only D.C. Restoration, but also the manner in which the two sets of sync. pulses are separated, and, again, the action of certain types of saw-tooth generators. In this way, we hope to at least partially kill several birds with the one stone.

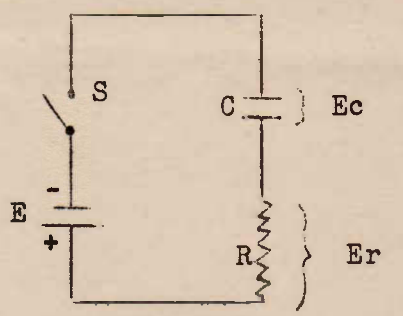


FIGURE 8.

Consider the circuit of Figure 8. When the switch S is closed the D.C. voltage E is applied across C and R in series. Electrons will flow around the circuit away from the lower plate of C, through R, and onto the upper plate of C. In this way C commences to become charged. The electron flow will only cease when the potential difference across C equals the battery e.m.f. "E", the condenser then being "fully" charged. The charging action, however, will not occur instantly after closing S, for the resistor R limits the rate of electron flow (i.e. the current). This means that the voltage across C (Ec) doesn't jump up to its final value instantly, but rises more or less gradually. The current flowing around the circuit will have a maximum value the instant after S is closed. As time goes on, however, and C acquires a charge this current will gradually decrease in value. The reason for this is that as C charges it produces a back "pressure" or voltage (Ec) which opposes the applied e.m.f. "E" (see Figure 9A). The greater the charge on C becomes, the greater this back pressure (Ec), and the smaller the charging current.

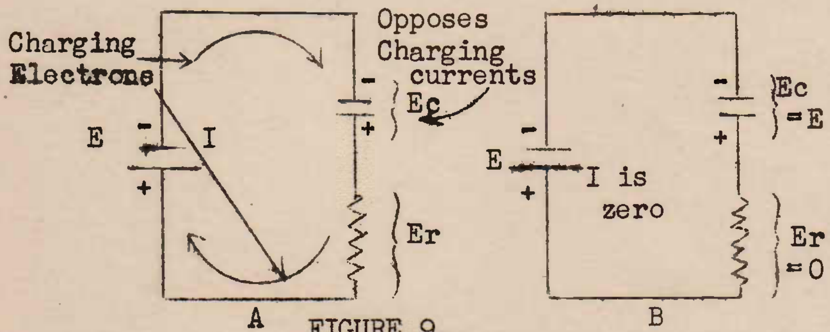


FIGURE 9.

Now the value of the current in the circuit at any instant of time determinates the rate at which C is charging. It follows that, as time goes on, after closing S, the rate of rise in condenser voltage (Ec) decreases as the value of Ec approaches the value of E. Hence the condenser will charge (i.e. Ec will increase) in accordance with a curve something like that in Figure 10. It will be noted that as C approaches full charge, the rate of further rise in Ec becomes very slow indeed. The consequence is, theoretically, that it will take an infinite time for the condenser to become fully charged. For practical purposes, however, we could assume that the charging process was complete after a time "t" shown on Figure 10. When this occurs the voltage across C equals the applied voltage E. No further current flows because the two equal voltages in the circuit, E and Ec, oppose and cancel each other (see Figure 9B).

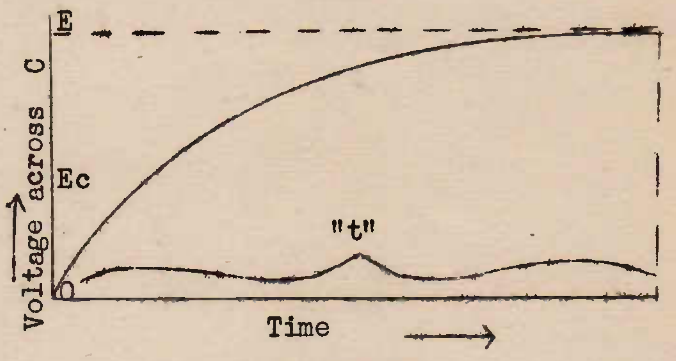


FIGURE 10.

The average slope or steepness of the curve in Figure 10 is a measure of the rate at which C charges through R. This rate depends upon two factors -- the value of the capacity and the value of the resistor. If either, or both of these are increased, the rate of charging will decrease. Conversely, a reduction in value of C or R, or both, will result in a more rapid charging process. Actually the charging time depends upon the product C multiplied by R (written C.R). Figure 11. shows the charging curves for different values of C.R. Curve A is for a medium value of C.R. Curve B, showing a more rapid charging rate, is for a smaller value of C.R, and curve C, for a larger value of C.R. shows a slower charging process.

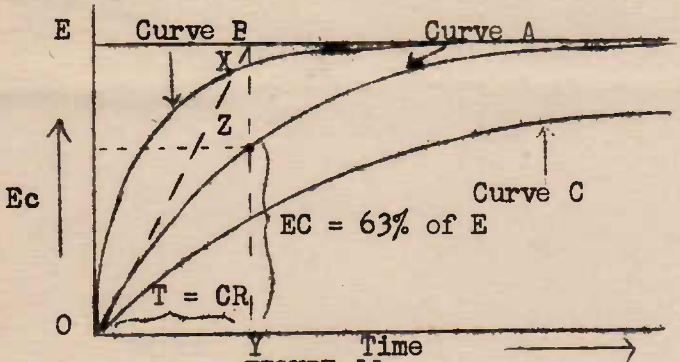


FIGURE 11.

The important product C x R is called the Time-Constant of the Circuit. It is found that in a time (in seconds) equal to C x R (C in farads, R in ohms) the condenser voltage Ec, rises, in all cases, to 63% of the applied voltage E. This is shown in reference to curve A in Figure 11. where in the time T = CR, Ec has risen to approximately $\frac{2}{3}$ of the value of E, The Time Constant, then, is given by the formula: T = C.R.

Where T is in seconds, C in Farads, R in ohms. The formula is also correct if C is measured in microfarads and R in megohms (T still being given in seconds).

For example suppose a battery of 100V is connected across a resistor of 3 megohms in series with a condenser of 2 microfarads. The Time-Constant of the circuit is T = 3 X 2 = 6 seconds. This is the time required for the condenser voltage to rise to 63% of 100V, i.e. to 63V.

The time-constant of a resistance-capacity circuit may be regarded as the time which would be taken for the condenser voltage to rise to the full value of the applied voltage, assuming that the rate of charging continued at its initial rate for the whole time. If this occurred the condenser voltage would rise according to the dotted line OX in Figure 11. The time taken to attain full charge is OY. Note that in a time equal to OY the condenser voltage actually only attains a value equal to 63% of E.

Equally as important as the rise in condenser voltage is the manner in which the resistor voltage (Er) changes with the charging process. When the switch of the circuit in Figure 8 is first closed all of the applied voltage E instantly appears as a voltage drop across R. This follows from the fact that, at this initial instant there can be no voltage across C (since C has not yet had time to acquire a charge). Now since the sum of the voltage drops around a circuit is always equal to the applied e.m.f, i.e. since E = Ec + Er, and Ec is zero, therefore, at this instant E = Er. Then, as time progresses, Ec commences to acquire a continually increasing charge, and Ec rises, with the result that Er falls in value. When C is fully charged, i.e. Ec = E, Er must have fallen to zero. This fact can also be seen by observing that now the current in the circuit is zero; and if the current through R is zero, the voltage drop across it (Er) must also be zero.

Figure 12 shows the changes in Resistor Voltage (Er) from the instant of closing the switch. When S is closed Er rises instantly from zero to the full value E. Then as time progresses Er falls off as shown by the heavy curve. The dotted curve in this figure represents the rise in Ec. A comparison of the two curves will bring out a most important point. When the voltage in a CR circuit is suddenly changed, this change in voltage instantly appears across the resistor. No such sudden change can appear across the condenser, because the condenser voltage can only be changed by altering the charge on it -- and this takes time, i.e. time for electrons to flow around the circuit.

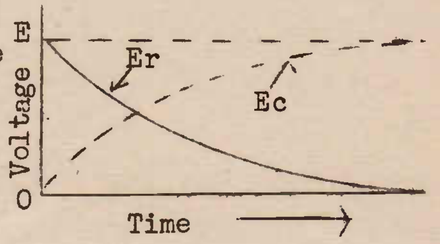
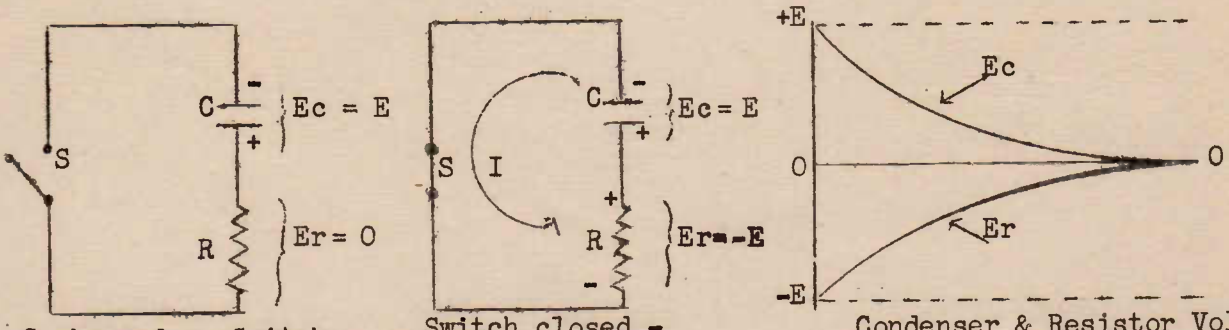


FIGURE 12.

Now consider the manner in which a charged condenser discharge through a resistor.



C charged -- Switch open. A.

Switch closed - C begins discharge. B.

Condenser & Resistor Voltages C.

FIGURE 13.

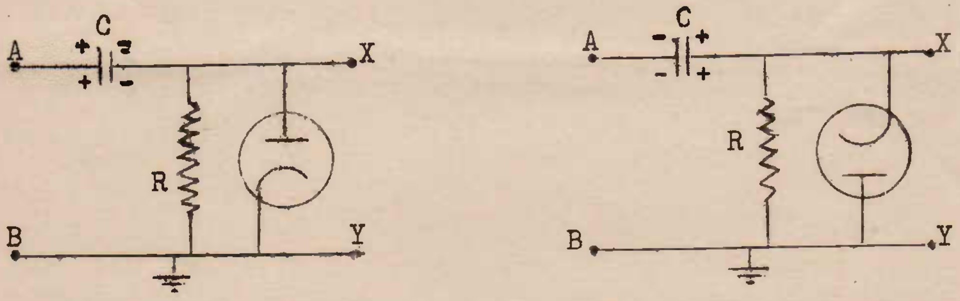
In Figure 13A we will suppose that C has been previously charged to a voltage E. With S open, no current flows and C maintains its charge. On closing S electrons instantly start to flow around the circuit (Figure 13B). The charged condenser may be regarded as a source of e.m.f, such as a battery of voltage E. Hence at the instant of closing S the full voltage E is applied across the resistor. Note, however that the resistor voltage is of reverse polarity or sign to the condenser voltage. This is seen from the + and - signs in Figure 13B. Hence if we call the condenser voltage (Ec) positive we must call the resistor voltage (Er) negative. This fact may also be appreciated by considering that the total voltage around the circuit must be zero (since there is no externally applied e.m.f. in the circuit). Therefore, Er + Ec = 0, from which we deduce that Er = -Ec.

Thus, when S is first closed Er instantly jumps from zero to the negative value -E, as shown in the lower curve of Figure 13C.

Now as time progresses, the condenser gradually discharges, and the voltage across it (Ec) falls towards zero according to the upper curve of Figure 13C. Since the voltage across R is always equal in value to that across C, but of opposite sign, Er gradually changes from the negative value -E towards zero, as shown by the lower curve of Figure 13C. This curve is exactly the same shape as that for Ec, except that it is inverted in respect to the latter. In a time equal to the Time-Constant of the circuit (CR) both voltages will have been reduced by 63% of their former value, i.e. to a value equal to 37% of E. Eventually, of course, the condenser will become completely discharged, and both voltages will be zero.

D.C. RESTORER CIRCUITS.

A D.C. Restorer consists essentially of a condenser, a resistor, and a rectifier (usually a diode) connected as in Figure 14. For reasons which will be apparent directly circuit A is called a "Negative" D.C. Restorer, while B is a "Positive" D.C. Restorer.



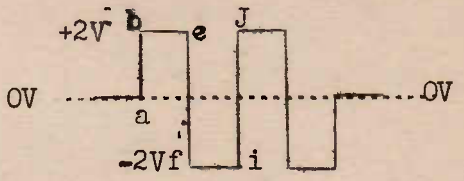
Negative D.C. Restorer
A.

Positive D.C. Restorer.
B.

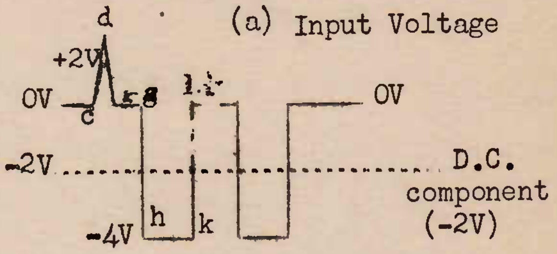
FIGURE 14.

To explain the action of the negative D.C. restorer we shall assume that a pure A.C. voltage (zero D.C. component) of square wave-form, as shown at A Fig. 15 is applied between the input terminals A and B of the circuit Fig. 14A. This voltage is shown with an amplitude 2V, varying between +2V and —2V. Since the lower side of the circuit is earthed we may assume that the potentials of points B and Y are always zero.

When the input voltage between A and B (Figure 14A) suddenly rises to +2V, this voltage instantly appears across the resistor R, i.e. between X and Y, (see resistor voltage in section on charge and discharge of a condenser through a resistor). This means that the potential of the output terminal of the circuit also suddenly rises to +2V (see rise cd Figure 15(b)). Now this state of affairs will not continue for any length of time; very rapidly the output voltage will fall to zero as shown by the curve dg in Figure 15 (b). The reason for this is that the anode of the diode becomes positive with respect to its cathode. The valve thus becomes a conductor, and electrons will flow from cathode to anode, and thence on to the right hand plate of condenser C (Figure 14A). The condenser will therefore rapidly charge till the potential difference between its plates is 2V. Since the output terminal X of the circuit is connected to the right-hand plate of C, its potential will be 2V more negative than the input terminal A. That is point X will have zero potential as shown at "g" Figure 15 (b). While the input voltage remains at +2V (see be, Figure 15(a)) the output voltage will remain at zero. When the input voltage suddenly changes from +2V to −2V, as shown by the fall e.f, Figure 15(a), the output voltage at X will suddenly fall from OV to −4V, -- see point "h" Figure 15(b). Note that the potential of output terminal X is always 2V more negative than that of the input terminal A. This is due to the potential drop from left-hand to right-hand plate of the charged condenser. Now while the input voltage remains at −2V (see Figure 15(a)) the output voltage will remain practically at −4V (see h.k. Figure 15(b)). Actually during this time the condenser may discharge slightly through R (Figure 14A), which would result in the output voltage rising slightly in the positive direction. In practice, however, the time-constant C X R is made very long in comparison with the duration of half a cycle of the A.C. voltage. Hence we may assume that once the condenser was <u>initially</u> charged by diode conduction on the <u>first</u> positive half-cycle of the input voltage, this charge will be maintained indefinitely. In any case any slight loss of charge of C during a negative half-cycle will be almost instantly replaced on the next positive half-cycle when the diode again conducts. (It should be unnecessary to point out that C cannot <u>discharge</u> through the diode on the <u>negative</u> half-cycles, for the latter's anode will then be negative in respect to its cathode.)



(a) Input Voltage



(b) Output Voltage

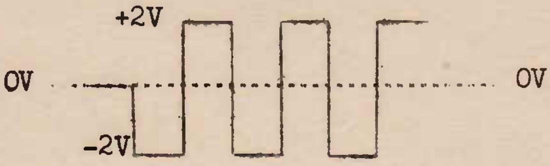
<u>FIGURE 15</u>.

The whole action of the D.C. restorer may be summarised thus: on the first positive half-cycle of the input voltage the condenser is charged by diode conduction, producing a P.D. between condenser plates equal to the amplitude of the A.C. voltage (2V). From this instant the potential of the output terminal X (Fig 14A) of the circuit will always be 2V more negative than the input terminal A. Thus when the input voltage is at +2V, the output voltage is at +2V −2V = OV. When input voltage is −2V, output voltage is −2V −2V = 4V.

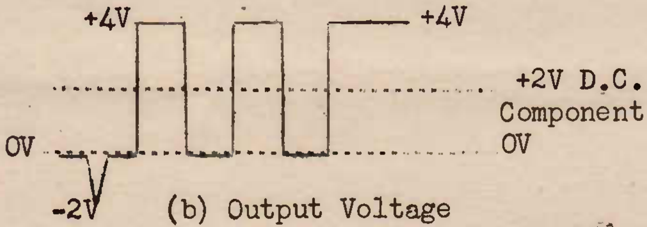
Comparing the graphs of Figure 15, the result is just as if the graph representing the input voltage were moved downwards a distance equal to 2V. Whatever the amplitude of the input A.C. voltage might be, the positive peaks of the latter will be shifted, and held, or "clamped" on the zero volts line. For this reason the circuit is often called a "Clamping" Circuit.

The output voltage (Figure 15(b)) has no positive half-cycles -- it is a pulsating D.C. voltage having a D.C. component equal to −2V (See Figure 15(b)). Thus starting with a pure A.C. voltage we have developed or established a D.C. component without in any way losing the A.C. component. Since the D.C. component which is developed is negative, the circuit responsible is called a <u>negative</u> D.C. Restorer.

Considering now the Positive D.C. Restorer of Figure 14(b). operating on a square-wave A.C., the diode first operates to charge the condenser on the first negative half-cycle of the input voltage. When input terminal A goes negative, this voltage is applied across the diode, such that its cathode is negative in respect to its anode. This is the same as saying that anode is positive in respect to cathode. The diode now conducts to charge the condenser so that its right-hand plate is positive in respect to its left-hand plate. This condenser charge is now maintained; any slight discharge through R being replaced by diode conduction on the next negative input voltage half-cycle. The P.D. thus developed across C results in the output voltage at X (Figure 14.) being always 2V more positive than the input voltage, as illustrated in Figure 16. Note that a positive D.C. component of +2V is established in this case, and the negative peaks of the A.C. input voltage are "clamped" to the zero volts level.



(a) Input Voltage.



(b) Output Voltage

ACTION OF POSITIVE D.C. RESTORER.

FIGURE 16.

ACTION OF D.C. RESTORERS ON TYPICAL VIDEO SIGNALS.

In a television receiver the D.C. restoration is achieved either in the anode circuit of the final video amplifier, or in its grid circuit. Now the video signal in the anode circuit of this stage must be a positive one, and here a positive D.C. restorer is used. On the other hand the signal at the grid of this final amplifier is a negative video signal, and negative D.C. restoration action is required if inserted at this point (See Figure 17).

At the left of Figure 18A is graphed a negative video signal which has lost its D.C. component. This a pure A.C., whose graph takes up a mean position about the zero line. The result of negative D.C. restoration is shown at the right. Note that the positive peaks (peaks of sync. pulses) are now held or "clamped" on the zero volts line. The result is that a D.C. component of signal is established replacing that lost by the blocking action of coupling condensers. Note also how the value of this D.C. component varies as the average illumination of the lines changes. A third important result achieved is that the blanking (black) level now remains at a constant voltage for all ten scanning lines.

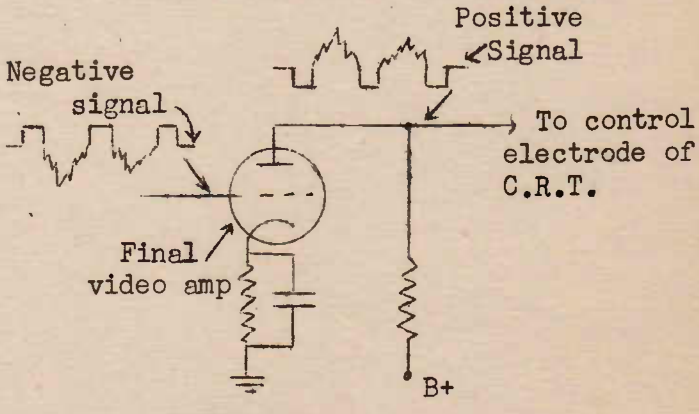
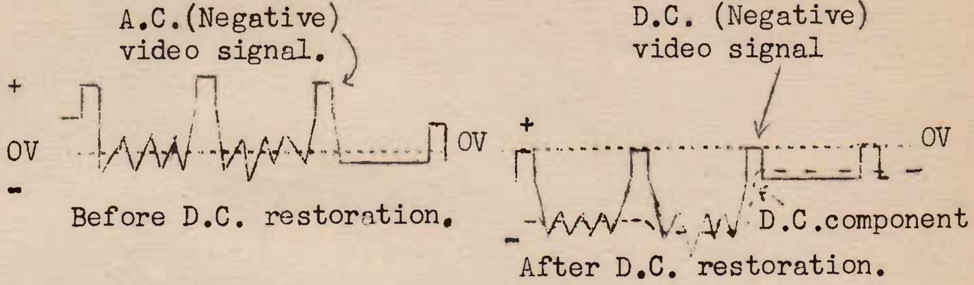


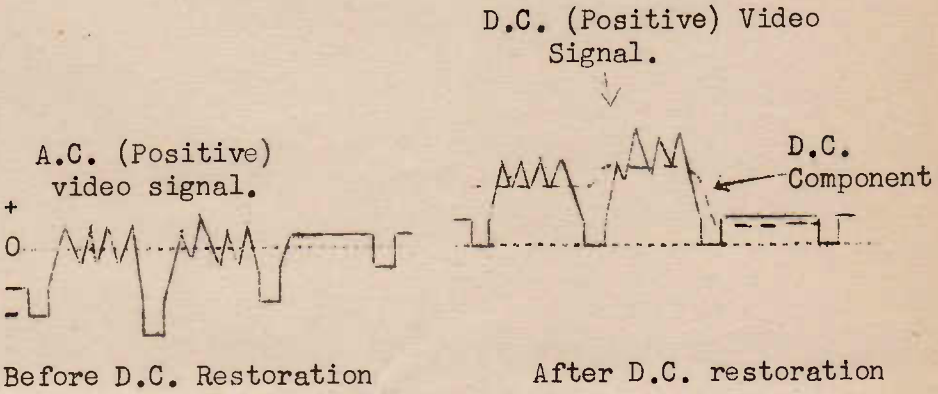
FIGURE 17.

The action of a positive D.C. restorer on a positive video signal is shown at B in Figure 18. The results are similar to those described above.

TYPICAL D.C. RESTORER CIRCUITS.



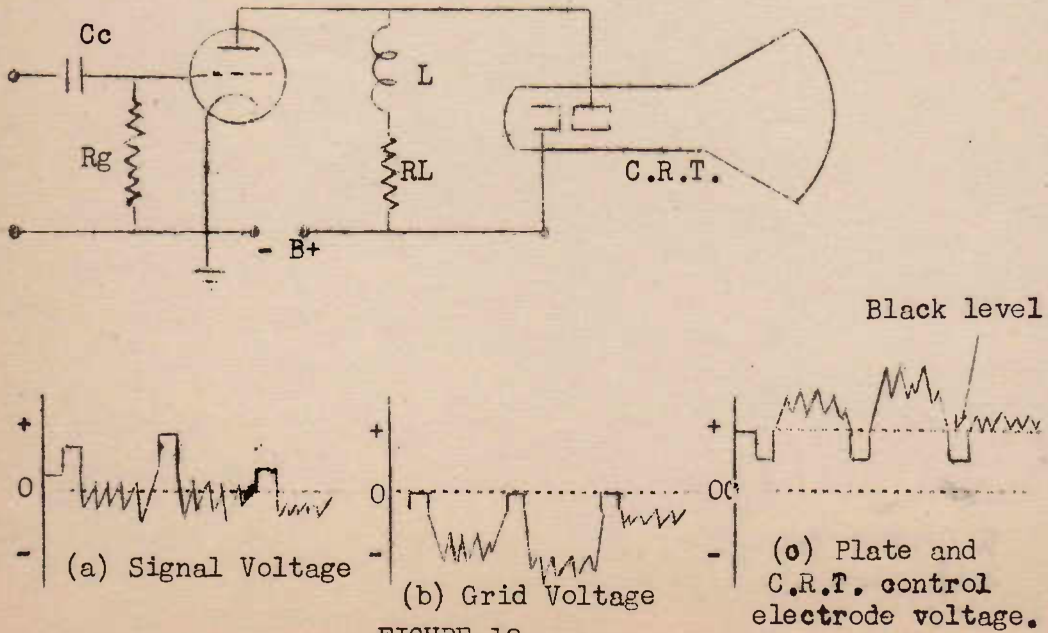
A. ACTION OF NEGATIVE D.C. RESTORER.



B. ACTION OF POSITIVE D.C. RESTORER.

FIGURE 18.

In some television receivers the use of a separate diode for D.C. restoration is avoided by operating the final video amplifier with zero grid bias. (See Fig. 19). Here grid current will flow whenever the signal voltage carries the grid more positive than the cathode. The grid, together with the cathode of the amplifying valve acts like a diode. Hence the condenser Cc, resistor Rg and the grid circuit of the valve (acting as a diode), constitute a D.C. restorer (negative type) similar to that of Figure 14A. The graphs of Figure 19 show at (a) the A.C. signal voltage (no D.C. component, and varying black level). The voltage on the grid, due to the "clamping" action of the circuit will be as at b. Here the positive peaks (the tips of the sync. pulses) have been held to the zero volts line. The black level, at this point in the circuit will be a negative voltage, equal to the amplitude of the sync. pulses (which remain of constant amplitude for a given signal and given receiver amplification. The signal at the tube's anode, which is applied directly to the control electrode of the C.R.T, is shown at (c) Fig. 19. Note that the signal now



(a) Signal Voltage

(b) Grid Voltage

(c) Plate and C.R.T. control electrode voltage.

FIGURE 19.

is a positive one due to phase reversal action of the amplifying tube. The black level of the signal will be fixed at some positive voltage.(Remember that for every voltage on the grid of a given tube there will be a corresponding anode voltage.)

The control electrode of the C.R.T. requires negative bias, such that the black level of the signal corresponds approximately to the cut-off value. This bias is provided by the voltage drop across the anode load resistor (RL)(Figure 19). due to the D.C. flow of anode current through it. This drop is, of course, such that the upper end of RL is more negative than the lower. Hence control electrode is more negative than cathode of the C.R.T.

If the circuit is correctly designed, the effect of signal voltage on the control electrode will be as in Figure 20.

This circuit has two serious defects: the video tube draws heavy plate current in the absence of a signal (since it has no steady bias), and the control electrode of the C.R.T. assumes cathode potential in the event of the plate current of the video tube failing.

These defects are avoided by the use of a separate diode for D.C. restoration as shown in Figure 21. Here V1 is the final video amplifier, RL and Cc being its plate load resistor and coupling condenser respectively. The positive video signal developed across RL is applied across Cr and Rr in series. Rr is shunted by the diode V2. It will be noted that Cr, Rr and V2 form a positive D.C. restorer exactly like that of Figure 14B. The video signal voltage at the point X (upper end of Rr) will therefore be "clamped" or held such that the lower tips of the sync. pulses are always on the zero volts level. The picture pulsations will, of course, go positive in respect to this zero voltage. In other words the diode circuit is acting as a positive D.C. restorer. Now the D.C. voltage on the control electrode of the C.R.T. is identical with that at point X, since there is no voltage drop across R1 (R1 carries no direct current). C.R.T. control-electrode bias is obtained by applying a positive voltage (with respect to ground) to the tube's cathode as shown.

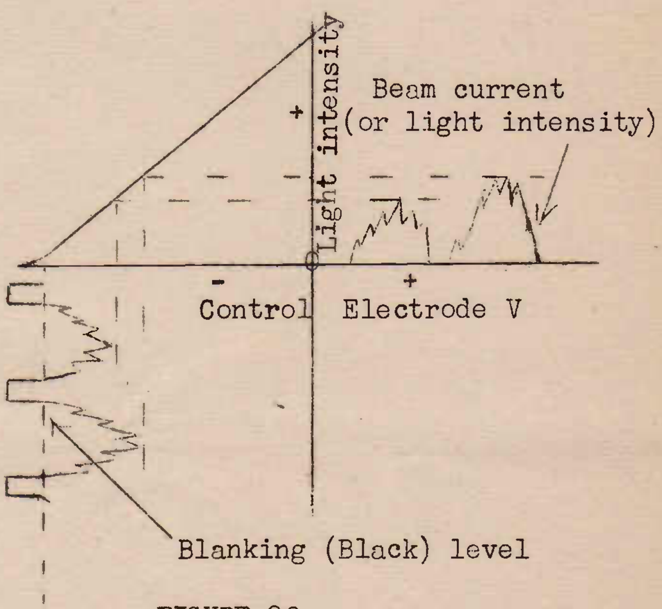


FIGURE 20.

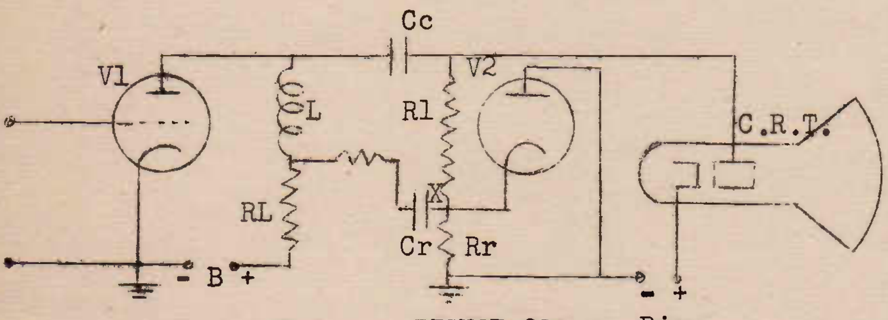


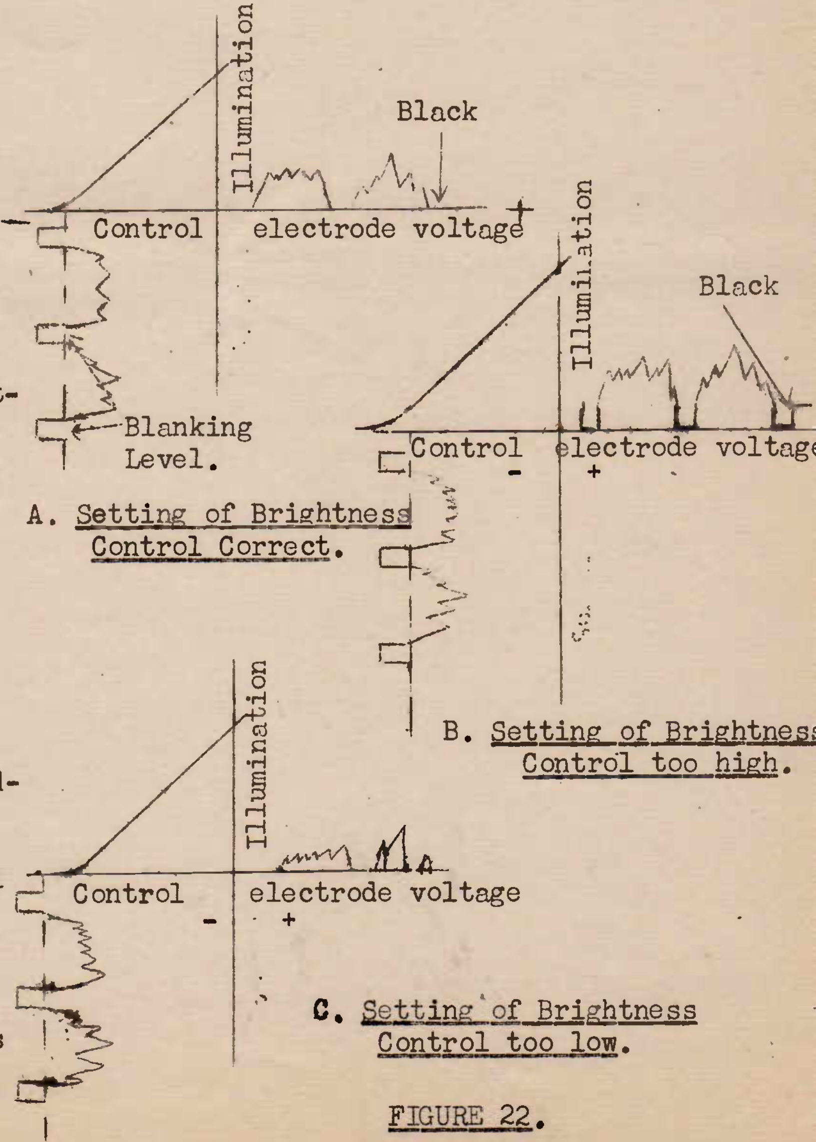
FIGURE 21.

BRIGHTNESS AND CONTRAST CONTROLS.

A television receiver, like a broadcast receiver, incorporates a number of variable controls, to allow adjustment of the equipment for best reception. The television receiver is, of course, a "dual" receiver consisting of two sections -- one for sound and one for picture reproduction. Each section has, in general, its own separate set of control knobs. It might be mentioned here, however, that in the case of a receiver designed for operation on several different channels, the "station selector" is common to both picture and sound sections. This, as explained in the previous lesson, usually takes the form of a selector switch which brings into circuit the appropriate antenna and oscillator coils for the television transmitter it is desired to receive.

Of those controls directly concerned with picture reproduction, it will be convenient at this point to deal with those usually described as the "Brightness" and "Contrast" controls. These are dealt with together, for their actions are inter-dependent; that is an adjustment to one of them usually necessitates an adjustment to the other.

The Brightness Control allows adjustment of the C.R.T. Control electrode bias (in relation to the tube's cathode). In other words it allows us to set the "black" level of the signal on this electrode to about the cut-off value of bias (see Fig.22).



A. Setting of Brightness Control Correct.

B. Setting of Brightness Control too high.

C. Setting of Brightness Control too low.

FIGURE 22.

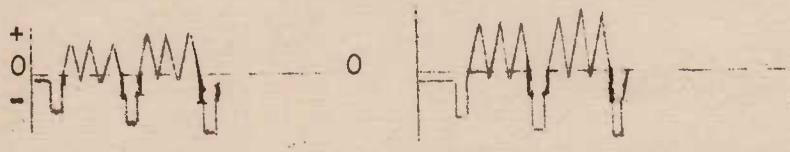
At A (Figure 22) the setting of the Brightness Control is correct. The "blanking" level (base of sync. pulses) of the video signal corresponds to cut-off tube bias, and therefore to zero illumination of the screen. The sync. pulses themselves lie entirely in the "infra-black" region.

If the control is set too high, as at B (Figure 22) the over-all brightness or illumination of the screen will be increased, but pure black will be represented by some screen illumination. This, of course is undesirable. In addition the scanning "retrace" will be visible.
It will be remembered that, during the line sync. pulse intervals the light "spot" is moving back rapidly from right to left on the screen, before commencing a new scanning line. The screen should be "blacked-out" during these short intervals when no picture detail is being received. If the brightness control is set too high the retrace lines will be visible on the screen, thus marring the picture.

The effect of setting the brightness control too low is illustrated at C (Figure 22). Here the black level of the picture signal is set beyond cut-off. This will mean that dull (though not black) sections of the original picture will be portrayed by **black** on the screen (i.e. no screen illumination). It will result in loss of shadow detail.

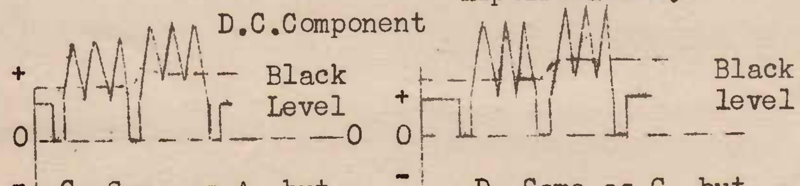
The correct setting of the brightness control is such that the retrace lines <u>just</u> become invisible on the C.R.T's screen.

The Contrast Control varies the receiver's amplification and consequently the video voltage applied to the cathode-ray tube. It corresponds to the volume control in a broadcast receiver. Whereas the latter operates by tapping off a portion of the detector's output, however, the contrast control usually adjusts the bias on the picture I.F. amplifier tubes. These tubes are of the remote cut-off (i.e. variable-"mu") type.



A. A.C. Signal

B. Same as A, but increased amplification.



C. Same as A, but after D.C. restoration

D. Same as C, but increased amplification.

FIGURE 23.

The effect of increased receiver gain is shown in Figure 23. At A is graphed a typical video signal (2 lines). B shows the effect of turning up the contrast control, i.e. increased amplitude of the A.C. signal. C and D show the signals after D.C. restoration. A comparison of C and D will show that increased receiver gain not only increases the amplitude of the A.C. component of the signal, but it also increases the D.C. component.

Increase of the amplitude of the A.C. component means that the difference between the light spots and the darker spots on the screen is accentuated. This, up to a point, augments the clarity of the picture detail. We say, "up to a point", because if the control is turned too high, control electrode current will flow on the positive peaks of the picture signal, resulting in "distortion" which results in a lack of detail in the bright areas. This effect corresponds to overloading in a sound receiver by turning the volume control too high so that grid current flows in one of the amplifying tubes.

It will be observed that actually the contrast control also alters the over-all or average brightness of the picture, but it is reiterated again that the <u>brightness</u> control should always be set so that the "retrace" lines are just obliterated. This involves adjusting the black level of the signal approximately to the C.R.T's cut-off bias. Now if graphs C and D of Figure 23 are compared it will be observed that an increase in contrast control raises the black-level (tops of sync. pulses). Hence each adjustment to the <u>contrast</u> control will, in general involve a re-adjustment of the <u>brightness</u> control in order to bring this black level back to the cut-off value of C.R.T's control electrode bias.

T.FM & F. LESSON NO. 9.

EXAMINATION QUESTIONS.

(1) State the polarity ("positive" or "negative") of the picture obtained in each of the following cases:-

(a) Cathode-above-ground detector, positive modulation, one video stage.
(b) Cathode-above ground detector, negative modulation, two video stages.

(2) What is meant by the D.C. component of a video signal? What does it represent in the picture reproduction?

(3) What components in a receiver cause a loss in the D.C. component? Why?

(4) A battery of voltage 10V is connected in series with a switch S, a condenser C of .05 mfd and a resistor R of value 3 megohms. Answer the following questions:-
On closing S what is,
(a) the initial current in the circuit
(b) the initial voltage across R,
(c) the initial voltage across G?

(5) After what period will the voltage across C (in question 4) be 6.3V (approx)?

(6) Draw graphs showing how the voltages across C & R(in question 4) change from the moment before S is closed.

(7) Draw a circuit diagram of a positive D.C. restorer, showing graphs of a pure A.C. input voltage and the corresponding output voltage.

(8) State two defects which would appear in the picture reproduction if the D.C. component of the signal were not reinserted.

(9) What voltage does the Brightness Control vary? What is the effect of having this control (a) too "low" (b) too "high"?

(10) What is the function of the Contrast Control? At what point or points in the receiver does it usually operate?

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T. FM & F. LESSON NO. 10.

BEAM DEFLECTION & SYNCHRONISATION.

The sections of the receiver to be dealt with in this lesson concern the formation of the scanning pattern on the C.R.T. screen. Scanning, it will be remembered, is achieved by simultaneous horizontal and vertical movements of the electron beam in the picture tube. Such movements are brought about by the application of saw-tooth voltages (or currents) to two pairs of "deflection" plates (or coils) within the tube. This lesson, then, will cover those stages or circuits of the receiver whose final outputs are applied to these deflection electrodes. The problems associated with the application of the video signal to the control electrode have already been fully dealt with.

The circuits concerned, and their proper relationship to each other, and to the receiver's detector and video amplifying stages (if any), are shown in Fig. 1. They include the horizontal and vertical scanning generators (followed by suitable amplifiers), the sync. pulse "clipper" circuit sync. amplifier, and two circuits for separating the horizontal sync. pulses from the vertical.

It must be remembered that the scanning generators, known also as "sweep circuits" or "Time Bases", are really self-maintained oscillators, which produce electrical oscillations having a "saw-tooth", or modified saw tooth, waveform. The vertical scanning oscillator operates at a much lower frequency (the "frame" frequency) than does the horizontal scanning generator (the latter operates at the "line" frequency). The problem of "interlaced"

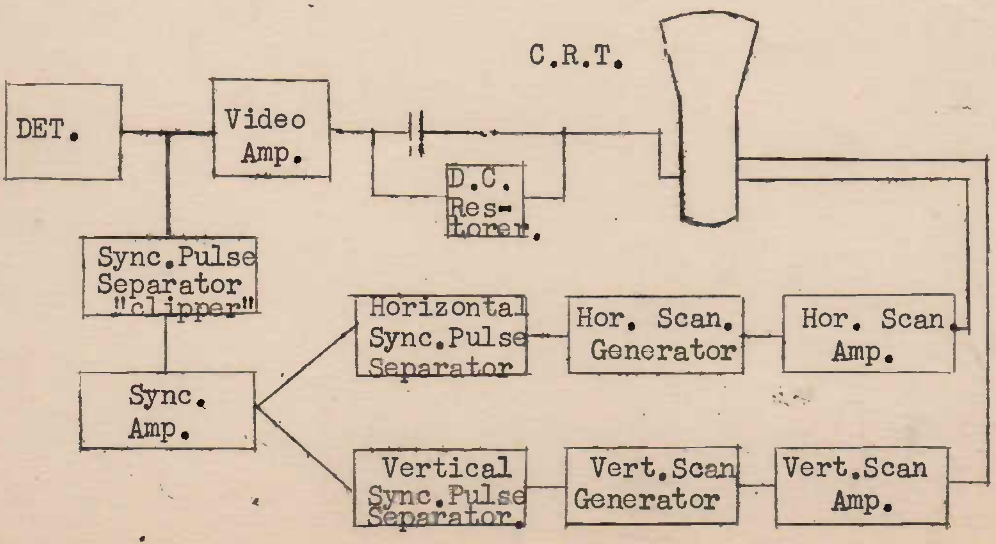


FIGURE 1.

scanning should, at this stage, be revised, if necessary. To give an example illustrating how these two frequencies are related, suppose we are operating upon a system using 405 "lines", 25 pictures per second. If interlaced scanning is used the C.R.T's electron beam must trace out 50 frames per second (2 frames per complete picture). The vertical scanning generator will therefore be required to generate 50 complete cycles of saw-tooth voltage per sec. Since the horizontal generator must cause 405 horizontal lines to be traced out for every complete picture, its frequency will be 25 X 405 = 10,125 cycles/sec.

The example shows that the vertical scan generator operates at the frame frequency (not the picture frequency). The horizontal scan generator has a frequency equal to the picture frequency multiplied by the number of lines per complete picture.

Now the student well knows that it is an impossibility to design any oscillator to run continuously at any exact frequency. Such factors as variations in supply voltage, temperature changes etc. will always lead to a certain degree of frequency "instability". This applies particularly to the special types of generators used for producing saw-tooth oscillations. On the other hand it is especially important that the scanning generators in a television receiver maintain, with a high degree of accuracy, their allotted frequencies. More important still, it is essential that, in the case of the horizontal (line) scanning the generator commences each cycle at the precise instant that the picture information for the beginning of that line is being received on the incoming wave. The student should be careful to note that, even if the scanning generator is operating at its correct frequency, the receiver line scanning may well be out of step with that at the transmitter. This would mean that each line on the receiver's screen would commence at any instant when picture information corresponding to some portion of the scene other than the left-hand edge is being received. The effect, of course, would be a displacement, in a horizontal direction of the picture details, as shown in Figure 2. For similar reasons to these it is equally important that the vertical ("frame") scanning generator be controlled to commence each of its saw-tooth oscillations exactly in step with those of the corresponding generator at the transmitter.

FIGURE 2.
HORIZONTAL DISPLACEMENT OF PICTURE DETAIL AS RESULT OF LACK OF CORRECT LINE SYNCHRONISATION.

Again, it is important that an exact timing relationship should exist between the actions of the two scanning (horizontal and vertical) generators of the receiver. This is essential in order to achieve accurate interlacing of the lines. In the discussion of interlaced scanning in an earlier lesson it was pointed out that each vertical oscillation moving the beam downwards for "odd" frames should cease on a half line, while each vertical oscillation for "even" frames should end at the completion of a whole line. This was essential in order that the lines traced out during an even frame would fall on the spaces "skipped" by the lines of the previous odd frame.

From the foregoing it will be realised that although the scanning generators are self-maintained oscillators, designed to operate approximately at their allotted frequencies, it is essential that they be controlled and "governed", externally, so that each saw tooth cycle is executed at the precise moment as required by the incoming signal. This external control of these generators is provided by the synchronising pulses which are superimposed, at the transmitter, on the television wave itself.

In dealing with the television receiver so far, we have followed the received signal through from aerial to detector, and thence, as far as the true video signal, representing picture detail, is concerned, through the video amplifier to the control electrode of the C.R.T. Referring back to Figure 1 we note that at a point in the receiver immediately following the detector there is a "parting of the ways" as far as the "composite" video signal is concerned. At this point the synchronising pulses (line and frame) are separated from the composite signal, and side-tracked to the scanning generators for the accurate timing control required for the latter. Hence we come to the first of the special circuits or stages of the receiver to which this lesson is specially devoted -- namely the "Sync. Pulse Separator" or "Clipper".

SEPARATION OF SYNCHRONISING PULSES FROM VIDEO SIGNAL.

Although the sync. pulses and the camera signal are both superimposed (as modulation) on the one carrier wave it is possible to achieve a separation of the former from the latter owing to the difference in amplitude which exists between them.

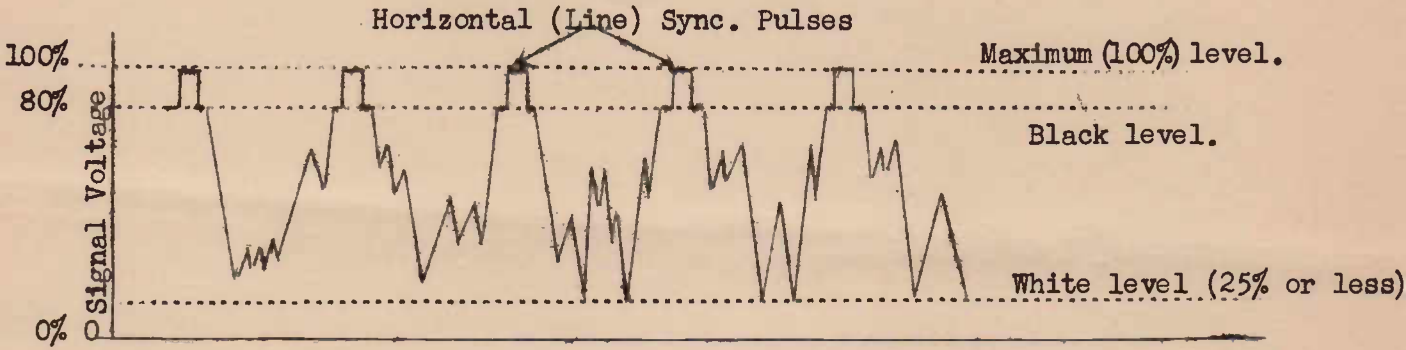
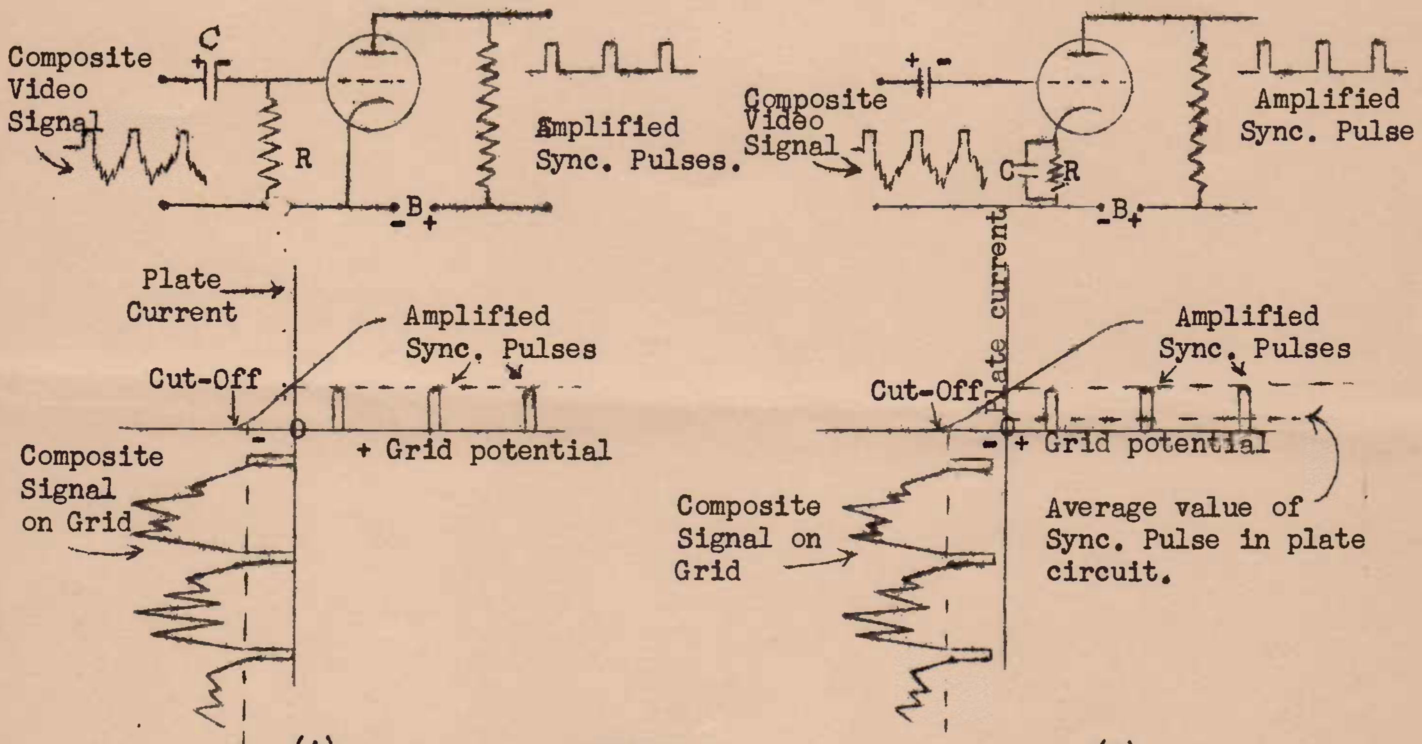


FIGURE 3.

A typical "negative" video signal is shown in Figure 3. Such a signal, of course, is the result of "de-modulating" the R.F. or I.F. carrier wave by the receiver's detector. The maximum (100%) level shown represents the detector's D.C. output when peak carrier amplitude is being received. The 80% level is the D.C. voltage across the detector's load when the carrier's amplitude has been reduced by 20% due to modulation, and so on. The actual value in volts of these levels will of course depend upon the strength of the particular wave being received as well as the overall amplification of the receiver up to the detector stage. Now, as has already been explained, the picture information is conveyed by voltage variations between the 25% (or less) level and the 80% level. Here the 80% level represents a detector output which when finally applied to the control electrode of the picture tube will produce no light (black) on the screen. Any increase in signal above this black (80%) level will therefore have no effect on the screen. Thus the region between the 80% and 100% levels is referred to as the "infra-black" or "blacker-than-black" region. It should be observed that the sync. signals are confined entirely to this particular region.

Separation of the sync. pulses is brought about by applying the composite video signal to a tube (diode, triode, or pentode) so biased that no current can flow through it until the infra-black region, (which contains the sync. pulses), is reached. This involves obtaining a value of negative bias such that the blanking (black) level of the applied signal corresponds to the plate-current cut-off of the valve. "Fixed" bias methods, such as battery bias or "back" bias (derived as a P.D. across a resistor in the power supply) are unsuitable for the purpose, for the reason that the blanking level of the signal does <u>not</u> remain constant, but ordinarily varies with the average level of scene illumination, as explained under the secion on D.C. restoration. Instead, some method of self or automatic-bias must be used.

Common types of "clipper" circuits using triodes (or pentodes) are shown in Figure 4. At A grid leak bias is obtained. The positive peaks of the sync. pulses carry the grid positive, and grid current flows. This charges the condenser C with the polarity shown in the figure. During the periods between the sync. pulses C will, of course, begin to discharge through R. The time-constant R.C, however, is made very large, and consequently this discharge will be negligible. In any case, any such loss will be made good the next time a sync. pulse carries the grid positive. The net result is that the tips of the sync. pulses are "clamped" approximately to the zero grid volts level, as in the action of a D.C. restorer. The condenser C is maintained in a charged condition. The P.D. across this condenser constitutes the grid bias, which is of such value that the blanking level of the signal is fixed at a negative voltage equal to, or slightly greater than, the grid-volts cut-off point (see lower diagram Figure 4A). Plate current can only flow when the tube's grid voltage is less negative than this cut-off point, i.e. during the sync. pulses. The sync. pulses, and not the camera signal, will therefore appear in the plate circuit.



(A) (B)

FIGURE 4.

At B in Figure 4 is shown a circuit using cathode bias. The cathode resistor R is very much larger than would be used for ordinary cathode bias purposes. The bias is obtained by the presence of the amplified sync. pulses in the plate circuit of the tube. These plate current pulses are "averaged out", as far as the cathode resistor R is concerned, by the condenser, C. The average of the plate current pulses is shown by the lower dotted line in the graph of Figure 4 B. This is the current (steady D.C.) which flows through R, and creates a P.D. which constitutes the grid bias. The value of this average plate current multiplied by the resistance of R, should give a voltage at least equal to the cut-off value of grid volts. If this condition is satisfied, then plate current will flow only when the applied signal exceeds the blanking or black level, and only sync. pulses will appear in the plate circuit. Using tubes of high Gm a cathode resistor of about 10,000 ohms is required.

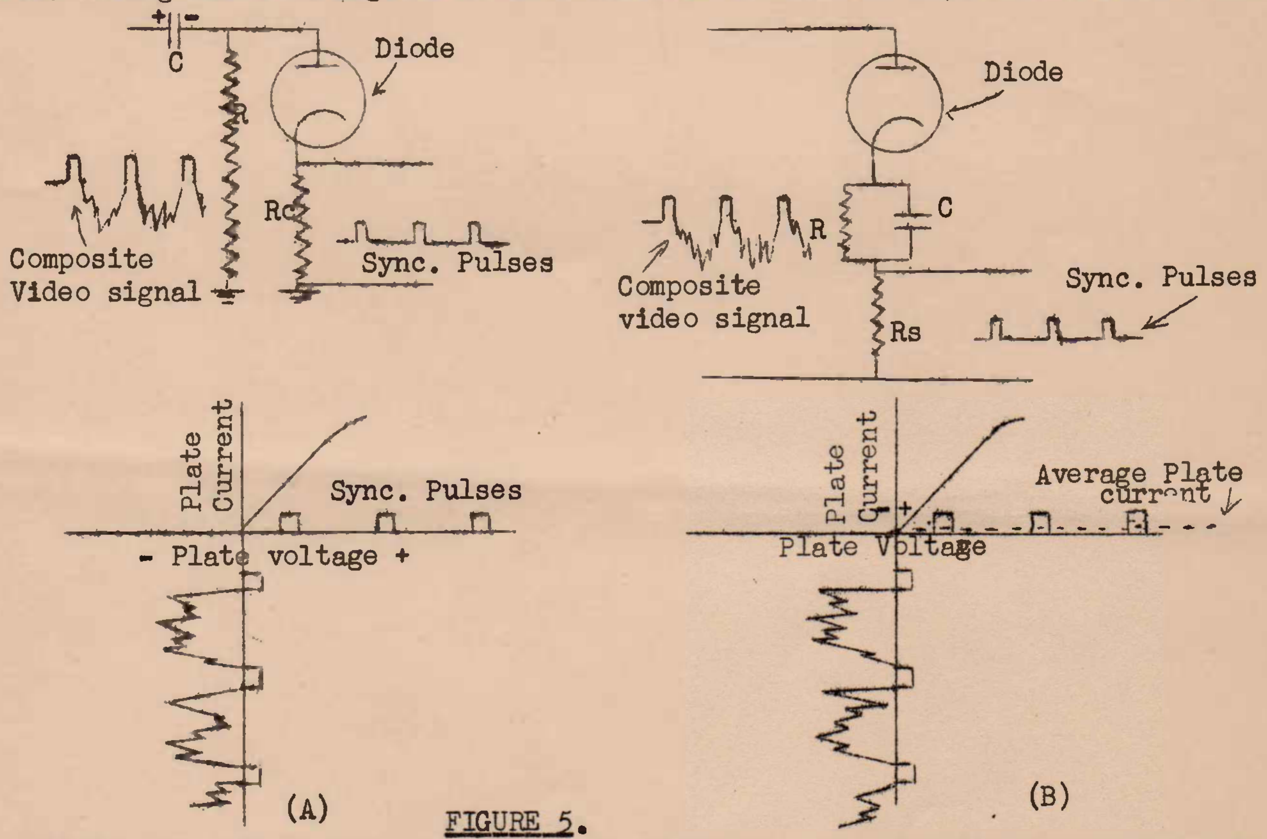


FIGURE 5.

Two circuits using diode tubes are shown in Figure 5. The circuit of A operates in a very similar manner to that of Figure 4A, in that bias is obtained by building up a charge on the condenser C as a result of plate current flow during the sync. pulse periods. To obtain a bias sufficiently large to ensure that plate current flows only during these periods the time-constant R.C. is made very large. The electrical action will be clearly understood by referring to the graph of Figure 5A. The anode is biased negatively to such an extent that the video signal must rise to the blanking level before current flows through the valve. The plate current pulses develop corresponding voltage pulses by flowing through the cathode resistor (un-bypassed) Rc.

The operation of the diode circuit of Figure 5B should be compared with that of Figure 4B. In both, cathode-bias is used. The condenser C averages out the pulses of plate current. The average current is shown by the dotted line in the graph. It is this average plate current, flowing through R, which produces the steady negative bias. The bias is such that the blanking level of the signal corresponds to the zero anode volts level, in order to ensure that sync. pulses only appear in the plate current flow. These pulses of plate current, flowing through the un-bypassed resistor Rs, develop the required pulses of voltage for application to the scanning generator.

SEPARATION OF LINE SYNC. PULSE FROM FRAME SYNC. PULSES.

The circuits described in the previous section separate the synchronising pulses from the main video signal. These sync. pulses, however, consist of two types -- those used to control the line (horizontal) scanning generator, and those whose purpose it is to synchronise the frame (vertical) scanning generator. These two types must be separated one from the other in order that they might perform their allotted tasks.

Referring to Figure 6, (a) shows a negative signal delivered from the receiver's detector, (b) gives the positive video signal as applied (via the video amplifiers) to the C.R.T's control electrode, and (c) represents the sync. pulses as separated from the rest of the video signal by the "clipper" circuit. Concentrating upon graph (c) of this diagram the first four pulses are line sync. pulses for application to the horizontal scanning generator. These consist of a number of single voltage pulses, of short duration, each occurring at the beginning of each horizontal line traced out by the generator. At the end of each frame (i.e. when the spot reaches the bottom of the picture area) the screen becomes blacked out by the signal returning to the blanking (black) level, as shown in Figure 6 at (a). In addition, there follow a number (six are shown) of pulses occurring at twice the line frequency. These despite their higher frequency (as explained later), will keep the line scan generator operating in correct synchronisation. At the same time they allow a short period for the frame (vertical) generator to settle down before commencing its next cycle, which lifts the spot to the top of the screen for the next frame. These six pulses are therefore called "equalising" pulses. Following the equalising pulses the true frame sync. pulses occur. The latter consist of a number (six are shown) of broad pulses as shown in graphs (a), (b) and (c) of Figure 6. (Note:- All pulses in graph (b) are of reverse polarity to those of graphs (a) and (c). This is due to the fact that graph (b) is a "positive" signal, while graphs (a) and (c) represent "negative" signals). At this stage it should be clearly understood that each line is terminated (and the next line begun) by a single narrow pulse. Each frame, on the other band, is terminated by a series (six as shown) of the broad pulses. As will be explained these six broad pulses are added or "integrated" to form a single large pulse as shown in graph (e) of Figure 6.

Graph (d) for this figure shows the output of the horizontal sync. pulse separator. Note that for the whole time during the interval separating the frames this output contains line sync. pulses, occurring at double the line frequency.

We now proceed to explain the circuits responsible for this separation of the two types of synchronising pulses.

LINE PULSE SEPARATION.

The sync. pulses used for line scanning synchronisation, as shown in Figure 6(a)are usually obtained by using what is known as a "Differentiating" circuit. This consists of an R.C. combination, from which the output is taken across the resistor,

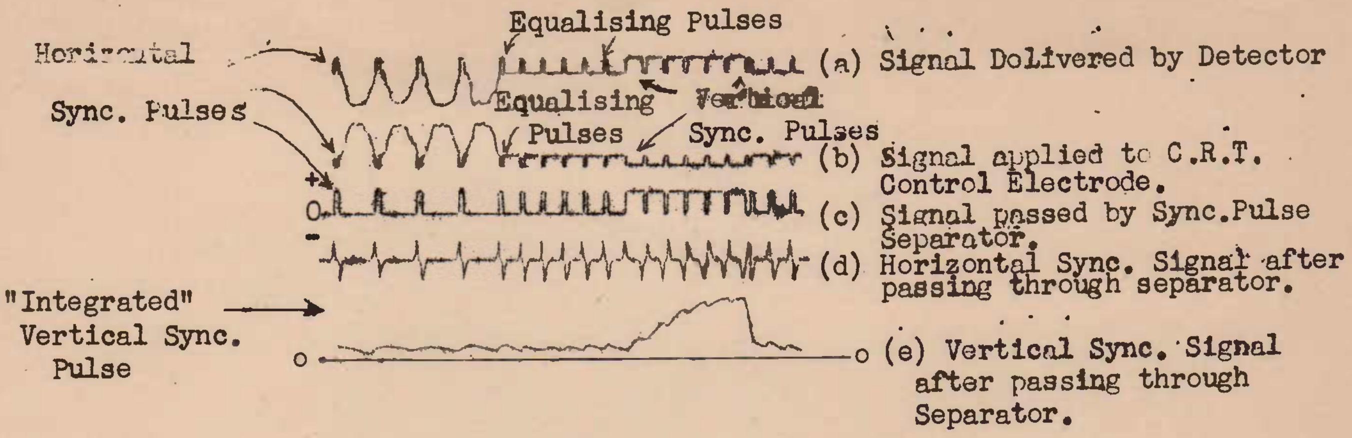


FIGURE 6.

as shown in Figure 7. This is the circuit shown in block form in Figure 1, as "Horizontal Sync. Pulse Separator".

Referring to Figure 7 we shall suppose that some sort of generator G is applying a voltage of square-wave form to R and C in series, as shown in the accompanying graph on the left. Further, we will suppose that the time-constant (R multiplied by C) of the circuit is very short compared with the half-period of the applied voltage (i.e. the time taken by half a cycle -- b c in left hand graph).

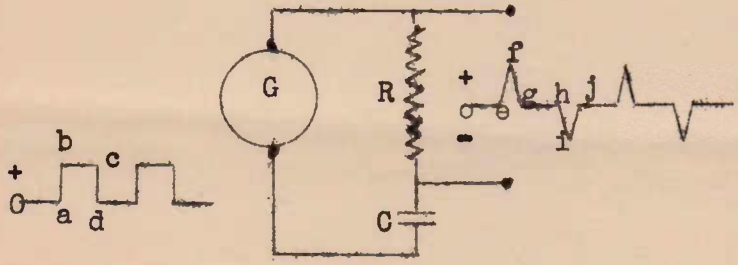


FIGURE 7.

When the applied voltage suddenly rises from zero to its maximum amplitude (a.b. in the graph) the condenser immediately commences to charge through the resistor. Initially, the full voltage a.b. will all appear across R (output) as shown by "e.f" in the output voltage. Now, on account of the very short time constant of R.C. the condenser will very quickly charge up to the applied voltage, and, as it does so, the resistor voltage will accordingly fall to zero. This fall in output voltage is shown by curve "f.g" on the graph (figure 7). For the remainder of the input voltage half-cycle ("b.c") C will remain charged, and the voltage across R will remain at zero -- see "g.h". When the input voltage suddenly falls to zero at the end of the half-cycle ("c.d") C commences to discharge through r. The full voltage of C is suddenly applied across R in the reverse,or negative direction. Hence, at this instant the resistor voltage suddenly jumps,negatively from h to i as shown on the output voltage graph. In a very short time the condenser becomes completely discharged, and the resistor voltage falls from the negative value i to zero at j, where it remains for the rest of the input half-cycle. All of this process will be repeated on the next cycle of the square-wave input.

The effect of the differentiating circuit of short time-constant upon a square-wave voltage should be carefully noted. Every time theinput voltage suddenly changes in value, a sharp pulse, of short duration, is produced in the output. A rise in input voltage results in a positive output pulse, and a fall in input voltage causes a negative pulse in the output. Note that these negative pulses occur in the output, even though the input voltage itself never goes negative.

For line sync. pulse separation in a television receiver the combined sync. pulse signal, consisting of both line and frame pulses, and representing the output of the "clipper" circuit, is applied across a differentiating circuit. The output, taken across the resistor, was shown at (d) Figure 6. The sync. pulses of Figure 6 (c) may be regarded as constituting a series of square waves having positive half-cycles of short duration. The time-constant of the line pulse differentiating circuit should be even shorter than this short period. The resultant output voltage graph (Figure 6 (d)) shows that an extremely sharp positive pulse results every time the input voltages takes a sudden rise (i.e. at the left-hand edge of a sync. pulse of Figure 6(c)). Likewise an equally sharp negative pulse results whenever an input pulse suddenly falls to zero.

The output of this line sync. pulse separator as shown at Figure 6 (d) consists, during any one frame, of a sharp positive pulse (together with its accompanying negative pulse) at the end of each line, i.e. at line frequency. During the period existing between two successive frames a slight modification occurs. The output pulses occur at double the line frequency. This is a result of the nature of the sync. signal between frames, when the "rises" and "falls" in voltage occur at the end of every half-line (see Figure 6 C). As will be clearly understood later, however, pulses at double the line scan. generator frequency are quite effective in synchronising it at its correct line frequency. Remember, by the way, that the line generator continues to trace out lines even during the interval when the vertical (frame) scan generator is returning the spot to the top of the screen before commencing the next frame.

It might be mentioned at this stage, that, although the differentiating circuit produces a series of both positive and negative pulses at line frequency (or double line frequency), as shown in Figure 6 (d), it is only the positive pulses which are effective in synchronising the line scan. generator.

INDUCTIVE METHOD OF LINE PULSE SEPARATION.

The well-known fact that a large counter e.m.f. is induced in an inductance whenever a current changes suddenly, may be utilised for developing a series of sharp pulses occurring only at line frequency or double line frequency. Either Self - or Mutual-Induction may be used as shown in Fig. 8.

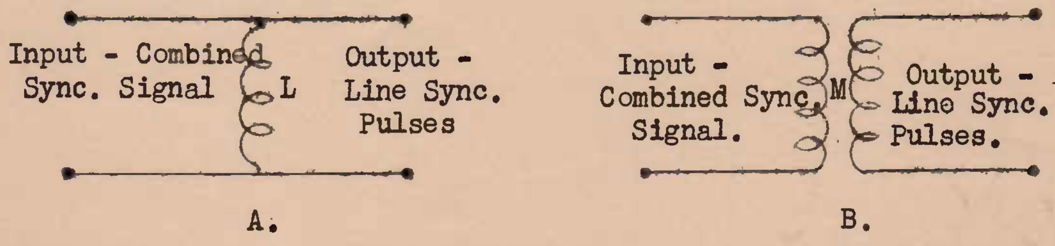


FIGURE 8.

If the combined sync. pulse signal as shown in Figure 6(c) is applied to the input of either of these circuits, the current through the coil suddenly changes at the "leading" or "trailing" edge of a line pulse. These sudden changes in current induce counter e.m.f.'s of self-induction in the case of circuit A, and of mutual induction in the case of circuit B. It is these induced e.m.f's which represent the output line sync. pulses. The outputs, as for the differentiating circuit, will be substantially, as shown in Figure 6(d). Except of reversed polarity, a sudden rise of current at the beginning of the pulse will produce a negative voltage peak. The succeeding fall of current will produce a positive peak of counter E.M.F. Only the negative pulses would be utilised for line synchronising in this case. They would be converted first to positive pulses before applying to the line scan generator, by passing them through a single valve stage for phase reversal and amplification.

FRAME (VERTICAL) SYNC. PULSE SEPARATION.

The frame or vertical pulses occur at a much lower frequency than do the line pulses. They occur only at the end of every frame, instead of at the end of each line. As we have already seen, any two frames are separated by a number (usually six) of broad pulses separated one from the other by negative pulses of short duration. (see graphs (a) (b) and (c) of Figure 6). The question may well be asked: why not have a single broad pulse extending over the period occupied by the six? The reason has already been partly explained. By breaking up the frame sync. singal by downward or negative pulses (at double line frequency), the output of the line pulse separator will continue to maintain the line scan generator in synchronisation during the period in which the spot is moving from bottom to top of the screen between frames. This period of time, short though it is, is sufficiently long for the horizontal (line) generator to trace out many cycles. If the frame sync. signal were not broken or "serrated" by these negative pulses of short duration, the line scan generator could easily get out of synchronisation in the interval between frames.

The purpose of the frame sync. pulse separator is to "integrate" or add up the six broad frame pulses into a single large pulse for application to the vertical scan generator. At the same time the separator must virtually eliminate the effect of the higher frequency line pulses.

The circuit usually employed for this purpose is that known as the "integrating" circuit. The latter consists simply of a combination of R&C from which the output is

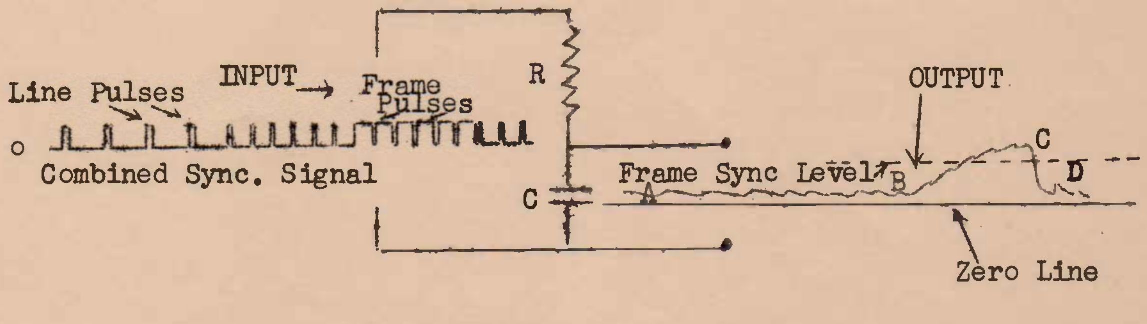


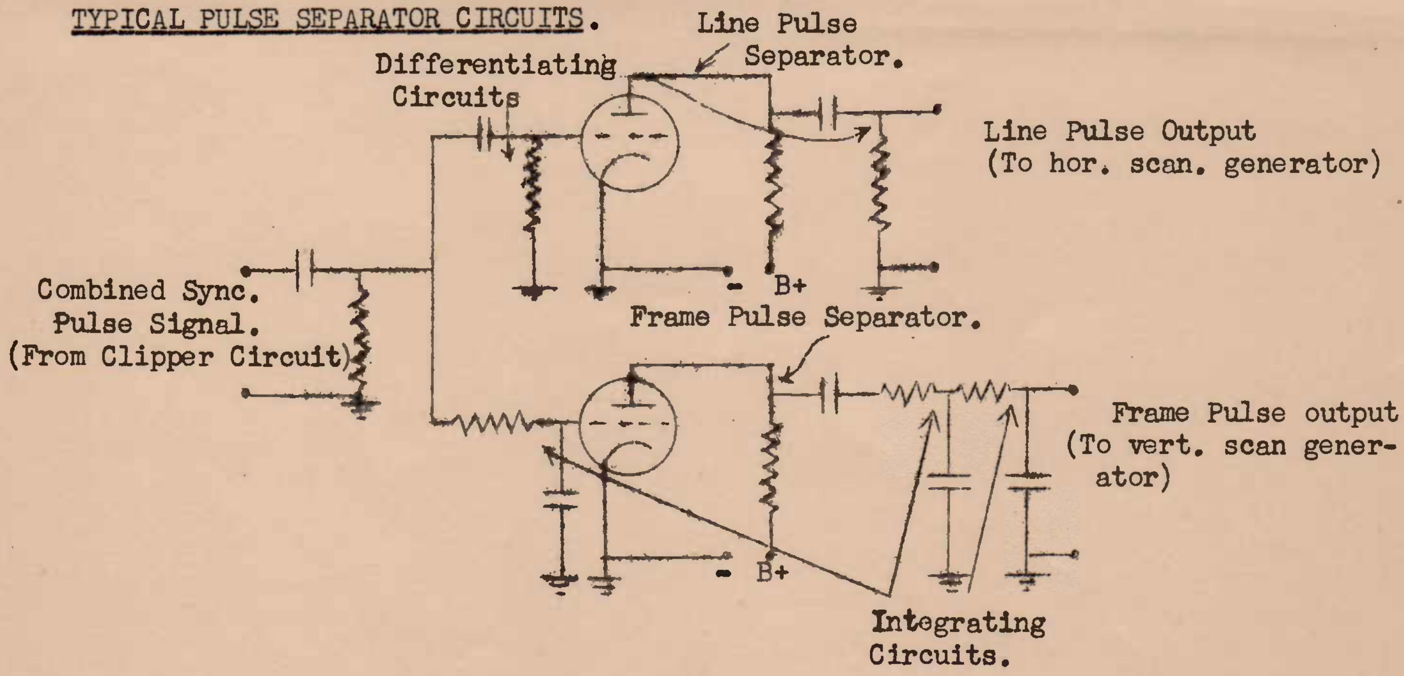
FIGURE 9.

taken across the condenser as in Figure 9. (Compare this circuit with the Differentiating Circuit of Figure 7).

The time constant of the R.C. combination is made long compared with the duration of the <u>line</u> pulses (and the negative pulses separating the frame pulses).

During the tracing of a frame the line pulses will have but little effect on the circuit's output. This is due to the long time-constant R C. When a time pulse is applied across the input the condenser will not have sufficient time to charge up to any great extent. What charge is acquired due to a line pulse will be practically entirely lost, due to condenser discharge, in the period which elapses before the next pulse arrives. The net effect is that, during frames, a small average positive charge is maintained on C, as shown between A and B on the output voltage graph of Figure 9. The small "kicks" in this average voltage are due to the time pulses. Now when the first of the six broad frame pulses arrives, the condenser voltage will rise to a higher level. This is due to the fact that the duration of the frame pulse is longer, and the condenser has time to acquire a larger charge than that due to a short line pulse. When the first broad frame pulse ends only a small fraction of this extra charge is lost, since the "gaps" of zero voltage separating the individual frame pulses are of very short duration. The arrival of the second frame pulse, of comparatively long duration, will result in a further increase in condenser charge, with but small loss at the end of this pulse. The net effect is seen between B and C of the output graph (Fig.9). The six broad frame pulses gradually build up a large voltage across C. When the last of the frame pulses passes, the condenser discharges to its former level. The action of the circuit has been to integrate the six separate frame pulses, occurring between any two frames, into one large pulse of sufficient amplitude to be effective in synchronising the vertical scan generator. Note that the line pulses appear in the output only as a ripple of negligible amplitude. This output, then, will appear as a series of large pulses, occurring at frame frequency, i.e. the frequency of the vertical scan generator.

<u>TYPICAL PULSE SEPARATOR CIRCUITS</u>.



<u>FIGURE 10</u>.
The Differentiating and Integrating Circuits for line and frame pulse separation are usually included in the grid or plate (or both) circuits of amplifying valves.

Figure 10 shows a line pulse separator and a frame pulse separator on a single diagram. For more efficient line pulse separation, two differentiating circuits (one in the grid and the other in the plate circuit of the upper valves) are used. Three integrating circuits (one in the grid and the other two in the plate circuit of the valve) are utilised for the frame pulses.

GENERATION OF SAW-TOOTH WAVES.

For linear deflection of the C.R.T's electron beam to produce the scanning pattern it is necessary, as has already been explained, to generate voltages of "saw-tooth" form. Assuming for the moment electrostatic deflection two such voltages are required. The one, having a frequency equal to the line frequency is applied between the pair of deflection plates producing horizontal movement of the beam. The other, at frame frequency, operates upon the remaining pair of deflection plates, causing the much slower up and down movement of the scanning spot. It should be understood, consequently, that the two saw-tooth generators used are exactly similar in principle. Their only difference is one of frequency.

Most types of saw-tooth generators have one thing in common. The shape of the voltage generated in every case is obtained by alternately charging a condenser through a resistor and then rapidly discharging it by means of a virtual short circuit.

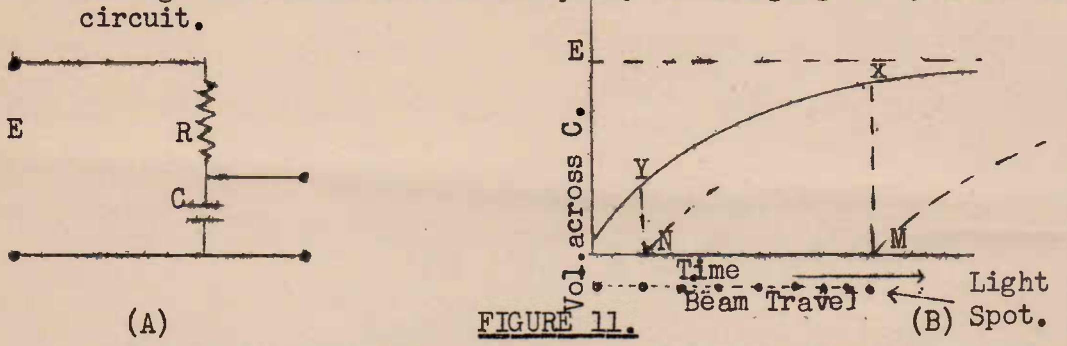


FIGURE 11.

If a steady D.C. voltage E is applied across an R.C. circuit as in Figure 11 at A, the voltage across C will rise in a manner shown by the curve at B. This rise in voltage is not a uniform or "linear" one, but becomes less and less rapid as the condenser voltage approaches the applied voltage E.

If, by some means, the condenser were suddenly discharged, by momentarily applying a short circuit across it when the voltage reaches the point X (Figure 11B), thus reducing the latter to zero, a single cycle of a modified saw-tooth wave would be traced out. This cycle would immediately be followed by a similar cycle, as the condenser commenced to charge again. The application of such a voltage to the horizontal deflection plates of a C.R.T. would result in a non-uniform (i.e."non-linear") movement of the spot across the screen (See Figure 11B), as the voltage rose. The sudden discharge of C (XM Figure 11B) would quickly return the spot to its original point.

Two points emerge from the foregoing discussion. Firstly, generation of saw-tooth voltages may be achieved by making use of an R.C. circuit together with some means of periodically discharging the condenser with great rapidity. For the latter purpose a rotating mechanical switch could be used, but for high frequencies, mechanical methods are unsatisfactory. Below we shall discuss various electronic arrangements which perform this function of condenser discharge.

The second point referred to above, is that, owing to the curved nature of the condenser charging graph, a non-linear trace (as it is called) would be produced on the screen with the result that the picture would be expanded on the left of the screen and compressed together on the right. This difficulty may be overcome in several ways. One way, would be to replace the resistor, through which the condenser charges, by some "constant-current" device, such as a pentode valve as shown in Figure 12A. To understand the function of the pentode, the reason for the non-linear rise in condenser voltage, when charging through a fixed resistor, should be understood. As the condenser voltage rises, the voltage across the resistor correspondingly falls. This results in a decrease in the current flowing through R. $(I = \frac{E}{R})$. It is this current which is responsible for the condenser charge. Hence as time progresses, the charging current, and therefore the <u>rate</u> at which the condenser charge increases, falls off, as shown by the curve of Figure 11. Now it is a well-known fact that the anode current of a pentode valve remains substantially constant for a wide variation of voltage applied between anode and cathode. In Figure 12A the resistor has been replaced by the anode circuit of a pentode. The grid and screen potentials are fixed at constant values by means of separate sources of e.m.f., EB and Eg. As C becomes charged from the source E, the voltage across the pentode progressively decreases, as explained for the resistor. Despite this reduction in voltage across the pentode, however, the condenser charging current flowing through it remains constant. As a result the condenser voltage rises in a uniform manner, as shown by the curve of Figure 12B.

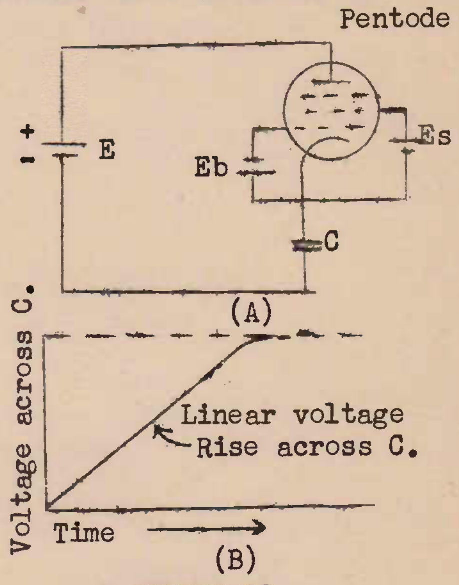


FIGURE 12.

This method of obtaining a linear "trace" has the disadvantage of introducing two extra tubes(one for each saw-tooth oscillator) into the receiver. A second method, using an ordinary resistor as in Figure 11A, is to restrict the rise of condenser voltage to a small fradtion of the full applied e.m.f. Referring to the graph of Figure 11B it will be observed that the early part of the charging curve is, for all practical purposes, straight. Suppose, then, that the discharging device used is adjusted to discharge C when the voltage has risen to the point Y instead of X (Figure 11B). The voltage suddenly falls to zero and a new cycle commences. It is found that if the condenser voltage is limited to about one-tenth of the applied e.m.f. (E) a substantially linear saw-tooth wave will be obtained.

The disadvantage of this method is that the amplitude of the saw-tooth voltage obtained is small. The amplitude required for scanning purposes may be calculated by reference to the deflection sensitivity of the C.R.T. used. If this figure is given as 0.5 mm. per volt, it means that a voltage of 1 volt applied between a pair of deflection plates will cause a spot displacement of 0.5 mm. If the screen is 20 cms. (200 mms) across we shall require $200 \div 0.5 = 400V$ for full deflection. In other words a saw-tooth voltage of amplitude 400V must be generated. If linearity is obtained by limiting the condenser voltage to $\frac{1}{10}$th of the supply voltage, the latter would require to be 4,000V. This is a very wasteful method of obtaining full deflection. A better way would be to use a supply voltage of,say, 400V, producing a saw-tooth wave of amplitude 40V, and then to follow the saw-tooth generator by an amplifying stage of stage-gain 10.

THE GAS FILLED TRIODE.

The gas filled triode is the first of the devices we shall describe to perform the function of periodically discharging the condenser when its voltage has reached the required value.

The gas filled triode is actually a "soft" valve, i.e. a valve into which a trace of gas has been purposely introduced before sealing off. The valve goes by many other names -- e.g. gas-filled relay, gas valve, gaseous discharge valve, thyratron etc.

The tube contains a cathode, anode, and grid, although the function of the latter is quite different from the control grid in an ordinary triode.

When the cathode is heated, the electrons emitted collide with the gas particles and ionise them, as we saw in the case of the gas-focussed cathode ray tube. The positive ions move in the direction of the more negative cathode and neutralise the negative "space-charge" which normally exists in the anode-cathode space. As a result the impedance of the valve is very much lower than that of an ordinary triode being only a few ohms, and the anode current when the valve is ionised is very heavy, being only limited by the cathode emission.

If the grid is maintained at zero potential, and the anode potential of a gas filled triode is gradually increased from zero, it is found that, at first, no current flows through the valve. When the anode potential has reached about 20 or 30V the gas becomes ionised, and a heavy anode current suddenly flows. The purpose of the grid is not to control the anode current, but to determine the anode voltage at which the discharge takes place. For example if the grid potential is maintained at say —5V, instead of at zero, the anode potential may have to be increased to 100V before the tube "strikes", i.e. ionisation occurs and anode current flows. Once ionisation has taken place any variation in the grid bias will have <u>no</u> effect on the value of anode current.

The most important point in the operation of a gas filled triode is the difference between "ionisation" and "de-ionisation" anode potentials. While it may be necessary to increase the anode voltage to, say, 100V (depending upon the fixed value of grid bias used)before ionisation occurs, and anode current flows, this potential may be decreased practically to zero before the current ceases. The cessation in anode current is due to the fact that, at some very low value of anode potential (the "de-ionisation" value) negative electrons combine with positive ions to produce neutral gas atoms.

The use of a gas filled triode in generating saw-tooth voltages is shown in Figure 13.

The R.C charging circuit is connected directly across the supply (H.T.) voltage. The gaseous discharge tube is across the condenser, which it periodically discharges as explained below. A constant negative voltage (bias) is applied to the tube's grid through the resistor Rg. The operation is as follows. When the H.T. is switched on the charging of C through R commences. The output from the circuit is taken from across the condenser. Hence as C charges, the output voltage rises as shown by "ab" on the graph. As the voltage across C rises, the tube's anode potential similarly increases. When this voltage has reached some given value (the "ionisation" potential), as determined by the grid bias Eb, the tube suddenly becomes ionised, forming a very low resistance path (practically a short circuit) across C. The result is that C quickly discharges (see "bc" on the graph). When condenser (and therefore anode) potential has fallen nearly to zero (the"de-ionisation" potential) the discharge suddenly ceases and C commences to charge again. In this way a series of saw-tooth voltage cycles are traced out, as shown by the graph. Note that the gas-tube acts as an automatic switch, discharging C periodically when the voltage across it has reached a certain value.

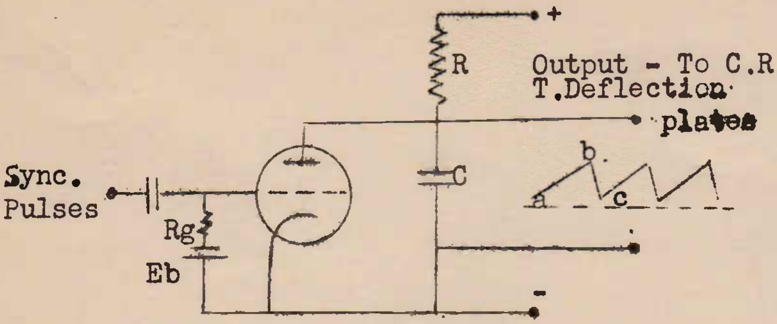


FIGURE 13.

It is important to observe the function performed by the grid. The potential on the latter only determines the value of anode potential (which equals voltage across C) at which the sudden discharge occurs. The grid potential has no effect either upon the value of discharge current, or upon the potential to which the anode must fall before the discharge ceases (the "de-ionisation" potential). It is obvious that, by altering the grid bias, the condenser voltage at which discharge occurs, may be adjusted. In other words alteration to grid bias results in a control over the amplitude of the saw-tooth wave generated. In practice this bias is adjusted so that the condenser voltage can only rise to about one-tenth of the supply voltage. When this is done the saw-tooth wave will be substantially linear, as already explained.

The frequency of the oscillations generated is determined mainly by the time-constant of the R.C. combination, since the latter determines the rate of condenser charge, and therefore the time taken for each cycle. By arranging for variation in C (e.g. by using a number of condensers together with a selector switch), or variation in R (by using a rheostat) the frequency of the oscillator may be adjusted over a given range.

It should also be observed that any alteration to the amplitude of the saw-tooth voltage, will also cause some change in frequency. For example, if the amplitude is increased, by increasing the grid bias negatively, each cycle will occupy a longer period of time and the frequency is therefore decreased.

In practice the grid bias is frequently obtained by means of an adjustable cathode resistor (e.g. a 500 ohm wire-wound resistor) heavily by-passed by means of a large condenser (e.g. 25 mfd. electrolytic). This condenser acts as a reservoir, maintaining a current through the resistor, and therefore negative bias, during the periods when no current flows through the valve (i.e. when the charging process is going on).

SYNCHRONISATION OF THE OSCILLATOR.

When used as a television receiver scanning generator, the oscillator frequency is adjusted approximately to the correct value (line or frame, as the case may be) by the choice of R and C. The exact frequency is maintained, and each cycle is commenced at the precise moment required, by utilising the synchronising pulses coming from the sync. pulse separator.

Referring back to Figure 13, it will be observed that provision is made to "inject" these pulses onto the tube's grid via a condenser.

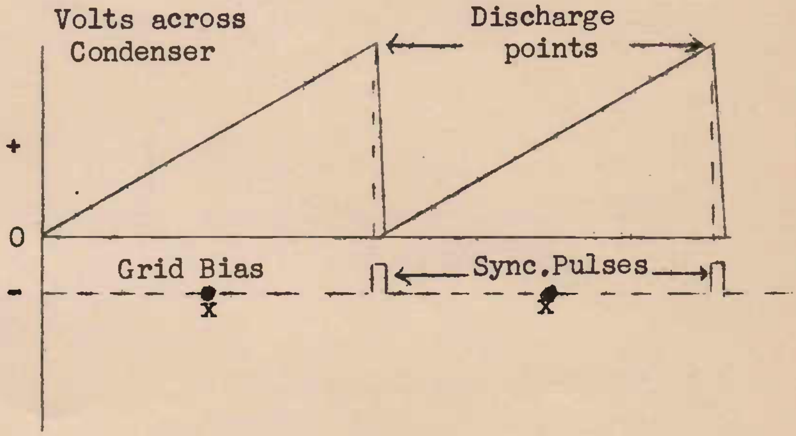


FIGURE 14.

Providing the generator is working at approximately its correct frequency, the condenser (and therefore anode) potential will be nearing the discharge (ionisation) point when the sync. pulse arrives on the grid (See Fig.14). The effect of a positive sync. pulse is to reduce momentarily the negative grid bias. This in turn reduces the tube's ionisation potential. Since anode potential should, at this instant, be nearing ionisation potential, the net effect will be that the sync. pulse will immediately initiate the discharge. In other words the sync. impulse automatically discharges the condenser at the end of each line or frame, and so causes the next line or frame to commence at the correct moment.

Earlier in the lesson it was stated that in the intervals between frames the horizontal pulses occurred at double the line frequency. It was further stated that the pulses occurring at the half-line points would not interfere with the scanning of the line scanning generator. The reason may now be understood. Referring to Figure 14, pulses occurring at the points marked X, could have no effect on the tube's operation. At each of these points the anode potential is still well below the normal ionisation point, and such pulses could have no chance of reducing the latter sufficiently to cause a discharge through the valve. Only those pulses occurring at whole-line periods, when the ionisation potential has nearly been attained, can therefore produce synchronisation.

USE OF "HARD" TUBES FOR CONDENSER DISCHARGE.

Due to the irregularities which occur in the "de-ionisation" process in a gas filled tube, and also due to the fact that this process requires some small, though appreciable, time to complete, this type of "saw-tooth" generator tends to be unstable, particularly when operating at high-frequencies. Despite this, however, the tube has been found to operate quite satisfactorily for both line and frame scan. generators in England. In America, on the other hand, other methods of automatically discharging the condenser were sought. Realising the precise manner in which the ordinary hard vacuum triode may be controlled engineers there decided to abandon the gas filled tube and to adopt the common triode for the purpose.

Now, as we know, the flow of current, or lack of it, through an ordinary triode, must be controlled externally be application of voltages to its grid. In the case of a "hard" tube, anode current flows while there is any potential on the anode, provided that the grid potential is not more negative than the cut-off point. If the negative grid potential is made to exceed this cut-off point, absolutely no current flows, and the tube acts as an open circuit.

Utilising these principles the triode may be adapted to function as a discharge switch for the condenser in an R.C. charging circuit. The method is illustrated in Figure 15. Here R.C. is the charging circuit, connected across the H.T. supply. The triode is connected across C as shown. The valve is biassed negatively, well beyond cut-off, so that no current can normally flow through it. If the circuit is left to itself, let us see what happens. C gradually charges up through R from the source. As the voltage across C increases, so does the anode potential of the valve. Now, since the negative bias on the grid of the latter is sufficient to ensure cut-off for all likely anode potentials, no discharge of C through the tube can occur. Hence C will finally charge up to the full supply voltage, and no further action will occur.

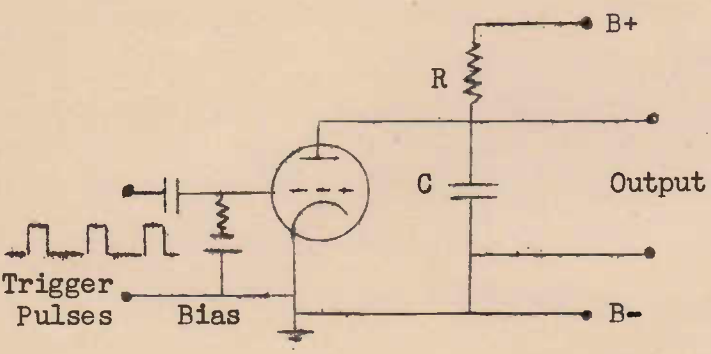


FIGURE 15.

Suppose, however, that sharp regularly occurring pulses, of high amplitude and short duration, are applied from some external source to the grid, as shown in Figure 15. The effect of a large amplitude positive pulse is to momentarily cancel the negative bias, and to allow a heavy surge of anode current to flow, as shown in Figure 16. This means, that, for the short period that each pulse remains on the grid, the valve acts as a very low resistance (virtually a short-circuit) across the charging condenser of Figure 15.

The net result is shown in Figure 16. The condenser charges in the absence of a pulse from the grid. When a pulse arrives the valve becomes conducting, and the condenser is rapidly discharged. When the pulse passes, the value again becomes in effect an open-circuit (due to cut-off bias) and C commences again to charge through R (Figure 15).

Thus we see that a "hard" valve used to discharge the condenser does not act automatically as does the gas filled triode. To imitate the action of the latter we must apply to the triode pulses from an external source. These pulses are called "trigger" pulses, since they imitate the discharge action. A separate valve used to supply these trigger pulses is sometimes called the "triggering" valve.

IMPULSE GENERATORS.

Whence do we obtain the regularly occurring pulses, necessary to cause the circuit of Figure 15 to generate a series of saw-tooth waves? It might be thought at first that these could well be the sync. pulses emerging from the appropriate sync. pulse separator. These signal sync. pulses, however, would vary in amplitude with the signal received, and normally would be of insufficient amplitude and sharpness for the purpose. Furthermore, if we relied upon those for operation of the generator, such operation would only take place when an actual signal was being received. In the absence of a signal the scanning generators would be inoperative, and the scanning pattern would disappear. This is undesirable, because the stationary spot on the screen might result in a "burn" to it, destroying the normal fluorescence. What we require is a "pulse generator", producing a regular series of large pulses of constant amplitude and short duration. The incoming sync. pulses could then be used simply to synchronise the generator in a manner similar to that described for the gas filled tube.

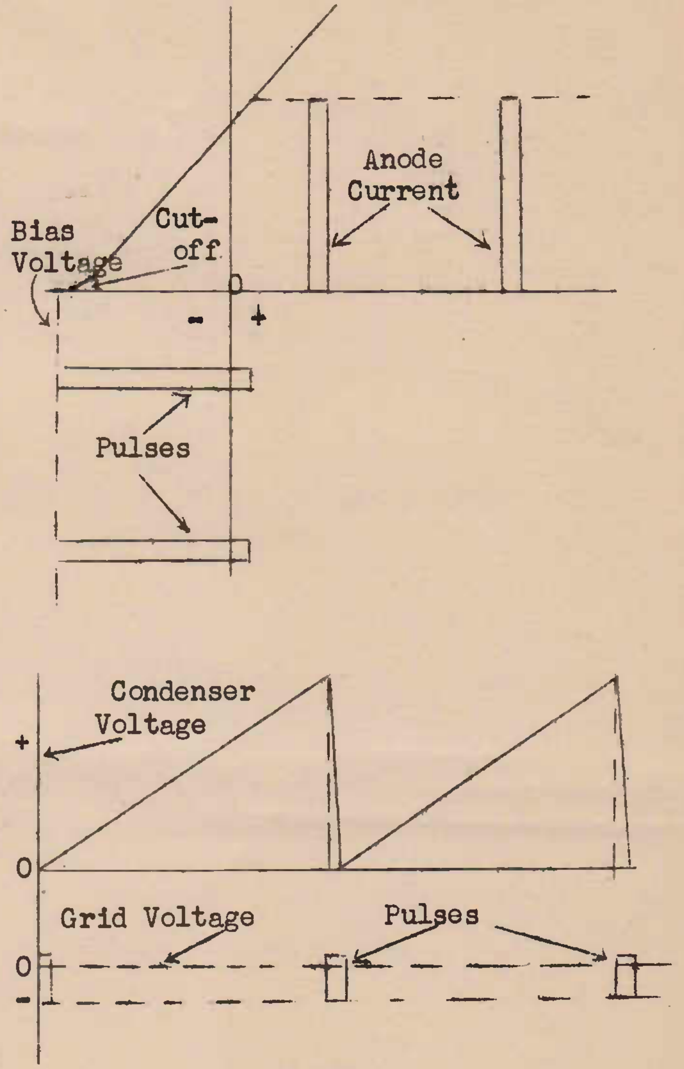


FIGURE 16.

There are many types of pulse generators, but we shall only describe two types -- (1) The Blocking Oscillator and (2) The Multivibrator used together with an R.C. Differentiating Circuit. We choose these two because they appear to be in most common use, they are among the mose reliable, and lastly, most other types may be regarded as modifications of them.

THE BLOCKING OSCILLATOR.

More fully described as the Single-Cycle Blocking Oscillator, this type of Impulse Generator is illustrated in figure 17. The circuit resembles an ordinary "feed-back" oscillator for generation of sine-waves, except that the coupling between plate and grid circuits is very "tight". An iron-cored transformer is used, the coefficient of coupling being practically unity.

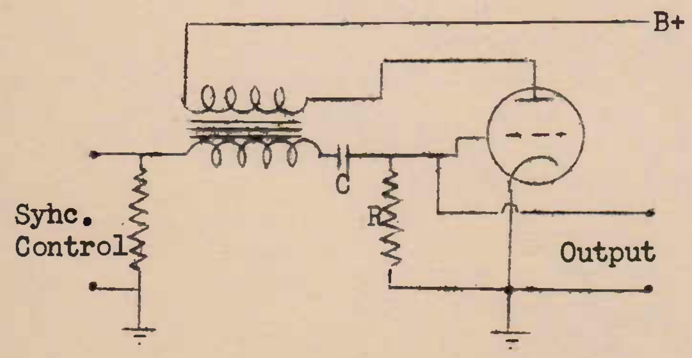
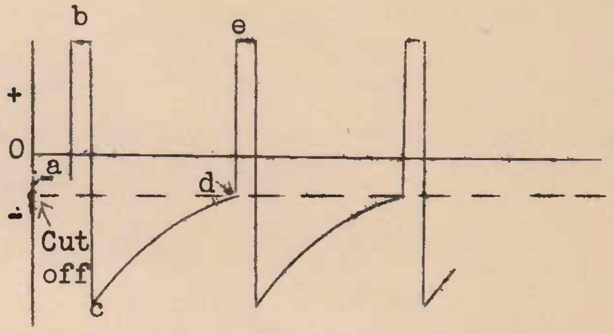
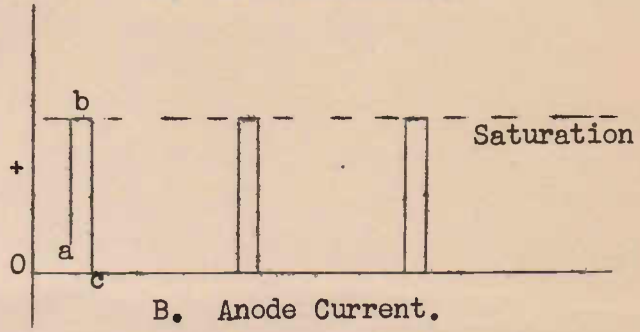


FIGURE 17.

The operation is as follows: when the supply voltage is switched on the circuit begins to oscillate in the ordinary way, by virtue of the coupling between anode and grid through the transformer T. Suppose that the oscillation starts with the grid at some negative point, (see point "a" Figure 18A,)and going positive. This causes an increase in anode current, which in turn induces a "feed-back" voltage in the grid coil of the transformer. The sense of the windings of this transformer are such that an increase in (anode) current through the primary induces a positively going voltage on the grid. This increase in grid voltage causes a further increase in anode current, resulting in a still more positive voltage on the grid. The net result is that, in an extremely short period of time the grid is driven to a large positive potential with respect to cathode (see "a.b" Figure 18A), while the plate current increases to saturation (see "a.b" Figure 18B). Since the plate current cannot further increase, the positively going feed-back voltage on the grid will now disappear. At the same time the grid will be collecting electrons from the cathode, because of its positive potential. This grid current will very rapidly charge up the condenser C (Fig. 17), the right-hand plate being negative. The grid thus finds itself suddenly driven negative well beyond cut-off -- see "b.e" Figure 18A. The anode current will accordingly fall suddenly from saturation value to zero -- see "b.c" Figure 18B.



A. Grid Potential.



B. Anode Current.

FIGURE 18.

Now the grid potential will remain negative while the charge on the grid condenser persists. The only path available through which C may discharge is by way of the grid leak R. This discharge will be comparatively slow since R is large (i.e. the time-constant R.C. is comparatively long). As C discharges through R, the grid potential "relaxes" from point "C" towards "d" (Figure 18A), according to the discharge curve shown. During this period, since grid potential is still more negative than cut-off (dotted line) anode current remains at zero.

As soon as the grid potential reaches and just passes point "d" (Figure 18A) anode current commences to flow. The increase in anode current produces, by feed-back, a further positive (or less negative) voltage on the grid, this, in turn, resulting in a further increase in current. Therefore, as before, as soon as point "d" is reached, grid potential virtually jumps to the very positive value "e". The process is then a repetition of the actions already described.

It is necessary that the oscillatory circuit comprising the transformer inductance and distributed capacities, be highly damped so that oscillations in the coils will abruptly cease when the grid is driven negative.

Referring to Figure 18A it will be observed that on the grid (forgetting the negative potentials) a series of short duration positive pulses are produced. These form the generator's output, and are used to "trigger" the discharge value in the sync. generator, as previously described.

The rate of repetition of the pulses depends upon the time taken for the grid condenser to discharge through the grid-leak to the valve's cut-off potential. Hence the "pulse repetition frequency" will depend mainly on the time-constant RxC (Figure 17). R and C have comparatively high values (long time-constant, and therefore low repetition frequency) in the vertical (frame) deflecting circuit, and smaller values for the horizontal (line) circuit.

SYNCHRONISING THE BLOCKING OSCILLATOR.

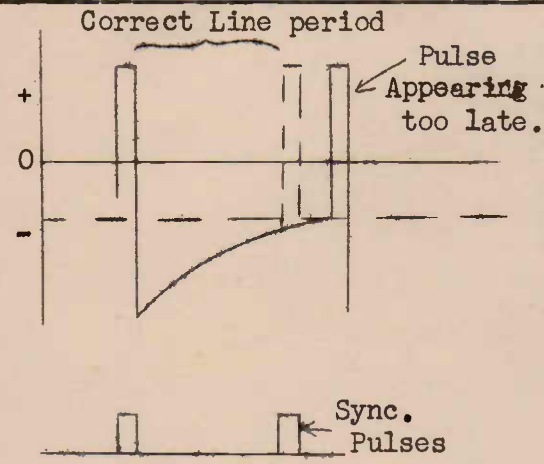
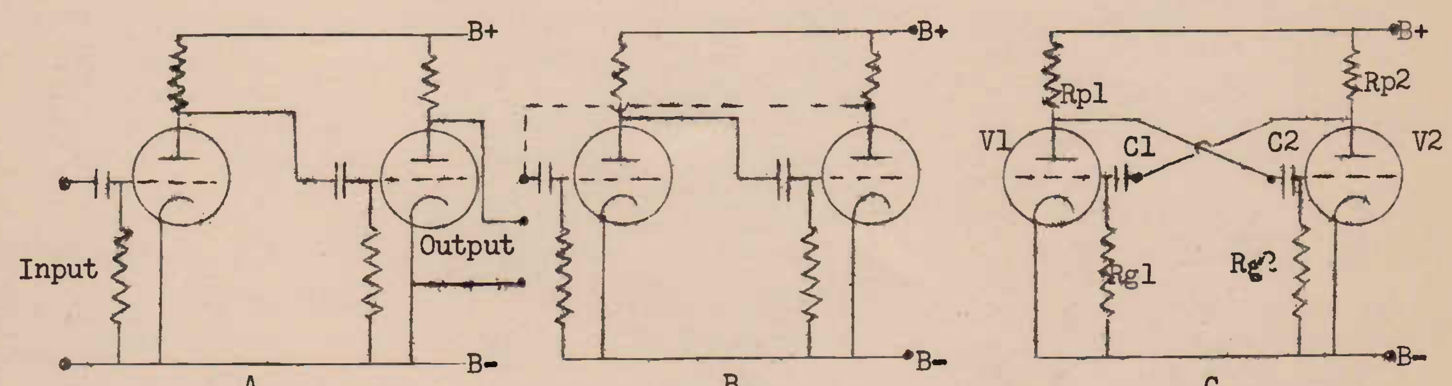


FIGURE 19.

The signal sync. pulses are applied, for timing purposes to the grid of the valve as shown in Figure 17. The synchronising action may be understood by imagining that the pulse generator is running at too low a frequency, i.e. the time between generated pulses is too long, as illustrated in Figure 19. If this state of affairs exists the discharge of C through R (Figure 17) is too slow, and by the time the second sync. pulse shown in Figure 19 arrives the grid potential has not quite reached the cut-off level at which plate current commences to flow. The effect of the positive sync. pulse, however, is to immediately lift the grid potential to this cut-off level, thus initiating the next generator pulse (as shown by the dotted line in Figure 19) before it would otherwise occur.

THE MULTIVIBRATOR.

The circuit of a simple multivibrator may best be visualised by regarding it as a two-stage resistance-capacity coupled amplifier, in which the output from the plate of the final valve is applied back to the input (grid) of the first.



A
2 Stage R.C. Coupled Amplifier.

B.
Same as A, with output Coupled Back to input.

C
Symmetrically arranged Multivibrator circuit.

FIGURE 20.

The development of the circuit is shown in stages in Figure 20. The circuit at (c) is identical with that at B, except the method of drawing it brings out more clearly its symmetrical or balanced characteristic.

In the explanation of the operation of the circuit which follows, we shall use the following symbols for brevity:-

Vgl = Voltage on grid of lst valve.
Val = " " anode " " "
Ial = Anode current of " "
Vg2 = Voltage on grid of 2nd valve etc.

Suppose, at any moment the anode current of the first value (Ial), owing to some slight irregularity, increases slightly. This causes Val to fall a fraction. The decrease in Val is applied through C2 (Figure 20) to the grid of the second valve, with the result that Vg2 goes a little negative. Hence Ia2 is reduced, causing a rise in Va2. This rise in Va2 is applied through Cl as a positively going voltage on grid of lst valve (i.e. an increase in Vgl). The effect of this is to cause Ial to increase still further. The important point is, that any small change in current or voltage at any point in the circuit gives rise to a series of changes which result in a further and larger change at the given point. In the case cited an initial small chance increase in Ial initiates a series of cyclic changes around the circuit with the result that Ial is almost instantly increased to saturation value. At the same time Vgl is driven very positive, and hence grid current flows in the first valve. This grid current charges condenser Cl, the negative charge on its left-hand plate (Figure 20C) then driving the grid very negative, well below cut-off.

Thus we find Vl in a state of cut-off, while V2 is conducting heavily. The anode potential of Vl (Val) will be at full supply value, while Va2 will be at some lower value, due to the flow of current through Rp2 causing a voltage drop across the latter.

Now Vl will remain cut-off for some appreciable time, since its negative grid potential can only be reduced by the comparatively slow discharge of Cl through Rgl (Figure 20C). (The time constant Rgl X Cl is fairly long.) When the negative potential on the grid of Vl has been reduced to the cut-off value, the first small increase in Ial will give rise to a series of rapid changes around the circuit whose net effect is to drive the second valve into a cut-off condition. V2 will now remain non-conducting, with Vl conducting normally, until C2 has had time to discharge sufficiently through Rg2.

The important point which emerges from the above approximate description of the circuit's operation is that, at any given moment, one valve is cut-off, while the other is conducting, and that this state of affairs is periodically and abruptly reversed. Considering any one valve, the anode current will vary as at A, Figure 21, varying alternately between a normal value and zero. The corresponding anode potential is shown at B in the same figure. This potential alternates between full supply value or B+ (when the valve is cut-off) and some lower positive value (when the valve conducts).

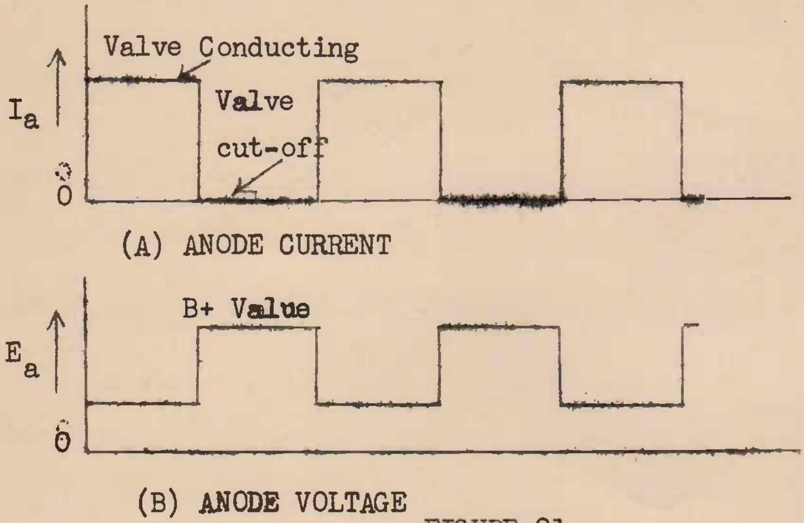
The output of the multivibrator is normally taken from the anode of either valve. Note that this output voltage is one of square wave-form. Actually such a waveform is only obtained from a symmetrical circuit (i.e. when the circuit components of one valve are equal to the corresponding components of the other valve), and also when the plate load resistors are small in value compared with the grid leaks

(See Fig.20C). Waveforms of many varieties may be obtained by using unsymmetrical circuits and by taking different values for resistors and condensers.

The frequency of the square-wave illustrated will depend upon the time that each grid is held below cut-off, and this in turn will depend mainly upon the time-constants Rg1,C1, and Rg2,C2 (Figure 20C).

It now remains to convert the square wave obtained from the multivibrator to a series of pulses of short duration in order to "trigger" the discharge valve.

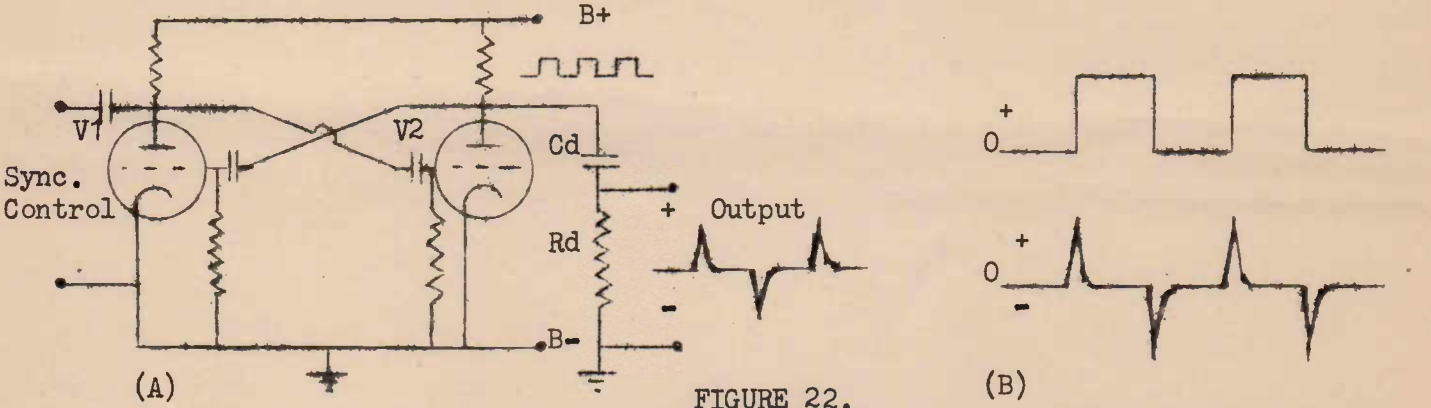
This is achieved by applying the square-wave voltage from the anode of one of the valves of the multivibrator across an R.C. differentiating circuit, as shown in Figure 22A. The final output taken across Rd will be a series of sharp pulses as shown. The "leading" edges (i.e. the rises in voltage) of the square-wave produce positive pulses, while the "trailing" edges (i.e. the falls in voltage) of the square-wave result in negative pulses (see Fig. 22B). Actually only the positive pulses are used for triggering the discharge valve.



(A) ANODE CURRENT

(B) ANODE VOLTAGE

FIGURE 21.



(A)

(B)

FIGURE 22.

SYNCHRONISING THE MULTIVIBRATOR.

As shown in Figure 22A the signal sync. pulses are applied to the anode of V1. Actually this is equivalent to applying them to the grid of V2 (for 1st anode is connected to 2nd grid by the coupling condenser).

The synchronising action is very similar to that described for the blocking oscillator. If the multivibrator is running too slowly, a positive sync. pulse, arriving before a cycle has ended, lifts the grid potential to the cut-off level, thus commencing the new cycle earlier than would otherwise occur.

GENERATING SAW-TOOTH CURRENTS FOR MAGNETIC DEFLECTION.

The simple R.C. charging circuit together with its discharge valve, as described earlier, produces a voltage of saw-tooth wave-form. Such a voltage, however, if applied to an inductance coil (such as the deflecting coil of a C.R.T. designed for magnetic deflection) will not produce a saw-tooth current, which is necessary for linear deflection.

The reason for this lies in the inductive property of the coil. It may be shown mathematically (and verified experimentally) that a saw-tooth current will flow through a pure inductance (i.e. no resistance) only when a square-wave voltage is applied across it.

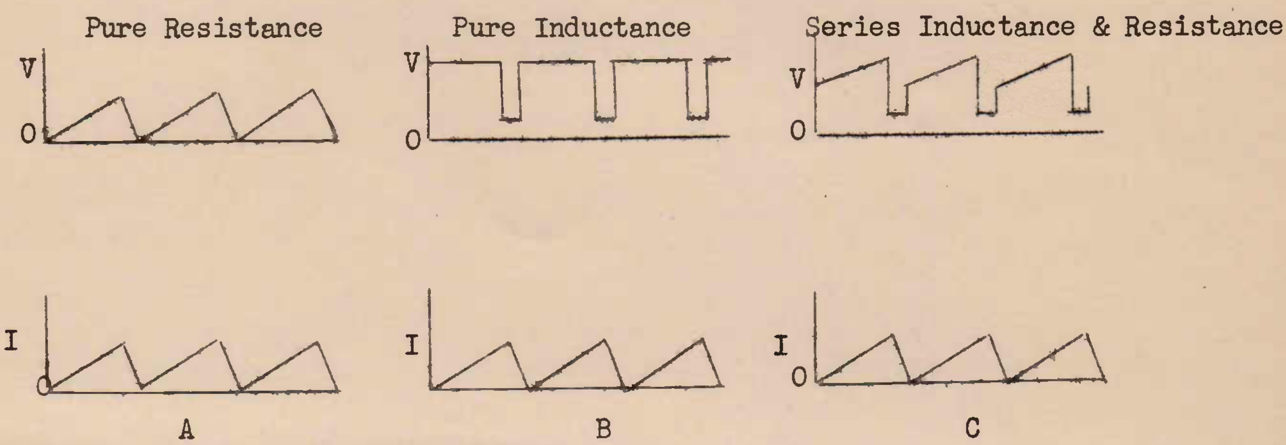


FIGURE 23.

applied across it.

In Figure 23 at A is shown a saw-tooth voltage producing a saw-tooth current through a pure resistance. At B is the case for a pure inductance. Here, in order to obtain a saw-tooth current, the voltage must have the square-wave form shown. Now any practical coil contains inductance in series with resistance. The voltage required to produce a saw-tooth current through such a combination will therefore be a combination of the saw-tooth voltage of A and the square-wave voltage of B. Such a combination is shown at C (Figure 23). The saw-tooth part of this voltage may be regarded as overcoming the resistance of the coil, while the square-wave part overcomes the inductive effect.

A voltage having the wave-form shown in the upper diagram of Figure 23C may be generated by modifying the simple R.C. charging circuit by including an extra resistance.

Figure 24 shows a gas filled triode circuit to which this modification has been made. Comparing this diagram with that of Figure 13 it will be noted that an extra resistor R2 has been added. The output is now taken from across the series combination R2 and C.

At an instant when the tube becomes non-conducting, the supply voltage is suddenly applied across R1 and R2 and C in series. Now we know that when a voltage is suddenly applied across an R.C. combination, the full voltage instantly appears across the resistance, and none initially appears across the condenser. If the resistance in the circuit is divided into two parts, the initial voltage will be divided between them in proportion to their values. For example, if in Figure 24, R2 is one-quarter of R1 + R2, then one-quarter of the supply voltage will initially appear across R2, and therefore in the output, when the cycle of oscillation commences. This abrupt rise in voltage is represented by "ab" in Figure 25. Now as time goes on the potential across C rises in the more or less linear manner as shown by "b.d". This further rise, towards the full supply voltage, will, of course, appear in the output also, since the latter is taken across C as well as across R2 (Figure 24). By choosing suitable values of R1 and R2 the output voltage from the scan generator may be modified to produce a current of saw-tooth waveform in any pair of deflecting coils.

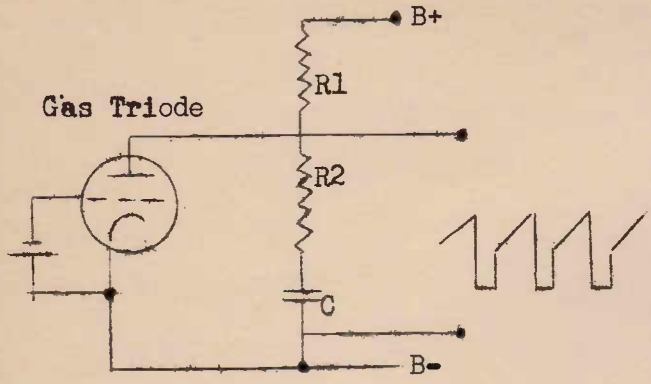


FIGURE 24.

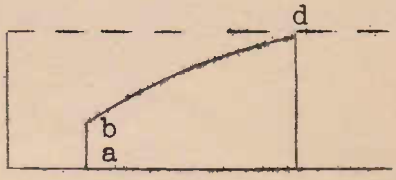


FIGURE 25.

DEFLECTION AMPLIFIERS.

The output from each scan generator is passed through an amplifying stage before application to the deflection electrodes.

In the case of electrostatic deflection, push-pull amplification is used, in order to obtain the large peak to peak output voltage required (400V and above) necessary for full deflection. Push-pull amplification also avoids a de-focussing effect on the beam which occurs when single valve amplification occurs.

In the case of electro-magnetic deflection a single valve output is used together with a step-down transformer to increase the current output. For full deflection the square-wave current must rise to a value of the order of 250 m.a.

T.FM & F. LESSON NO. 10.

EXAMINATION QUESTIONS.

(1) Which receiver stage prevents the picture signal from entering the scanning generators? What would be the effect of picture signal impulses upon the latter?

(2) Why is fixed bias unsuitable for a "clipper" circuit?

(3) Why is the vertical (frame) sync. signal between any pair of frames broken up into a number of separate pulses?

(4) State briefly the difference between a Differentiating and an Integrating Circuit.

(5) Name two faults which could occur as a result of faulty scanning generator synchronisation?

(6) What function does the grid of a gas-discharge tube perform?

(7) How would you vary (a) the amplitude (b) the frequency of a sawtooth generator, employing a gas filled tube.

(8) What is the function of an Impulse generator in a television receiver? Name two types of Impulse generators.

(9) What determines the frequency of a Blocking Oscillator?

(10) If the line scan. generator of a receiver completely failed, what would you expect to see on the screen?

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T.FM & F. LESSON NO. 11.

RECEIVER POWER SUPPLIES.

It is a much more complicated problem to provide sources of D.C. power for a television receiver than it is for an ordinary broadcast set. In the case of the latter we simply require a power unit whose purpose it is to convert the 240 V. A.C. from the mains into a supply of 200-300V D.C. for the "high-tension" (B+), a supply of (usually) 6.3V A.C. for the cathode heaters of the amplifier valves, and a supply of (usually) 5V A.C. for the rectifier filament. The student is familiar with the more or less standardised power unit which will fulfil these functions.

Now let us recall again the comparative complexity of the modern television receiver. In addition to the sound receiver section (see Fig. 1) we have the picture receiver proper, the scanning generator (time-base) section, and finally the C.R.T. itself. All of these sections, excepting the last mentioned, require two power sources -- one at about 250V. D.C. (the normal B+ supply) the other being a low-voltage A.C. (usually 6.3V) for the heaters. At first consideration it might be thought that an ordinary power unit, making use of a full-wave rectifier for the B+, and a single low voltage transformer winding for the heaters, could be used, without difficulty, to supply all these three sections.

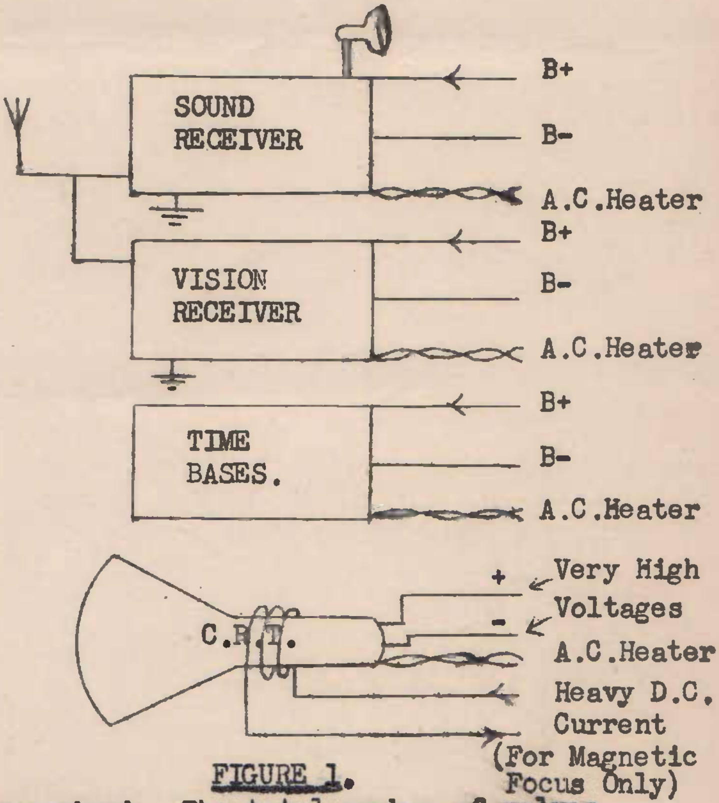


FIGURE 1.

A difficulty, however, arises in the large current out-put which would be required. The total number of valves involved may be many times that used in the ordinary broadcast receiver. Nevertheless, in the case of the smaller television receivers a full-wave rectifier tube such as the 5U4G, having an output drain of 175 m.a, used in conjunction with a suitable transformer, is adequate to supply the three receiver sections.

In the case of the larger receivers the difficulty may be overcome by utilising two full-wave rectifiers in parallel. This will, of course, providing, the transformer is of sufficient current rating, double the available output current.

The power for the cathode-ray picture tube most be obtained from a separate source. Here we require a high D.C. voltage of at least 2,000V, but perhaps as high as 10,000 V (or even 25,000V for the projection-type tubes). In addition we want a low A.C. voltage (say 6.3V) for the C.R.T. cathode-heating. The latter must be provided from a separate transformer winding, when the heater is connected internally to the C.R.T. cathode. The reason is that the latter is not, in general at ground potential, (as are the heaters of all other valves). If heater and cathode of the C.R.T. are not internall connected, then, of course current may be drawn from the one heater winding supplying all other tubes. Finally, if magnetic focussing is used, we require a comparatively heavy direct current (100 -- 200 m.a.) for the focus coil. The latter is usually obtained by passing all, or part, of the low-voltage B+ supply through this coil.

It appears, then, that we shall require a dual-power-supply. The unit supplying the high voltages for the C.R.T, together with its heater current, is usually referred to as the "High-Voltage" supply. The other providing the high-tension (B+) at about 250 V. for all other tube, is known as the "Low-Voltage" supply.

POWER TRANSFORMERS.

It is possible to use but a single transformer for the two power units, all secondaries being wound, suitably insulated one from the other, on the same core. These secondaries will comprise: centre-tapped winding for the full-wave rectifier, low voltage heater winding, low voltage filament winding for filament of the full-wave rectifier (all these belong to the "low-voltage" power unit), and in addition, for the "high-voltage" unit, a winding of very many turns providing an A.C. voltage for rectification, and finally a low-voltage winding for the rectifier's filament. These windings are shown in Figure 2.

THE "HIGH-VOLTAGE SUPPLY".

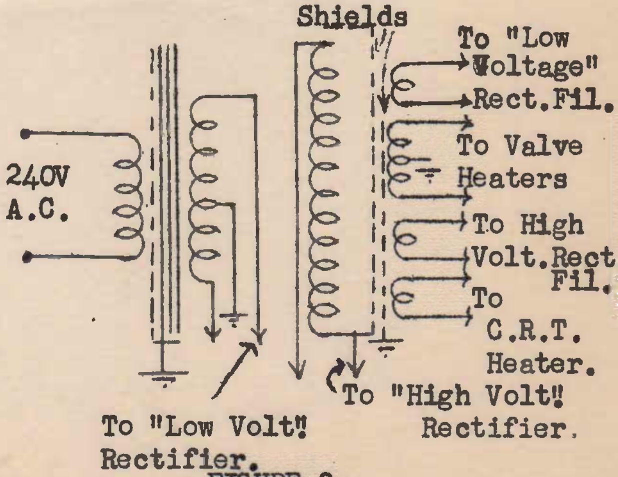
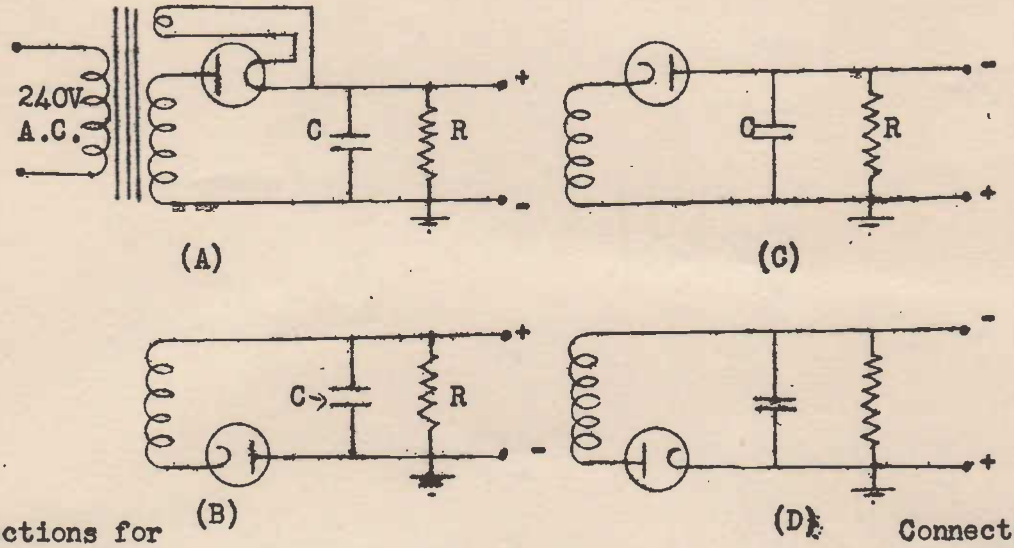


FIGURE 2.

The high-voltage power unit usually makes use of a half-wave rectifier (i.e. a single diode). Full-wave rectification requires a centre-tapped transformer winding, which is impracticable when operating at several thousands of volts. The difficulty lies in bringing out a centre-tap with sufficiently good insulation to prevent a break-down where it comes in contact with those turns of the winding which are at high-potentials. In any case half-wave rectification is quite adequate for the purpose since the current drain taken by the C.R.T. is extremely small. The electron beam of the latter represents a current of only about one-tenth or so of a milliamp. A bleeder circuit of very high resistance, taking only one or two milliamps is usually used. With such small currents required there would be but little point in using full-wave rectification.

HALF-WAVE RECTIFIERS.



Connections for Positive Output.

Connections for Negative Output.

FIGURE 3.
HALF-WAVE RECTIFICATION.

Figure 3 illustrates various methods of connecting a single diode to the secondary of a power transformer for half-wave rectification. In all diagrams but the first (A) the transformer primary, and the diode's filament winding, have been omitted. This has been done in order to bring out more clearly the simple theory of the circuits' operation. The secondary of the power transformer should be regarded as a source of alternating e.m.f, which is to be converted to a steady direct current. The diode acts as an almost perfect rectifier, i.e. a device which permits current flow in one direction only around the circuit.

Note the effect of the different connections shown in Figure 3. Circuits A and B produce a positive output voltage (with respect to ground) across R. Circuits C and D give a negative output. A slightly better filtering (smoothing) action is obtained in cases A and C compared with that obtained in cases B and D. When a positive output is required the connections are almost invariably made as in circuit A. When negative outputs, in respect to ground, are required, however, circuit D is often used in preference to that shown at C. Although a greater percentage ripple could be expected from circuit D, this arrangement has the advantage that the filament of the diode is at D.C. zero potential. The significance of this is that, in certain cases, the filament current for the diode may be taken from the transformer heater winding which is used for other values in the receiver. The heaters of the latter are, of course, always at ground potential. In the other circuits (A,B and C) shown in Figure 3 note that the diode filament is at a high D.C. potential (positive or negative) with respect to ground. Hence, in these cases, a separate rectifier filament winding, adequately insulated for high potentials, must be used.

RESISTANCE-CAPACITY FILTERING.

Since the average student is accustomed to power supplies utilising a choke (inductance), together with one or more condensers for smoothing purposes, it will be well to explain briefly the operation of a resistance-capacity filter.

A resistor, (or even a series of resistors) is a much smaller, lighter and cheaper component than an iron-cored choke. It may well be asked, therefore, why resistance-capacity filtering is not used in the "low-voltage" power supply. The reason is connected with the fact that such power supplies are called upon to deliver comparatively heavy current drains. Now the choke, or resistor, whichever is used, must, for effective smoothing action, present a very great impedance to the A.C. "ripple" component, which it is desired to eliminate from the output. If a resistor is used this same high impedance (in this case pure resistance) will be presented to the D.C. component of the output as well as to the A.C. Hence it is seen that the D.C. drain from the rectifier will be limited to a very small value. This does not constitute a draw-back in the case of high-voltage power supplies used to operate cathode-ray tubes, since, as already pointed out, these tubes require only a fraction of a milliamp. for their beam currents.

In the case of the "low-voltage" power supplies, on the other hand, a current output of several hundred milliamps is usually required. This means that the D.C. impedance of the filter system must be comparatively low. At the same time we still require the high impedance to the A.C. ripple voltage. A choke may present an impedance of many thousands of ohms to the ripple frequency (100 cycles/sec for full-wave rectification), while its D.C. resistance may be only several hundred ohms.

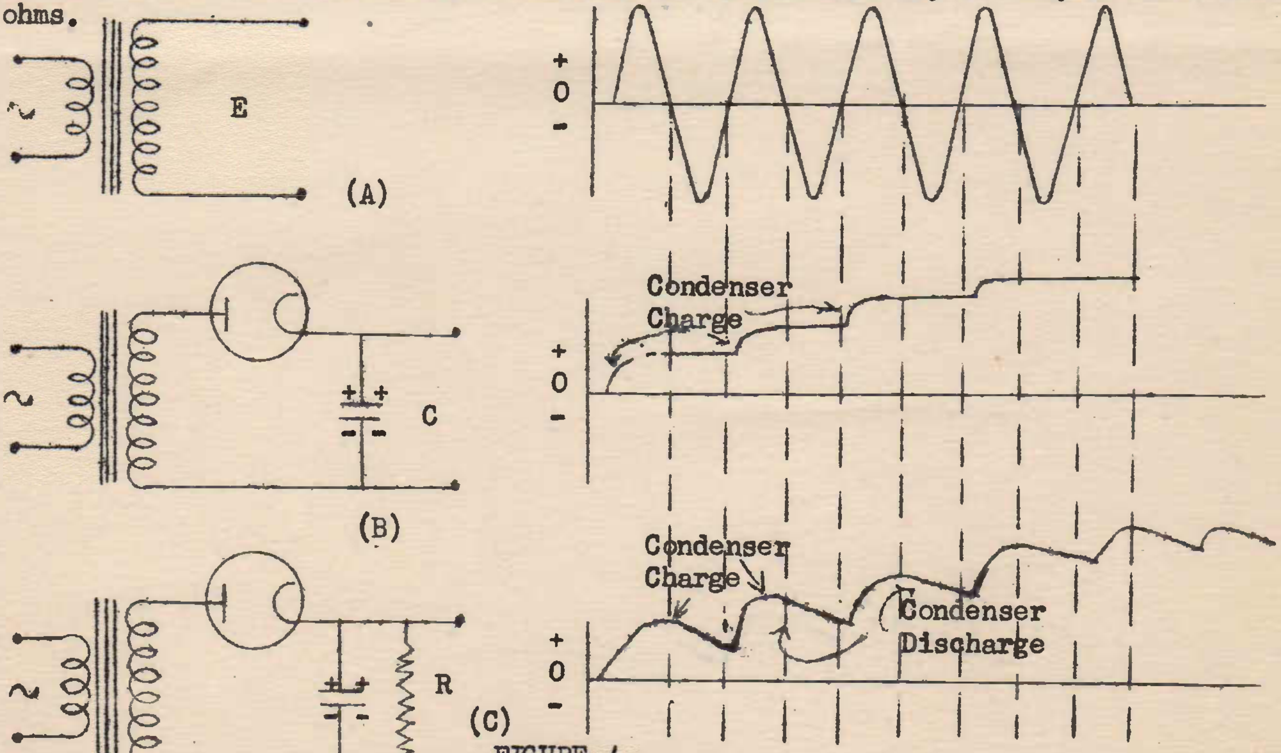


FIGURE 4.

The theory of the resistance-capacity filter may be simply explained as follows. An A.C. voltage, to be converted to a D.C. is obtained from the transformer secondary as shown in Figure 4A. At B we have shown a diode, in series with a condenser, connected across the secondary. The diode passes current only on the positive half-cycle of the voltage shown at A. Hence on these half-cycles the condenser C of Fig 4B will charge up. During the negative half-cycles the condenser must retain its charge, since no discharge path is provided for it, the valvo being completely non-conducting. After a few cycles (depending upon the transformer impedance and diode resistance which determine the charging rate) the condenser will become charged to a voltage equal to the peak voltage of the applied e.m.f. Thereafter the diode passes no further current, and the condenser remains charged. This charging process is illustrated in the graph of Figure 4B.

When a bleeder resistance is connected across C, as shown in Figure 4C, the condenser charges, as before when the diode conducts on the positive half-cycles of the A.C. voltage. During the negative half-cycles, when the diode is non-conducting, C discharges partially through R. This rate of discharge will depend upon the time-constant C X R. If the latter is long compared with the period of one-half a cycle, the fall in condenser voltage will be very small during the time the diode is not conducting (see lower graph Figure 4). In any case the charge lost through R will be replaced by diode conduction on the peak of the next positive half-cycle.

The net result is a D.C. voltage which rises and falls with the applied e.m.f. This rise and fall constitutes the "ripple" voltage. Note that the frequency of the ripple equals that of the mains voltage (50 C/sec). (In full-wave rectification the ripple frequency is double the mains frequency). Note also that the amplitude of the ripple will be negligibly small provided that the time-constant C X R is long compared with the period of half one cycle of the A.C. (i.e. $\frac{1}{100}$ th of 1 second). This follows since the drop in condenser voltage due to discharge through R during a negative half-cycle will be very small.

VALUES FOR BLEEDER RESISTANCE AND FILTER CONDENSER.

The degree of filtering obtained depends, then, upon the time constant C X R. For a given percentage ripple C may be large, and R small, or C may be small and R large. Since the cost of a condenser designed to withstand voltages of several thousands of volts increases faster than the capacity it is desirable to keep C as small as possible. On the other hand if C is made too small, R must be so large as to reduce the bleeder current to too small a value. The effect of this is to reduce the "regulation" of the power supply -- i.e. its ability to maintain a constant output voltage for varying load-currents. In a television receiver the load current of the high-voltage supply is the beam current of the C.R.T. The latter current varies with the video signal applied to the control electrode. A typical compromise is to choose a bleeder of total value 2 to 5 megohms, and a filter condenser between 1 m.f. and .3 m.fd.

DOUBLE SECTION R-C. FILTER.

An improvement on the simple R-C filter described is to add an extra resistor Rf between the diode and the bleeder (Rb) and an extra condenser C1 (See Fig. 5).

The action is as follows. C1 charges on the positive half-cycles as already explained. On the negative half-cycles C1 discharges (slightly) through Rf and Rb in series. Since Rb is usually about ten times as large as Rf, most of the discharge voltage, and therefore the ripple, appears across Rb., and is thereby

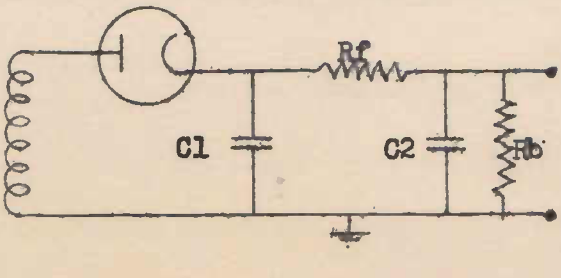


FIGURE 5.

applied across C2. This condenser is charged to the peak value of the discharge voltage, which in itself is partially filtered. The discharge of C2 can take place only through Rb -- the time constant C2 X Rb being long. Hence the output voltage, partially filtered by the RfC1 combination, is further smoothed by RbC2.

The advantages of the double-section filter, compared with the single-section, lie in the smaller values of capacity which may be used for the same degree of filtering. Typical values are .025 to .05 m.fd for C1 and C2, about .5 meg. for Rf and 5 meg. for Rb. These condensers are very much cheaper than those of the order of .5 mfd. Again, the much smaller stored charges in the smaller capacities minimises the danger of severe shock. A disadvantage of the double section filter is that a slightly reduced output voltage is obtained, due to the voltage drop across Rf. This voltage drop is not effective in the output, which is taken across Rb only. An example will better illustrate this point. Suppose that Rf (Fig.5) is .5 megohms, and Rb 4.5 megohms. Rf is one-tenth of the total resistance between the rectifier cathode and ground. If the total voltage between the latter two points is 5,000 V, one-tenth of this, i.e. 500 V, will appear as a voltage drop across Rf. The remaining 4,500 V, appearing across Rb will represent the rectifier's output.

THE BLEEDER NETWORK.

The electron gun of a cathode ray tube requires several voltages of varying magnitudes, all being measured in respect to cathode. These different voltages are obtained by tapping off the required amounts from the total rectifier output. The bleeder, represented by Rb in previous diagrams, is therefore composed, in practice, of a series of resistors rather than a single component. One or more of these resistors is usually in the form of a carbon-type potentiometer, to allow a variable voltage to be tapped off for C.R.T. control purposes.

Perhaps the most usual arrangement is to establish the C.R.T. control electrode at ground potential, by connecting it directly to the lower (ground) end of the bleeder network, as shown in Figure 6. We are referring here, of course, to a rectifier producing a positive output. Resistors R1, R3 and R5 are of the ordinary fixed carbon type. R2 and R4 are potentiometers. Since no current flows in the control electrode circuit (just as no current flows in the grid circuit of an amplifying tube when negative bias is used), there will be no potential drop across Rg (Fig 6). In other words the D.C. potential of the control electrode is maintained at ground level. A variable tap is taken for the cathode at a higher point in the chain, i.e. at a point which is positive in respect to ground. This ensures that the control electrode is <u>negative in respect to the cathode</u>. The negative bias is varied by varying the positive potential (in respect to control electrode) of the cathode as shown. The resistor R1 ensures that <u>some</u> negative bias is always on the control electrode. Since the value of negative bias on the

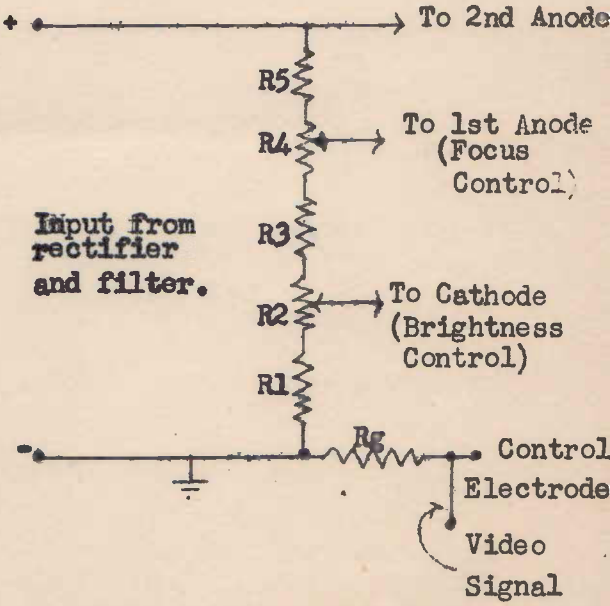


FIGURE 6.

control electrode determines the intensity of the electron beam, adjustments to R2 will vary the average brightness of the picture. R2 is therefore described as the Brightness Control.

The full positive output of the supply is applied to the second anode of the C.R.T. A lower positive potential is applied to the first anode, by taking a tap at a lower point down the bleeder voltage divider. This tap is from the moving arm of potentiometer R4 (Figure 6). Provision is made here for a variable voltage on the 1st anode for focusing purposes as explained under the section on cathode ray tubes. Hence R4 constitutes the Focus Control. This control, of course, determines the size of the scanning spot, and hence the quality of the picture. Since the correct setting of the focus control is, up to a point, a matter of individual taste, the knob, in some receivers is brought out to the front where ready adjustments may be made to it. Generally speaking, however, the focus only requires occasional adjustment, as when the receiver is first installed, or when the C.R.T. is replaced. For this reason most manufacturers regard the control as of the "pre-set" type, and therefore in most receivers it is accessible only from the back or chassis of the set.

The resistors R3 and R5 serve to limit the variable voltages which may be safely applied to the cathode (for bias) and to the 1st anode (for focus).

OTHER METHODS OF OBTAINING CONTROL ELECTRODE BIAS.

Instead of earthing the control electrode it is sometimes found that the cathode is at earth potential. With this arrangement it is necessary to provide some variable source of negative potential (with respect to ground). This is usually done by some method of back bias, usually in the negative lead of the low-voltage power supply.

A very common arrangement is to place the control electrode at the same potential as the anode of the final video amplifying tube, and to provide the negative bias by applying some more positive potential to the C.R.T. cathode.

The advantage of this arrangement is that the final video amplifier may be directly coupled (i.e. without the use of a coupling condenser) to the control electrode.

A typical circuit is shown in Figure 7. The low-voltage supply is of 300V, from which lower voltages are tapped off using a bleeder resistor R1,R2, R3. The full 300V. is used for high tension for all values except the final video amplifier 6V6, which is operated from a tap giving about 260V. for plate and one giving 75V for the screen. The low screen voltage is used to prevent the tube from drawing excessive current when no signal is applied to its grid. Note that this tube is operated without cathode bias.

The cathode of the C.R.T., is not at ground potential, but at some positive potential which may be varied from, say, 200V. up to 300V, the full B+ voltage. Since the control electrode is connected to the anode of the 6V6, its potential is below 260V. The net result is that control electrode is negative with respect to the cathode. The potentiometer R4, (which is in series with R5 across the low-voltage supply) provides a means of varying the C.R.T's control electrodes bias, and therefore constitutes the Brightness Control.

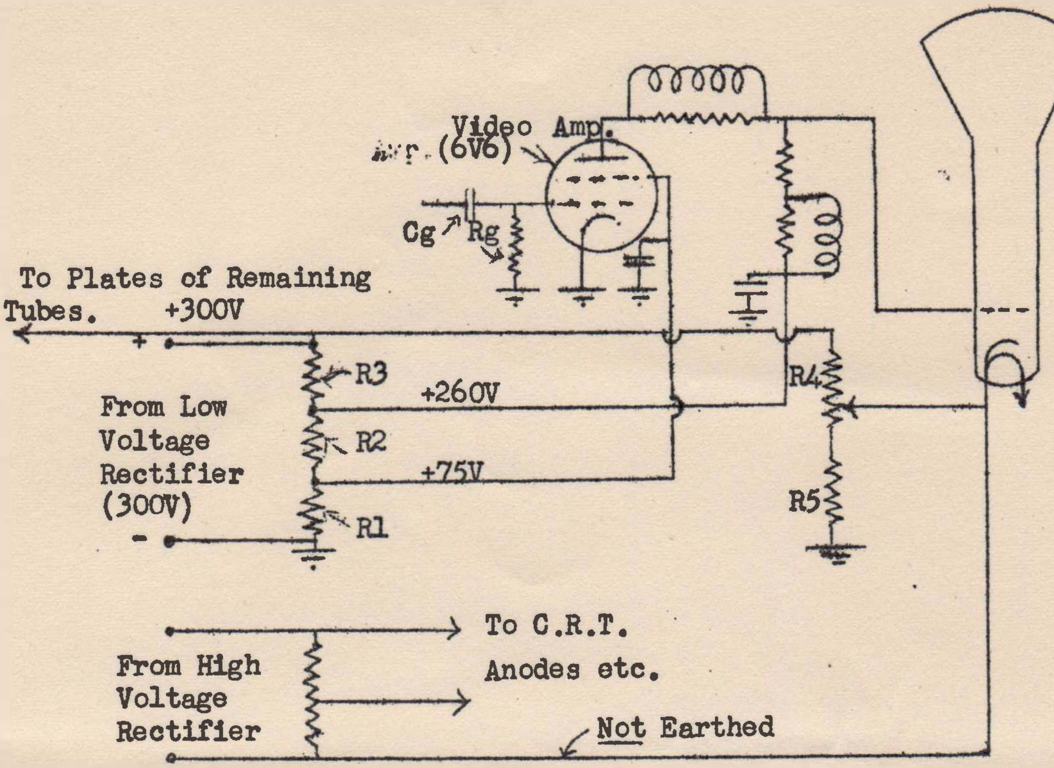


FIGURE 7.

A further interesting point concerning the circuit is that the negative side of the high-voltage supply is not earthed, but is practically at 300V.+, being connected, together with the C.R.T. cathode to the moving arm of the potentiometer across the low-voltage supply. In this way, the full high-voltage supply is applied between 2nd anode and cathode of the C.R.T.

It was stated above that the main advantage of this system, which operates the C.R.T.'s control electrode at a potential equal to that of the anode of the final video amplifier, is that direct coupling may be used for the latter's output. This greatly simplifies the problem of D.C. restoration. The D.C. component of the video signal is restored at the grid of the final amplifier. As shown, the tube (6V6 in Figure 7) is operated without cathode bias. When no signal is being received the video amplifier's bias is zero. As soon as the video signal is received the grid draws current, thus creating a negative bias which, if the grid condenser and leak (Cg and Rg) are of correct values, will be of such value as to maintain the grid potential always at the blanking level of the signal. In other words Cg, Rg and the grid circuit of the tube, acting as a rectifying diode, constitutes a simple D.C. restorer circuit. Since the plate of the amplifier is directly coupled to the control electrode there will be no further loss of the D.C. component.

INTER-CONNECTION OF HIGH-AND-LOW VOLTAGE SUPPLIES.

It is possible to augment the high voltage available for operation of the C.R.T. electron gun, by applying betwen final anode and cathode the total voltage of both high-and low-voltage power units. The manner in which this is achieved is illustrated in Figure 8. Here the negative side of the high-voltage rectifier unit is not earthed, but is connected to the positive (output) lead of the low-voltage unit. The result is that the two outputs are effectively connected in series, so that the total voltage of the positive lead of the high-voltage circuit, measured in respect to earth, is the sum of the outputs of the two rectifiers. For example if the two outputs are 300V. and 2,000V., the potential of the high-voltage output lead (in respect to earth) is 2,000V. + 300V. = 2,300V. Actually the arrangement here is very similar to that of Figure 7. But in order that the increased high-voltage is effective in operating the C.R.T, <u>the cathode of the latter must be earthed</u>, as shown in Figure 8. The question of bias now becomes one of obtaining a negative voltage (in respect to ground) from some point in the circuit, for application to the C.R.T.'s control electrode. This may be accomplished by means of a back bias resistor included at point "X" in Figure 8.

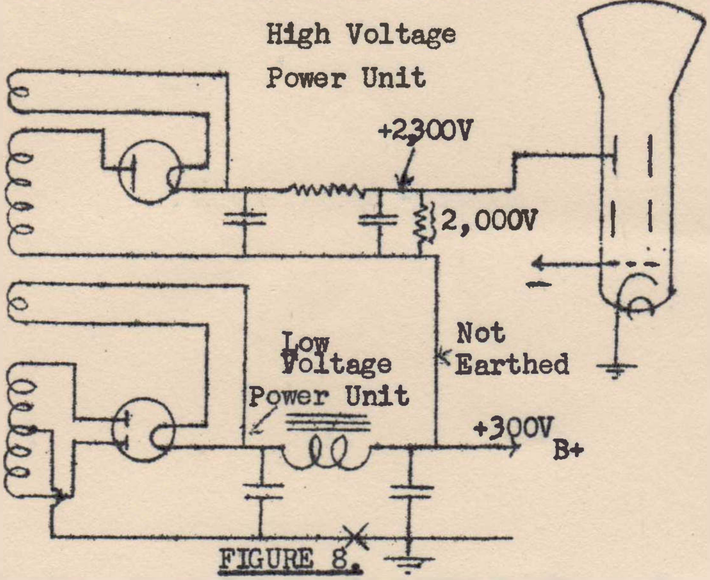
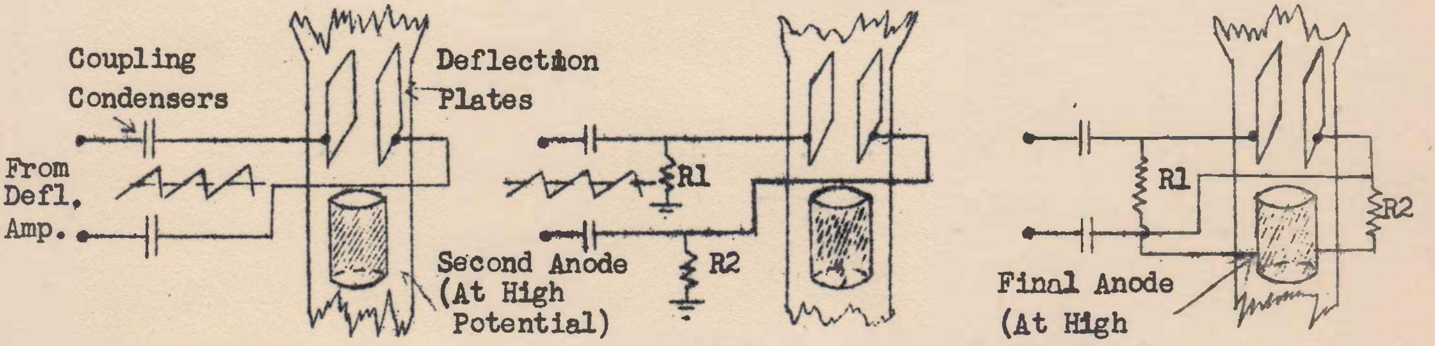


FIGURE 8.

D.C. POTENTIAL APPLIED TO DEFLECTION PLATES AND "SHIFT" CONTROLS.

Referring still to the electrostatic type of C.R.T, we must now consider the D.C. (or average) potential at which the deflection plates are operated. So far in these lessons we have simply stated that an alternating voltage of saw-tooth wave form (from the scanning generator amplifier) is applied between each pair of plates, for horizontal and vertical movement of the beam.

These A.C. saw-tooth voltages are, of course, applied from the amplifiers through coupling condensers.



(A)
Deflection Plates Floating

(B)
Deflection Plates
Earthed

(C)
Deflection Plates Connected
to Final Anode.

FIGURE 9.

As a general rule each of the deflection amplifiers (amplifying the saw-tooth outputs from the scanning generators) is of a push-pull type, consisting of two valves, producing output voltages from their plates 180° out-of-phase with each other. These out-of-phase saw-tooth voltages are shown at A, Figure 9, applied through coupling condensers to a pair of deflection plates. In this diagram the plates are shown "floating", i.e. there is no D.C. path connecting them to ground. Such an arrangement is unsatisfactory. Although the deflection plates form no part of any circuit which carries a direct current, they can, and will in practice, collect electric charges. Such charges can arise, for example, as the result of slight leakage through the coupling condensers. The result will be that the plates may build up large, and variable, potentials. This will lead to unstable operation of the tube. The effect is similar to that obtained when an ordinary amplifying valve is operated with a "floating" grid.

At B in Figure 9 the deflection plates are shown connected to ground through resistors R1 and R2. These resistors are of large values (1 or more megohms) and prevent the A.C. voltages being short-circuited to earth. At the same time R1 and R2 will maintain the plates at earth potential, as far as D.C. voltages are concerned. With this arrangement it should be noted that, even when the A.C. voltages are applied to the plates, the average potential of the latter is, at all times, zero. This point will be clearer by referring to Figure 10. The two saw-tooth voltages are 180° out-of-phase as shown at A and B. The average of these is obtained by adding, for all instants of time, the instantaneous values of the voltages. When voltage A is, say, positive, voltage B is an equal amount negative, and the average or net voltage is therefore zero for the two plates as a whole.

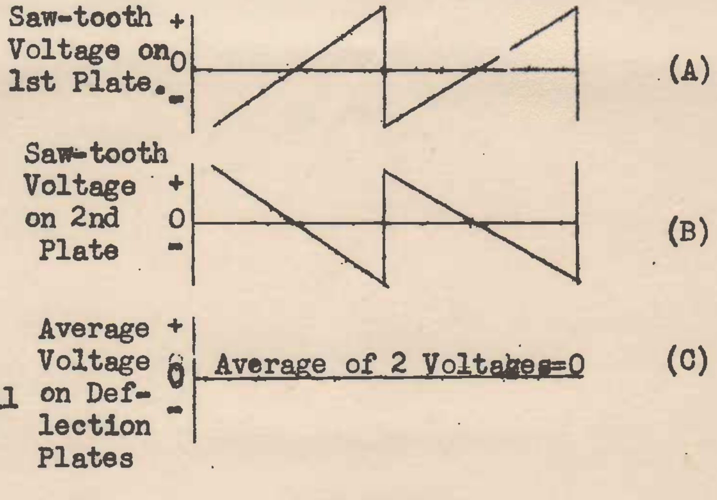


FIGURE 10.

In the case of a television receiver however, where the final anode of the C.R.T. is operated at a high positive potential with respect to earth, there is a serious objection in placing the deflection plates at zero potential. Between these plates and the final anode there will exist a large potential difference (equal to the high-voltage rectifier's output), and therefore a powerful electrostatic field. This field will seriously interfere with the correct focusing of the electron beam. It will be remembered that this focusing action is brought about by carefully adjusted electrostatic fields between the cathode and the several anodes within the tube. Any other field must be avoided.

To eliminate the electric field between the deflection plates and the final anode, we must place both these points at the same potential, so that no potential difference exists between them. This could be done by connecting the plates to the final anode via high resistances as shown at C, Figure 9. The tube would now operate correctly. The saw-tooth voltage from the amplifier would now simply carry one plate more positive than the average potential, while the opposite plate goes an equal amount more negative. This alternating potential difference between the pair of plates will swing the beam backwards and forwards to produce the scanning motion. At the same time the average potential of the pair of plates will remain constant at a value equal to the final anode potential, and hence no de-focusing effect will occur.

The student should not forget that the C.R.T. contains two pairs of deflection plates, (one for horizontal deflection, and the other for vertical deflection). The foregoing discussion applies equally well for one pair as for the other.

PICTURE "SHIFT" OR "CENTRING" CONTROLS.

In the manufacture of an electrostatic type C.R.T. the job of mounting the comparatively large and heavy electrodes within the glass envelope proves a very difficult one. The result is that, in any particular tube, it is rarely found that the beam spot falls exactly at the centre of the screen when no deflection voltages are applied. This means that when the scanning system is operating the picture frame will not be perfectly centred with respect to the tube's screen.

To overcome this difficulty we require two controls, one to move the spot, if necessary to left or to right, the other to shift it either up or down, as required. These controls are called "Horizontal Shift" (or "Centring ") and "Vertical Shift" (or "Centring ").

Beam Shift is brought about by making provision to apply, between each set of deflection plates, a D.C. potential difference whose value and polarity may be adjusted as required. The usual method of doing this is as shown in Figure 11. Included in the bleeder circuit, at its positive end is an extra resistor R1, of such value that a P.D. of perhaps several hundred volts is developed across it. The final anode is connected to the centre point of this resistor, so that the potential of this electrode is actually slightly less than the output voltage of the rectifier. Also connected to the centre point of R1 is the right-hand plate of the horizontal deflecting pair. This connection is made via the resistor R4 (of large value) which avoids short-circuiting of the A.C. saw-tooth voltage. In this way the right-hand plate is maintained permanently at a D.C. potential equal to that of the final anode. The resistors R4,R5,R6 and R7 are the ones previously indicated in Figure 9.

Across R1 (in parallel with it) is connected a potentiometer R2, the moving arm of which goes, via R5, to the other horizontal deflection plate. Now when the moving arm of R2 is in its central position the potential applied to left-hand deflector plate is equal to that of the centre point of R1, i.e. to the final anode and right-hand plate potential. In this position no potential difference exists between the pair of plates.

Now suppose the moving arm of R2 is moving towards the upper end of the resistor. The potential picked off will now be more positive than that of the central point of R1. Consequently the potential applied to the left-hand deflection plate will be more positive than that on the right-hand plate, and the beam will be deflected to the right. In this way the picture may be adjusted centrally upon the screen, as far as horizontal position is concerned.

An exactly similar system is duplicated for action on the vertical deflection plates. For this purpose we have the potentiometer R3, and the resistors R6 and R7.

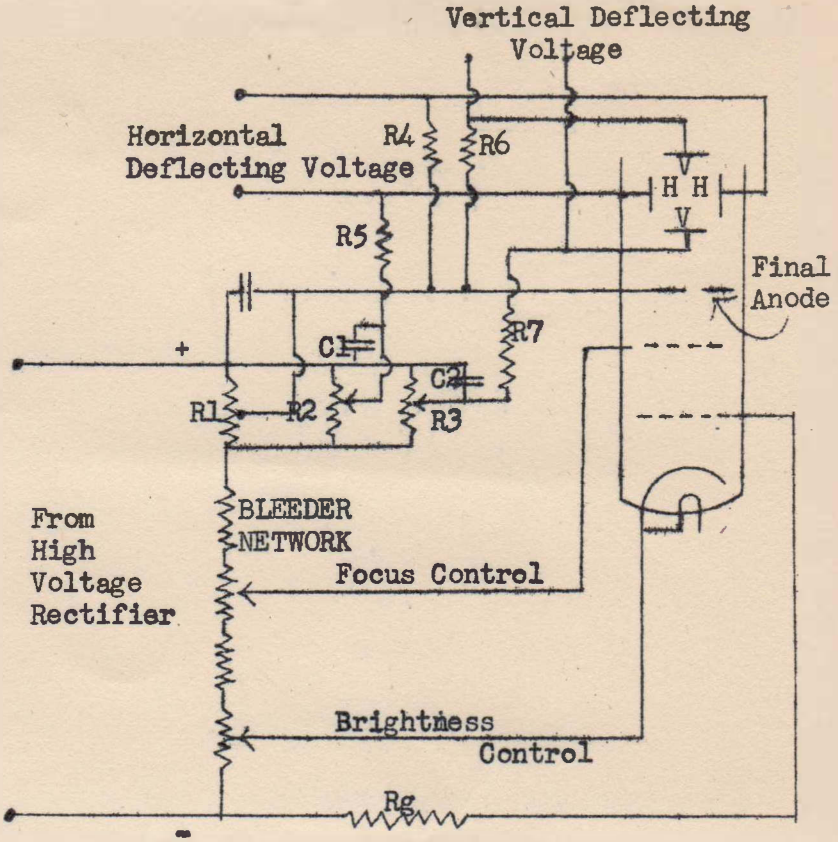


FIGURE 11.

Condensers C1 and C2 serve to smooth out sudden fluctuations in voltage when the shift controls are moved, thus to give a smooth motion of the picture to left or right, or up and down.

HIGH-VOLTAGE PRECAUTIONS.

Special care must be exercised in the mounting of all leads and components in a television receiver which are at the very high voltages. Wiring, for example, should be well separated from the chassis, and sharp turns and points should be avoided, for the latter tend to aid an electrical discharge.

In particular it should be noted that potentiometers used for Focus Control and Picture Shift are at very high voltages with respect to earth. It would never do to mount these potentiometers directly upon the side of the metal chassis, even though the component's resistor, and moving arm, are internally insulated from the metal shaft. Such insulation is inadequate to withstand voltages of several thousands volts. The usual method is to mount these potentiometers on a special panel of insulation within, and well separated from the main metal chassis. The shafts are long, and incorporate a length of insulating material as shown in Figure 12.

In order to safeguard service mechanics, and receiver owners, all high-voltage wirings are usually enclosed so that they are inaccessible without automatically switching off the high-voltage power supply.

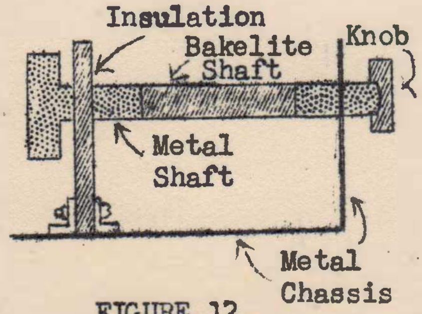


FIGURE 12.

Another important point concerns the coupling condensers through which the deflection voltages are applied from the amplifiers to the deflector plates. A pair of these condensers is shown back in Figure 9A. The wires on the right-hand side of these condensers are at several thousand volts. Their left-hand plates, on the other hand are at comparatively low voltages, something less than the low-voltage B+ supply. Hence the condensers must be of a special high-voltage rating to withstand the large potential differences between their plates. Such condensers are much larger and more costly than the more humble types, of similar capacity, having ratings of only 400 - 600 V.

MAGNETIC FOCUSING.

Since most of our space has been taken up in describing the application of the power supplies to electrostatic type tubes it must not be concluded that this type is more important, or even in more common use, than the electro-magnetic tube. Actually electro-magnetic deflection and focusing is becoming more and more important, and will probably completely supersede the electrostatic methods, particularly where a large screen is required. We are taking less space over the electro-magnetic type simply because there is less to explain.

The circuits are much simpler, particularly from the point of view of high-voltage considerations.

When electro-magnetic deflection is used we do not have to worry about operating the deflection system at high voltages. The deflection coils, wound outside the tube are operated with low-voltage saw-tooth currents as already explained in an earlier lesson. There is no question of defocusing effects occurring.

If magnetic focusing is also used, the problem is further simplified. The electron gun then operates at fixed potentials, and it may involve but a single high-potential anode. Hence the bleeder circuit of the high-voltage power unit will be less complicated.

The methods of obtaining control electrode bias are exactly the same as already described.

ELECTRO-MAGNETIC FOCUSING.

This type of focusing, it will be remembered, is achieved simply by passing a steady direct current of several hundred milliamps through a coil wound around the neck of the tube. The current used is usually the total (or part) of the low-voltage power supply. The deflection coil is placed in series in the negative (earth) lead of the supply. Since this coil is of low resistance there is but little potential drop across it. Such potential drop would, of course, subtract from the total output voltage of the power unit available for operating picture and sound circuits.

The arrangement is shown in Figure 13a. The total current supplied from B+ to the tubes, and returning via the chassis to the centre tap of the transformer, will split between the deflection coil and the rheostat R1 in series with R2. By adjusting R1 the fraction of this total current passing through the deflection coil may be varied,

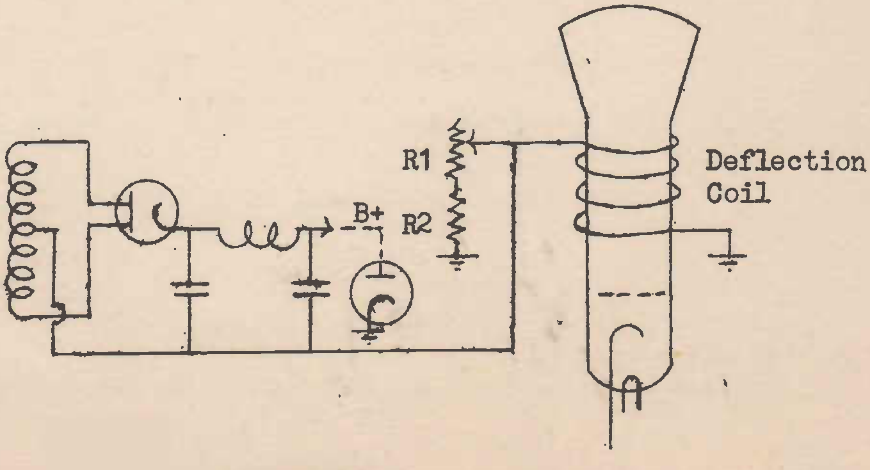


FIGURE 13a.

to produce fine focusing of the beam. The presence of R2, in series with the rheostat, ensures that some current will pass through the coil for all settings of R1.

A modification of this system is shown in Figure 13b. Here a resistor R3 has been placed in the negative lead of the low-voltage supply. This resistor is of such value that a P.D. of about 30V is developed across it (similar to "back-bias"). This voltage is then applied across the deflection coil and rheostat R1 in parallel. R1 acts, as before, as the focus control.

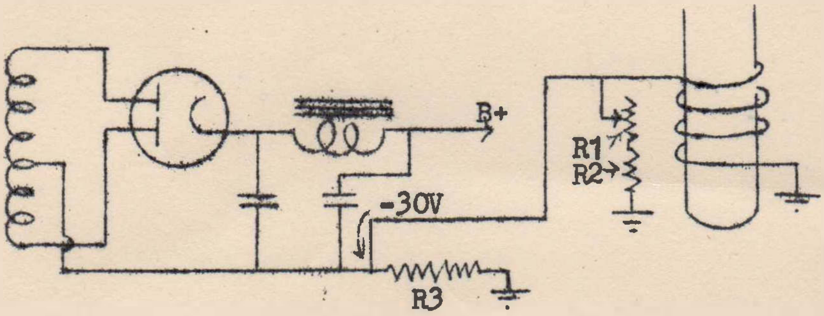


FIGURE 13b.

RADIO FREQUENCY HIGH-VOLTAGE SUPPLIES.

High-voltage power supplies operating from the 50 C/S mains are not particularly efficient or suitable for operating C.R.T's.

In the first place they can invariably supply many times the current which is necessary to operate the electron gun. The latter requires only a fraction of a milliamp. The reason for this is that it is not practicable to wind the secondary of the power transformer with thinner wire which would reduce the unnecessarily high current capacity, and at the same time reduce the weight and size of the transformer. Furthermore the voltage step-up of a power transformer depends entirely upon the turns-ratio between primary and secondary. To obtain the very high voltage required we must have a large turns ratio; and since we must have at least 4 or 5 turns per volt in the primary (in order to adequately magnetise the iron core), this means that the secondary winding must consist of a very large number of turns. Such a transformer is very large, heavy and expensive.

Again the capacities of the smoothing condensers in the filter system of a rectifier depend upon the ripple frequency, which equals the supply frequency for half-wave rectification. Operating with the low frequency of 50 C/sec. these capacities must be comparatively large (of the order .25 or .5 mfd).

Another difficulty to be overcome is the presence of stray magnetic fields. The electron beam is very susceptible to stray fields, and more complete shielding of the power unit is necessary than in the case with the ordinary sound receiver.

Most of these difficulties and drawbacks would be reduced or eliminated if, instead of drawing our A.C. power for rectification from the 50 cycles mains, we had some source of radio-frequency power instead. Such a source of power could be created in the receiver by using a special small r.f. oscillator.

If this were done, we could use a small and light weight r.f. transformer for the necessary voltage step-up instead of a heavy iron-covered 50 cycle power transformer.

An additional advantage would involve the filter condensers to smooth the rectified output. The "ripple" frequency of, say, 1,000,000 C/sec. could be effectively filtered by means of condensers of very low capacity, .005 mfd or less. Since large condensers of high voltage rating tend to be costly, the saving would be quite appreciable.

The shielding of an r.f. power unit is also much simplified. Adequate shielding is obtained simply by enclosing the unit within a can similar to that using for r.f. coil shielding. This is very much lighter than the heavy iron shields required for a 50 C. power transformer. The circuit of a simple r.f. high-voltage power unit is shown in Figure 14.

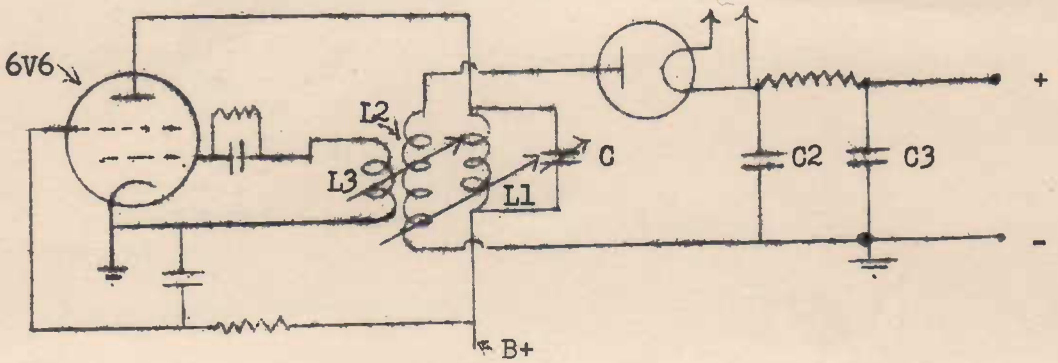


FIGURE 14.

The value (6V6, or similar type) is acting as an r.f. oscillator of the tuned-plate type. Coil L1 and condenser C form a tuned circuit. L2, together with its stray and self-capacities also acts as a tuned circuit, having the same resonant frequency as L1C. All three coils L1,L2 and L3 are wound on a former so that coupling exists between them. L3 provides the feed-back voltage to the grid, necessary to maintain self-oscillations.

An r.f. oscillation, at a frequency which mainly depends upon L2 and its stray capacities is set up in the circuit L1C. L1 and L2 constitute a step-up transformer. Hence whatever r.f. voltage is developed across L1 is magnified many times in L2.

The voltage across L2 is now applied to a diode acting as a half-wave rectifier. This part of the unit is exactly as described previously, except that the filter condensers C2 and C3 may be very much smaller in capacity tan would be required in the conventional power unit for the same degree of filtering.

Although the unit requires an extra valve, it is very much lighter than one operating directly from the 50 cycle mains.

The power required to operate the oscillator value (at about 300V) can be supplied by the ordinary low-voltage power unit of the television receiver.

The high-voltage output (D.C.) obtained is adjusted approximately with the screen dropping resistor. The screen voltage applied will determine the gain of the tube, and hence the amplitude of the r.f. voltage across L1. This in turn will determine the r.f. voltage developed across L2, and applied to the diode for rectification. Fine adjustment may be made to the output voltage by adjusting C1. If the circuit L1 C1 is de-tuned from the operating frequency (as determined by L2 plus stray capacities) the size of the oscillations will be reduced. This, of course, will affect the final D.C. output obtained.

Such units as these are usually operated at a comparatively low radio-frequency, usually between 100 K.C. and 1 M.C. A higher frequency (which would still further simplify the filtering) is difficult to obtain, because L2 must have a fairly large number of turns, to produce the necessary voltage step-up. Any increase in L2 will lower the frequency of oscillation. The figures given for frequency represent a practical compromise.

An additional advantage of the r.f. power supply, not mentioned earlier, lies in its safety from the point of view of electric shock. Although the voltage output, of course, may be very high, the <u>power</u> available is limited. This power is limited to the power output (r.f.) of the oscillator valve, which, though quite adequate to operate a C.R.T. is insufficient to produce in the human body a dangerous shock. Since, also, the filter capacities are small, the energy stored in them is also quite small. In this connection the student should be aware that condensers (unless of very small capacities) in high voltage circuits can be very dangerous things.

A field in which the high-voltage r.f. power unit may find extensive use is that of portable battery equipment. An r.f. oscillator of the type described may quite well be operated from ordinary radio batteries and this makes possible the design of television receivers for operation in areas where A.C. power mains are not available.

T.F.M & F. LESSON NO. 11.

EXAMINATION QUESTIONS.

(1) Why may half-wave rectification, with resistance-capacity filtering be successfully used for the High Voltage power supply of a television receiver?

(2) Draw a simple circuit diagram showing the connections required for half wave rectification, with a negative output, and diode filament earthed.

(3) Upon what quantity does the degree of filtering of a simple resistance-capacity filter depend?

(4) Name the controls in a television receiver which may take the form of potentiometers in the bleeder circuit of the high-voltage supply.

(5) What is the advantage of operating the grid of the C.R.T. at (or near) the plate potential of the final video amplifier?

(6) Why should the average potential of a pair of deflection plates in a C.R.T. be fixed at a value equal to that of the final anode of the tube?

(7) Which power supply is associated with the control of focus in an electro-magnetically focussed tube? State briefly the method usually used.

(8) Give two reasons to explain why an r.f. type high-voltage power supply may be much lighter in weight than the conventional type.

(9) How may fine adjustment be made to the output voltage of an r.f. power supply?

(10) In what ways does the use of a magnetically controlled tube simplify the circuits of a receiver.

AUSTRALIAN RADIO COLLEGE

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T.FM & F. LESSON NO. 12.

COLOUR TELEVISION.

In black-and-white or monochrome television the system reproduces only the varying intensities (brightness) of the different elements of the picture or scene, irrespective of their colours. It does not differentiate between lights of the same brightnesses but of different colours. The result is similar to that of a black-and-white photo, where, on the final print objects of all different colours, (providing they reflect the same amount of light in the original scene) are reproduced by the same shade of grey.

At this stage the student should re-read the early lesson which dealt with the fundamentals of light. He should, in particular, make sure that he understands the following points:- (1) the brightness of light depends upon the amplitude (strength) of the light-wave.(2) The colour of light depends upon the frequency of the light-wave. (3) The colour "spectrum" consists of the following colours (in order of increasing frequency) red, orange, yellow, green, blue, violet). (4) White light consists of a mixture of all colour frequencies in the proportions they appear

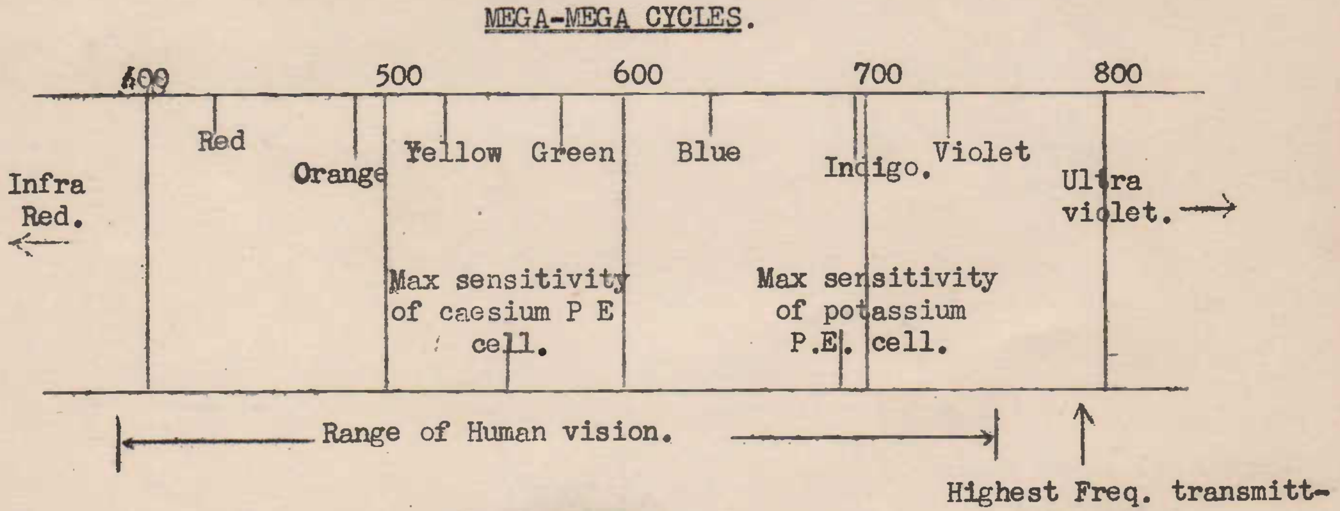


FIGURE 1.
COLOUR SPECTRUM.

in sunlight. (5) No colour is pure. For example a green light consists of a band of frequencies of which those around the green portion of the spectrum predominate. The frequencies present, however, may extend to the yellow, or even (in weaker proportions) down to the red parts of the spectrum. Similarly, in "green" light, there may be some light wave frequencies corresponding to blue or even violet light. The narrower the band of frequencies, the purer will be the green light.

Colour television makes use of the same general principle as is used in colour photography. This principle involves the super-imposition of 2, or 3 separate pictures, each of different colours to produce a picture in natural colour (i.e. showing all the colours of the spectrum).

The principle may be explained thus. Suppose we view a coloured scene through a red-coloured glass. Such a glass (or "filter") will readily pass, or transmit, red light, but it will tend to absorb, or block, light of other colours. The red glass, however will not entirely block all other colours. It will pass lesser amounts of yellow, and still lesser amounts, perhaps, of green. It may entirely block blue light. A scene viewed through such a filter will have a decided reddish tinge. Blue objects will appear black (absence of light), since no light from them can get through. If now we view the same scene through a green glass, the light from green objects will be readily transmitted, together with smaller amounts of yellow and blue. Finally we use a blue-violet glass, blue is readily passed with smaller amounts of green, and perhaps still smaller quantities of yellow. Red, however, may be entirely blocked.

The effect of each filter on passing, or transmitting the different coloured lights is shown graphically in Figure 1a.

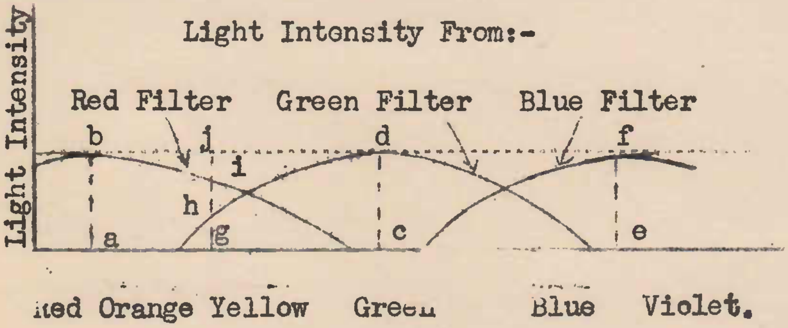
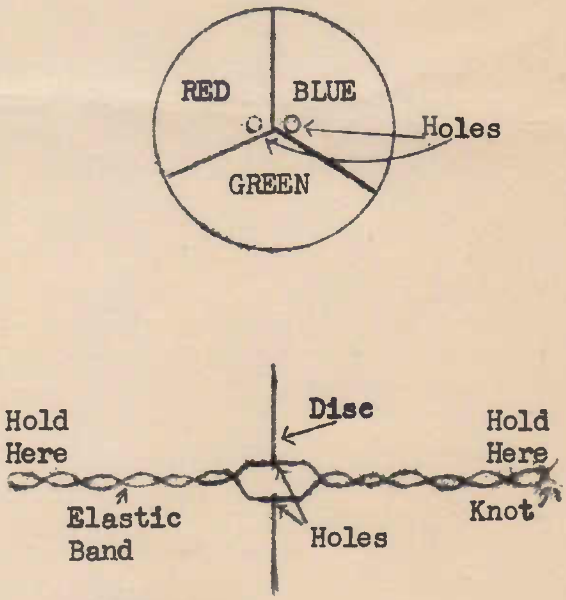


FIGURE 1a.

Suppose now, as in colour photography, 3 separate pictures were taken using in turn the red, green, and blue filters. Without delving into the details of colour photography, the three negatives so obtained are printed in their respective colours. Finally the three pictures are superimposed in such a way that the total light received by the eye from the composite picture is the sum of the lights produced by each component picture. The result is a picture in natural colour. Red objects in the scene would be catered for entirely by the picture obtained when using the red filter. Similarly greens would be reproduced from the gree-filter picture, and violets from the blue-violet filter-picture. Intermediate colours would be fully catered for, each of these colours having light contributed from a pair of pictures. For example, returning to Figure 1a, consider 3 objects of colours red, green and blue respectively. The red filter would pass a maximum amount of light (ab) from the red object. The green filter would pass the maximum light (cd) from the green object. Similarly the blue-violet filter would pass the maximum light (ef) from the blue object. Assuming that the three objects were of equal brightness these amounts of lights transmitted by the respective filters (and therefore reproduced in the final picture) would be equal, i.e. ab = cd = ef (Figure 1a). Note that the red filter passes no light from the green or blue objects, etc.

Now consider a yellow object, equal in brightness (light intensity) to the red, green and the blue objects. Referring to Figure 1a, the red filter passes an amount of yellow light from this object equal to gi. The green filter passes an amount equal to gh. Since the total light appearing in the final composite picture is the <u>sum</u> of the lights from the separate pictures, the total yellow light appearing would be equal to gi plus gh = gj. Since gj is equal to ab or cd or ef, the yellow object would appear in the picture equally bright as the red, green or blue. In a similar way all other intermediate colours would be catered for.

From the foregoing it is seen that the three colours red, green and blue-violet can be combined to reproduce all the colours of the rainbow, and therefore, also, white light (since "white" light is simply the effect on the eye of a mixture of <u>all</u> colours). Such colours (red, green, blue) are called "primary" colours. If the student still doubts that the effect of adding these three primary colours is white light a simple experiment should convince him. Cut out a disc of cardboard about 2 or 3 inches in diameter. Divide the disc into three equal segments as shown in Figure 2. Paint these respectively red, light green and blue. Double a length (about 18" or 2 ft) of thin elastic and pass the end through two small holes near the centre of the disc. (Fig.2). Tie the ends of the elastic together. With the disc at the centre of the doubled length of elastic pull in and out on the elastic, so making the disc spin rapidly in one direction, then the other. The coloured lightx reflected from the segments will mix in the eye, and the disc will appear a uniform white. At first a dirty greyish colour may be obtained, but by experimenting with particular shades of red, green and blue, something approaching white, or at least very light grey, will be obtained.



<u>FIGURE 2.</u>

All natural colours may be simulated by the use of but two colours. For example if a filter of yellowish-red, and one of greenish-blue are used, a picture in more or less natural colour may be obtained. In this case the filters would need to be of less pure colours than in the case where three colours were used. That is each filter would be required to transmit <u>some</u> amounts of most of the colours of the spectrum. Two colours which when mixed will produce all colours of the spectrum (and, therefore white light) are called "complementary" colours.

The two-colour system has been used in television, but it is now generally considered that three colours are necessary for a high degree of colour naturalness.

<u>TRANSMITTING COLOUR PICTURES</u>.

In all systems of colour television it is first essential to analyse the original picture or scene into its "primary" colours by using colour "filters". The light transmitted through each of these three filters is converted into a video signal by allowing it to fall on a photosensitive surface (such as that contained in a television camera). In this way three separate video signals are generated, corresponding to the three primary colours. These three signals must be conveyed intact through the ether to the receiver. There are two main systems which have been developed with considerable success. These are called the "Sequential" system and the "Simultaneous" system.

In the sequential system the three pictures (corresponding to the three primary colours) are sent in turn, or in sequence, over the one carrier wave. At the receiver the three pictures are reproduced, in turn, as they arrive. At any one moment only one colour is being sent and reproduced. If the rate of alteration of the colours is rapid enough, however, the three colours will merge into each other as a result of the "persistence of vision" effect of the eye.

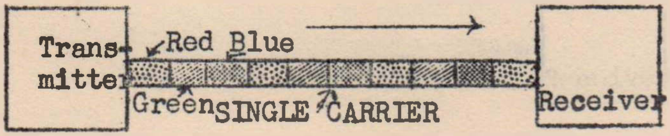
In the simultaneous system the three video signals representing the separate primary colours are sent simultaneously.by using three separate carriers, or subcarriers. The three primary colour pictures are reproduced simultaneously at the receiver by utilising three separate picture tubes. The primary colour pictures are mixed by projecting them on to a single screen.

Both systems produce pictures of similar standards of definition and colour quality, if the same total bandwidths for transmission are used.

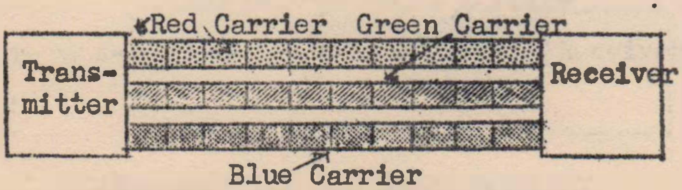
The essential different between Sequential and Simultaneous system is illustrated in a purely diagrammatic way in Figure 3.

THE SEQUENTIAL SYSTEM.

We shall describe the details of this system first, since, cronologically, its initial development preceded that of the Simultaneous system. It has been commonly described as the mechanical system since, to date, most apparatus used in its development has made use of mechanically rotated discs at receiver and transmitter. This, however, is not a very good or significant term, since, as we shall see later, these discs may be avoided by using techniques originally developed for the Simultaneous system. They are also eliminated in a special C.R.T. developed by Baird. If this is done the system becomes an entirely "electronic" one.



Each Rectangle Represents a Frame.
Red Frame ▨
Green Frame ▨
Blue Frame ▨
(A) SEQUENTIAL SYSTEM



THREE SEPARATE ADJACENT CARRIERS
(B) SIMULTANEOUS SYSTEM
FIGURE 3.

The Sequential system, recently demonstrated by the C.B.S. (Columbia Broadcasting System) , in America made use of a rotating colour filter wheel in front of the television camera, and a similar wheel rotating synchronously in front of the c-r tube at the receiver. These colour wheels consist, in their simplest form of three segments, each segment being a colour filter for one of the three primary colours- red, green and blue (Figure 4). The filter material is some coloured transparent material such as a coloured glass etc. The wheel is rotated at such a rate before the television camera that the latter "perceives" the scene for an interval of time exactly equal to one field. (Note the terms "field" and "frame" are now used in the American sense; i.e. a "frame" means a complete scanning of both "odd" and "even" lines; a "field" denotes a coverage of the picture area by one set of lines -- even or odd -- only.) Thus while each filter section is before the camera the picture area is scanned completely by alternate lines, and the video signal generated represents the variations of light intensity for the colour only. The camera output therefore represents a succession of "fields", each for a different colour.

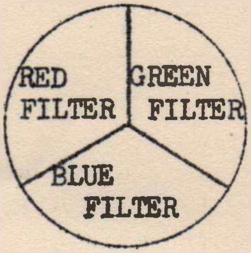


FIGURE 4.

At the receiver the c.r. tube screen is viewed through the rotating colour filter wheel. This wheel rotates at the same speed as that at the transmitter, so that each filter section covers the tube for an interval of time equal to one field. The two-wheels must further be synchronised so that when the transmitter is scanning the scene through say, a red field; the red filter is before the c.r tube in the receiver. Similarly for the other filter sections. The system is illustrated in a simple diagramatic manner in Figure 5.

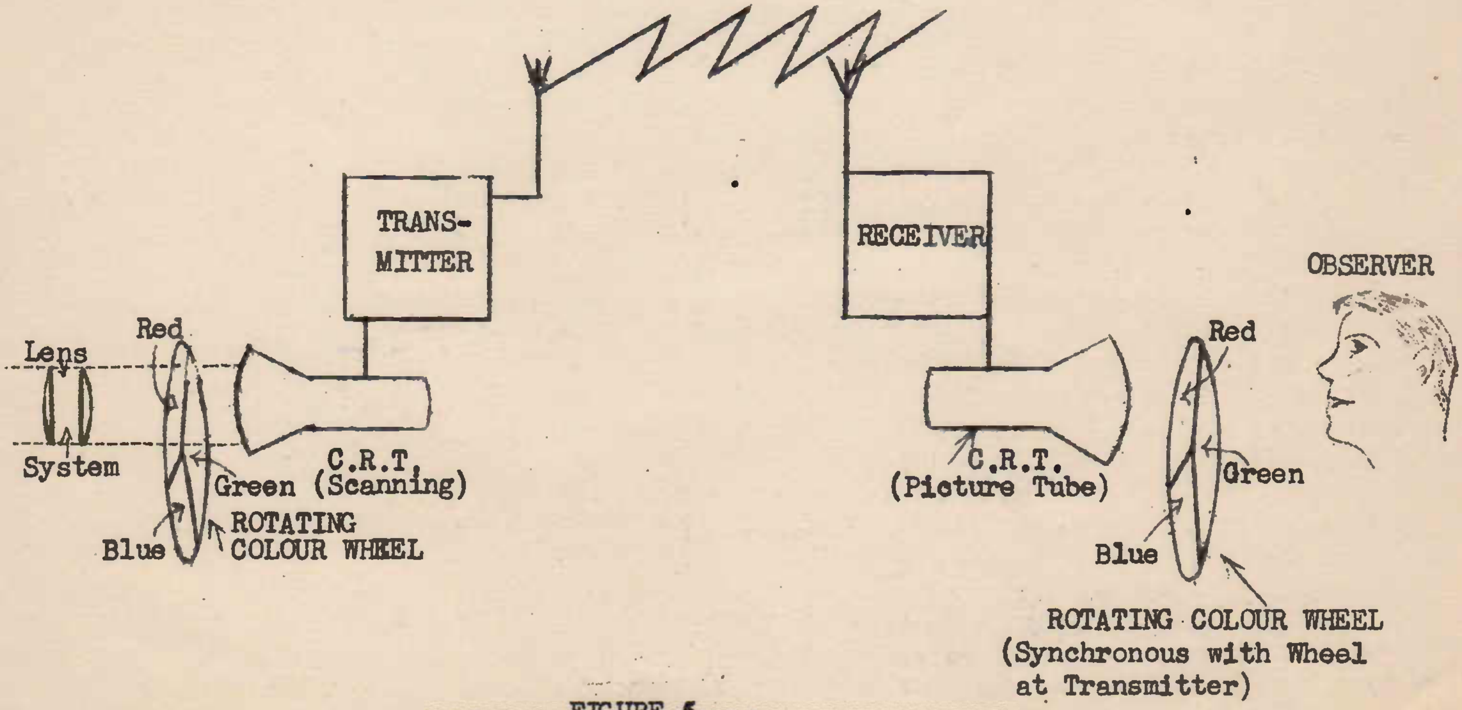


FIGURE 5.
PRINCIPLE OF SEQUENTIAL COLOUR SYSTEM.

The C.R. tube at receiver has a white phosphor, i.e. a screen producing a white light. The different colours are produced successively by viewing the light emitted through the different filter sections in turn. It should be noted, therefore that the colours, as such, are not actually transmitted from transmitter to the receiver. The video signal for any frame, whether it be for red, green or blue, consists simply of a varying voltage, the variations representing different *intensities* of light. Signals for all frames, therefore, when applied to the C.R.T. control electrode will produce a white light of varying degrees of brightness. But the C.R.T. screen is seen at any moment through a coloured filter. Hence the light seen at any given moment will be either red, green or blue, according to the filter section in front of the screen. For example consider the frame interval of time that the red filter section remains before the receiver screen. During this interval the C.R.T. spot is tracing out lines with varying light intensity corresponding to the variations in light intensity of the red portions of the original scene. This is so because the television camera, for the interval under consideration, is "perceiving" the scene through the red section of its wheel. At the receiver the viewer sees only variations of *red* light, since the white light from the C.R.T.'s screen is viewed, for this interval through a red filter. The same thing happens for each of the other two colour frames. The necessity for perfect synchronisation between transmitter and receiver colour wheels is thus obvious. Now, provided that the rate of repetition of the sequential colour frames is sufficiently rapid, the eye will not see the separate colour pictures individually, but these will blend together giving the effect of a naturally coloured picture. Colours other than the three primary colours (for example yellow, orange, bluish-green etc) will be produced, as previously explained, by blending of the primary colours in varying proportions.

"FLICKER" CONSIDERATIONS.

In black-and-white television flicker has been eliminated by transmitting the fields at a sufficiently fast rate - 50 fields per second, or 25 completely interlaced frames (or pictures) per second (30 and 60 respectively in America). The smooth merging of the separate fields is also enhanced by using phosphors of fairly slow decay rates (i.e. phosphors which continue to glow for some appreciable fraction of a section after the spot has passed).

In the sequential colour system the phosphor must have a sufficiently fast decay rate to ensure that the light from one colour frame has completely disappeared before the next frame commences. This complicates the flicker problem. Of greater and more fundamental importance than this aspect of the flicker problem, however, is the serious flicker which is seen when a large area of the *one* colour is transmitted by this system. Suppose 50 fields per second (to correspond with the standard for black-and-white transmission) are used. When a large area of, say, blue sky is transmitted, the blue is only reproduced during one of every three fields. The red and green fields do not cater for blue. Hence the blue sky is reproduced only $50 \div 3$ or $16\frac{2}{3}$ times per second. This is too slow and produces quite noticeable flicker.

To reduce the flicker to a standard comparable with that of the black-and-white system, therefore, each colour should be transmitted 50 times per second, i.e. 50 red fields, 50 green fields and 50 blue fields per second, a total of 150 fields per second. This means that each field should be scanned in one-third of the time involved in black-and-white transmission. Hence the scanning spot should move three times as fast over the mosaic in the television camera. The net result of this requirement is that the video frequency would be three times as great for a given number of scanning lines and therefore a given standard of definition. This, of course would involve a signal having a band-width three times as great as that required for a nominally equivalent black and white picture. It might well be mentioned here that the post-war standard decided upon in America for black-and-white transmission is 525 lines per picture. This same standard has been used for the experiments in colour television.

Thus we see that if the same number of scanning lines and a frame frequency three times as great is used colour television should provide a picture of equal definition as (i.e. containing the same amount of detail) and comparable lack of flicker with that obtained in the black-and-white system. Actually, it is claimed, with those standards the apparent effect is better in the case of the colour picture. This is due to the fact that the improved naturalness due to the inclusion of colour, masks, as far as the human eye is concerned, any deficiencies in lack of detail etc. Thus the improvement obtained is a "subjective" one, i.e. the viewer thinks he is seeing a more finely detailed picture -- and, after all, this is the important thing.

CARRIER FREQUENCIES REQUIRED.

Since the sequential colour system involves a range of video frequencies three times as great as that necessary for black-and-white transmission for the same number of lines in each field, the width of the r.f. channel will also be three times as great. Where 4 mc/sec. was used for black-and-white 12 mc/sec. will be needed for colour. It is impossible to incorporate signals having such bandwidths in the part of the spectrum so far used for black-and-white, viz 40-100 mc/sec. For this reason it has been decided to devote that part of the spectrum between 400 and 1,000 mc/sec. to colour television. (Note that 1,000 mc/sec. represents a wave-length of only 0.3 metres or 30 cm.)

SOUND-ON-VISION TRANSMISSION.

The C.B.S. organisation in its experiments on the sequential colour system decided to make use of a sound-on-vision system for transmitting the accompanying sound. In this system the sound is carried on the picture carrier during the small intervals between lines (i.e. during the time allowed for spot "fly-back" or "retrace" at the end of each line, and before the next).

In an earlier lesson a system of sound-on-vision transmission, using pulse modulation was mentioned. The system used by C.B.S, however, is somewhat different. It is not pulse modulation. "Bursts" of an 8 mc. frequency modulated wave are superimposed on the picture carrier (485 m.c) between each pair of lines. An 8 mc. oscillation is generated at the transmitter and frequency-modulated with the sound. The 8 m.c. voltage, thus modulated, is then used to modulate the much higher frequency picture carrier in the "gaps" between lines. This modulation of the picture carrier with the 8 m.c. sub-carrier (as it is called) is amplitude modulation -- just as a 4 mc. (say) video signal amplitude modulates the carrier.

The modulation "envelope" of the picture carrier is shown in Figure 6. Here the intervals between the lines are, of course, exaggerated. Actually, in practice, these gaps each occupy only 8% of the total line period. No attempt either is made to show the frequency deviation representing frequency modulation of the 8 mc. sub-carrier.

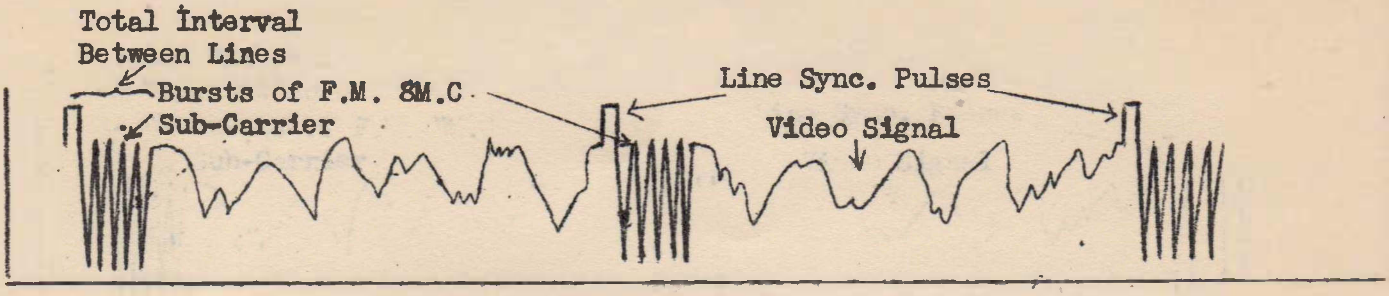


FIGURE 6.

At the receiver the bursts of 8 mc. sound carrier appear immediately after the picture second detector, together with all the video frequencies representing picture detail. This will be understood if it is kept in mind that both video frequencies and 8 mc. sound carrier are used to amplitude modulate the vision carrier. Immediately after the vision detector the 8 mc. sub-carrier (still frequency modulated) is picked out by means of a circuit tuned to 8 m.c. The sound carrier is then passed to a discriminator circuit, which is really a special type of detector for F.M. This circuit reproduces the original audio frequencies carred as F.M. on the 8 mc. wave.

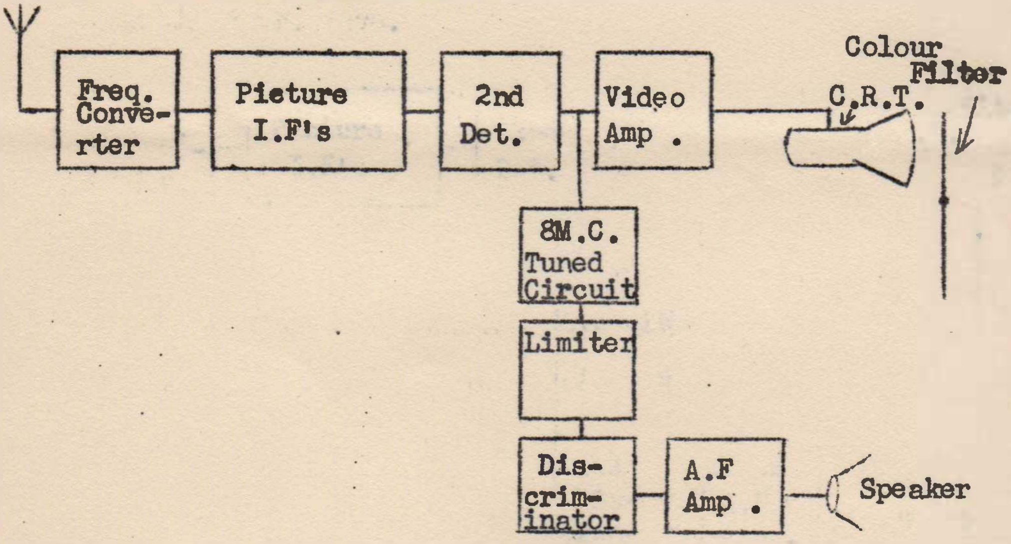


FIGURE 7.

The arrangement is shown in Figure 7. The "limiter" shown before the discriminator (F.M. detector) is designed to eliminate any amplitude modulation on the sound carrier. This, in effect prevents any video frequencies being carried as amplitude modulation, and finally reaching the speaker.

Note that the system eliminates the necessity for a separate sound intermediate frequency channel.

The fact that the sound is not carried continuously does not really matter. The rate of repetition of the sound sub-carrier "bursts" is that of the line frequency (30,000 C/sec. or more). This is above the audio-frequency, and the sound will appear to the ear as continuous.

THE SIMULTANEOUS SYSTEM.

This system requires, at the transmitter, the simultaneous generation of the three primary colour video signals. To achieve this, the camera arrangement involves a"beam-splitting" optical system whereby a focussed image (in natural colours) of the scene is split into the three primary colours--red, green, and blue.

The arrangement is shown in Figure 8. Two "colour-selective" mirrors are used.

These are made of a semi-transparent material which possesses the property of reflecting light of one of the primary colours, and transmitting (i.e. passing) all other light colours. The coloured scene is focussed by means of a lens system. Falling upon the first colour-selective mirror, (which is red-selective), a reddish image is reflected on to the mosaic of the first camera. where it is scanned to produce the "red" video signal. All other colour components pass through this mirror, and fall upon the second colour-selective mirror, which is blue-selective. The green components of the image are not affected by this mirror and pass straight through it, forming a greenish image on the mosaic of a second camera shown at the right of Figure 8. This gives the green channel. The blue light waves in the light image are reflected from the surface of the second mirror and from the blue image on the mosaic of a third camera at the bottom of Figure 8, which produces a video signal corresponding to the varying intensities of blue light.

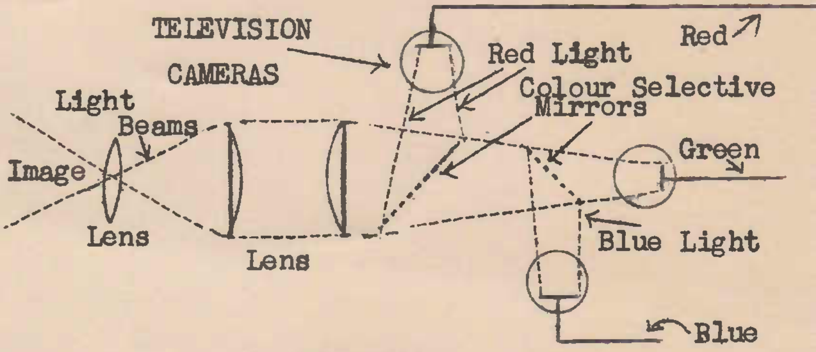


FIGURE 8.
BEAM SPLITTING CAMERA.

The three separate video signals are used separately to modulate three separate carrier waves. These have frequencies as close as is possible to each other without their side-bands overlapping. Hence the over-all band-width of the television channel is only very slightly in excess of three times the width of a single channel.

At the receiver the composite signal is picked up by a single aerial, and either (after frequency conversion) fed through three separate I.F. channels, or through a single channel. In the latter case the three colour channels are separated before the second detector by means of wave-filters (i.e. wave-traps).

After detection the three separate video signals are applied separately to the control electrodes of three separate c.r. tubes. These tubes are fitted with fixed colour filters, or use special colour phosphors. In either event each tube produces an image in its own primary colour. The coloured images are mixed to form a single image in natural colour, by projecting the three images, using lens, on to a single screen.

Figure 9 shows the three small 3" projection type cathode-ray tubes used in the simultaneous type receiver developed by the R.C.A. organisation in America. Projection lens (removed, and held by the technician) project the three images on to a screen in the lid of the receiver.

Note that no moving parts are used in this system.

In this (simultaneous) system the blending of the colours is inherent (i.e. it does not depend upon the persistance of vision for colour blending). Also each colour field is repeated at the field frequency. Further the phosphors may have slow decay rates, since each colour uses its own phosphor, and there is no necessity for all the light to disappear before the next frame arrives. For these reasons a very

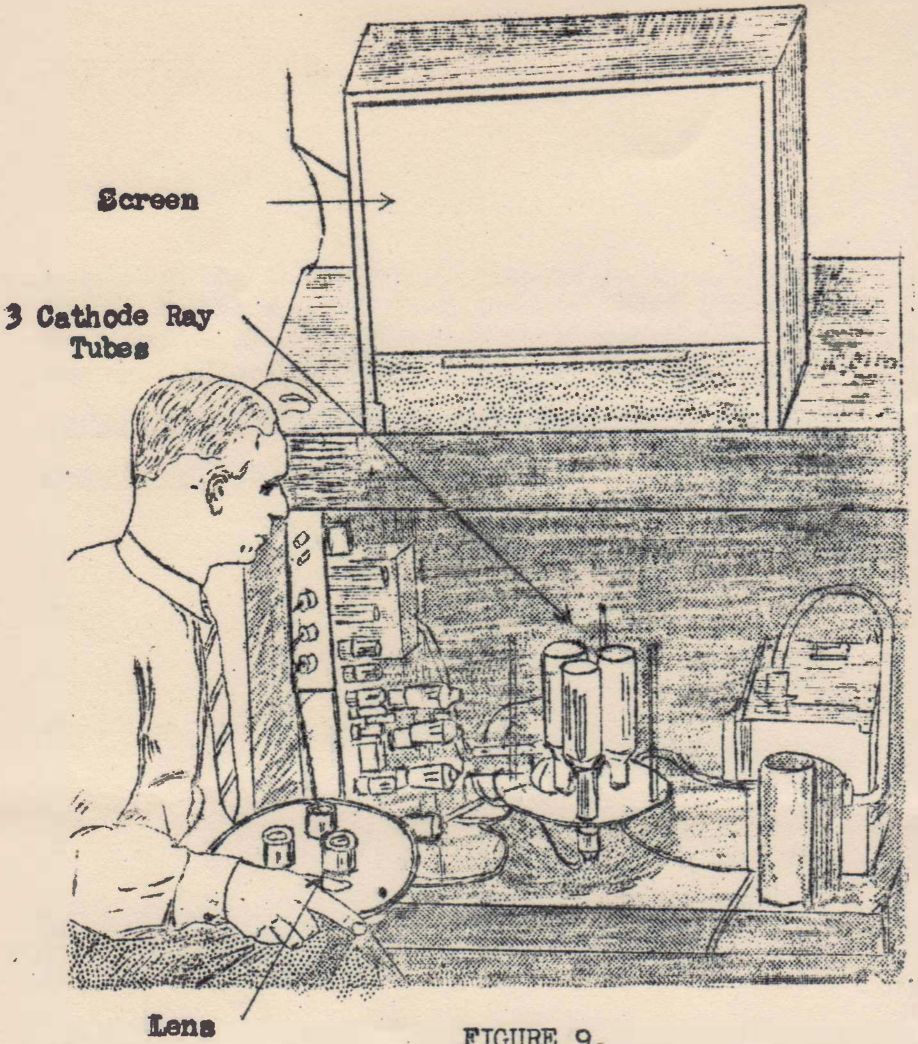


FIGURE 9.

much slower field rate may be used than is necessary for the sequential system. In America the rate has been chosen to coincide with that of the black-and-white transmissions, i.e. 60 fields per second (30 complete frames or pictures per sec.). In England, and in this country the corresponding rate (owing to the difference in power supply frequency) would be 50 fields per sec.

With this field rate the system probably gives a flicker performance superior to that of the sequential system operating at 150 fields/sec. The performance, as regards flicker, would also be much superior to that of the black-and-white system using 50 fields/sec.

The video frequency range <u>for each colour channel</u> in the simultaneous system would equal that of the black-and-white system. But since, there are three colour channels each television channel would have a total band-width three times (approx) as great as that for the black-and-white. This equals the figure for the sequential system operating at 150 fields per.sec.

ELIMINATION OF ROTATING DISCS IN SEQUENTIAL SYSTEM.

The sequential system could be made purely electronic by utilising, at the transmitter, the beam-splitting camera arrangement developed for the simultaneous system, and substituting, in the receiver, the three separate projection C.R.T's. in place of the single tube with rotating disc.

If this were done it would be necessary to "key" the three cameras at transmitter in sequence. This would involve an electronic switch which would switch into the modulator the three colour signals in turn. Similarly, at the receiver, an electronic switch would be required to "key" the separate C.R.T's, so that each tube would be operated <u>in turn</u> at field frequency. Note that only one transmitter camera, and one receiver C.R.T. would be in use at any one moment.

COMPARISON OF SEQUENTIAL AND SIMULTANEOUS SYSTEMS.

<u>Band-Width Required</u>. For comparable standards of definition and flicker performance,

the two systems require about the same total band-width. The sequential system uses a single wide band, while the simultaneous system uses three separate narrower bands. In each case the band-width required is about three times that used in black-and-white transmission. Actually, for reasons given above, using equal total band-widths the simultaneous system could be expected to give superior flicker performance to that obtained from the sequential system.

BRIGHTNESS:- The simultaneous system produces a brighter picture. Reasons are:- (1) When using rotating discs the mosaic at the transmitter and the phosphor in the C.R.T. at the receiver must have rapid decay times in the sequential system. Thus the advantage of light-storage effects is lost. (2) If the trio of C.R.T.'s at the receiver use coloured phosphors the light loss due to colour filters is avoided. Since these filters absorb 85 to 90% of the light a much brighter picture will result in this way. Of course if the three tubes, together with keying arrangements, were adapted for use in the sequential system, both systems would be on a par in this respect. (3) Apart from the above points there is a fundamental reason for a brighter picture from the simultaneous system. In the sequential system only one light-source is on at any one moment, operating sequentially with different colours, whereas in the simultaneous system all three light sources operate at once. Hence, other things being equal, the simultaneous system should produce a picture three times as bright. This is one of the main considerations in favour of the simultaneous system, since the problem of picture brightness has been one of the most difficult to solve in colour television.

EQUIPMENT COST. The sequential system requires, in general simpler equipment. It uses only one camera, transmitter, antenna, receiver, I.F. amplifier, video amplifier and picture (c.r.) tube. The simultaneous system requires three separate transmitter sections and antennae for three colour carriers, usually three I.F. amplifiers and detectors in the receiver, and three separate video amplifiers and picture tubes.

OTHER COMPARISONS. One of the main disadvantages of the simultaneous system is that, so far, a direct viewing screen is out of the question. The three colour pictures must be combined by the projection method. This involves costly lens systems. A possible solution of this problem would be the use of Baird's "Telechrome", developed in England and described in the next section of this lesson.

Both systems make use of normal methods for beam scanning synchronisation. The sequential system signal however, requires extra sync. pulses to time the mechanically driven colour filter wheel. Even if the use of the colour wheel is avoided by making use of the three projection tubes, the electronic switch which keys the tubes for the different colour frames must be synchronised with the corresponding switch at the transmitter.

BLACK-AND-WHITE RECEPTION FROM COLOUR TRANSMITTER.

By tuning a black-and-white receiver to the "green" carrier of a simultaneous system signal normal black-and-white reception may be obtained. Experiment has shown that the video signal obtained from the green filter carries the majority of the fine detail of the picture, and is quite adequate for black-and-white reception.
Since each of the colour channels operates at the same field and line frequency as used for black-and-white, it would be easy to convert a normal receiver to

operate on the green carrier of a colour transmitter. All that would be required is an r.f. converter to reduce the carrier frequency to that for which the receiver was originally designed.

This is an important point when considering conversion from black-and-white television to colour. It would mean that receivers designed for black-and-white would not be rendered obsolete. For this reason alone the simultaneous system may be favoured rather than the sequential.

BAIRD'S "TELECHROME".

This is a special form of C.R. tube designed for operation on a sequential system without the use of filters (either fixed or rotating). It has made possible a purely electronic system with direct viewing of the screen. The colour picture appearsdirectly on the fluorescent screen.

For a two-colour system the tube takes the form shown in Figure 10.

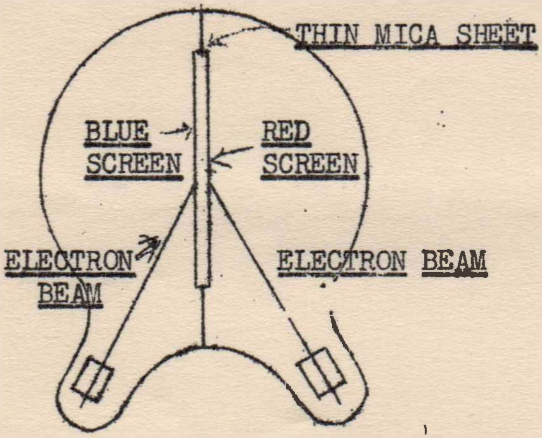


FIGURE 10.

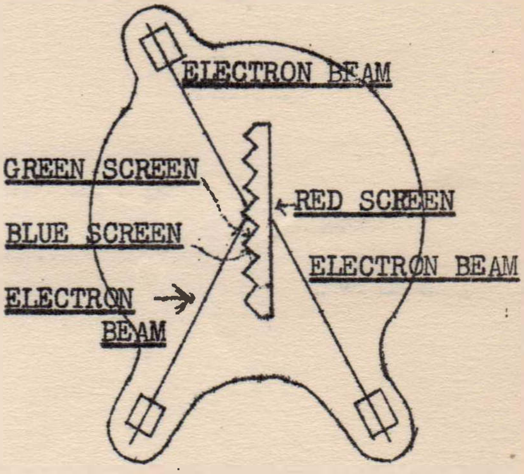


FIGURE 11.

Two electron beams scan opposite sides of a thin transparent mica screen, one side of which has been coated with orange-red fluorescent powder, and the other with blue-green fluorescent powder. The two electron beams are modulated with two video signals corresponding to the two colours. Since the screen is transparent the two colour pictures merge into a single picture in natural colour.

Where three colours are to be used one side of the screen is ridged as shown in Figure 11. The front side of the screen gives the red image, one side of the back ridges give the blue components, and the other side of these ridges produce the green. Three electron beams are now used. Note that of the two beams scanning the ridged surface, each beam only impinges upon one side of the ridges.

The tubes give very bright pictures due not only to the absence of filters, but also due to the fact that phosphors producing the correct colours are chosen. Colour phosphors produce more light than do white phosphors for the same accelerating voltages.

Baird's system is a sequential one, the three electron beams being keyed in turn for the different colours. There appears no reason however, why the tube should not be used in a simultaneous system, the three beams being continuously modulated by the separate colour signals. This should produce a very bright picture indeed.

T.FM & F. LESSON NO. 12.

EXAMINATION QUESTIONS.

(1) Explain why the video signal produced by an ordinary television camera when viewing, a blue object against a black back ground, is identical with that obtained when viewing a red object against the same back ground.

(2) What is the function of a colour filter?

(3) What is meant by "primary colours"?

(4) State the fundamental difference between the sequential and simultaneous systems of colour television.

(5) Considering a two colour system involving rotating colour filters at transmitter and receiver, what would be the effect on the received picture if transmitter and receiver wheels were completely out of synchronism?

(6) In the case of a sequential system explain why flicker may be noticeable when reproducing a large area of blue sky.

(7) What is the function of a colour selective mirror?

(8) What is the chief advantage gained by the use of a "telechrome" picture tube?

(9) Why is a wider frequency channel required for colour television than for black-and-white television?

(10) State one important advantage of (a) The sequential system over the simultaneous system (b) the simultaneous system over the sequential system.

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T.FM & F. LESSON NO. 13.

RECENT DEVELOPMENTS.

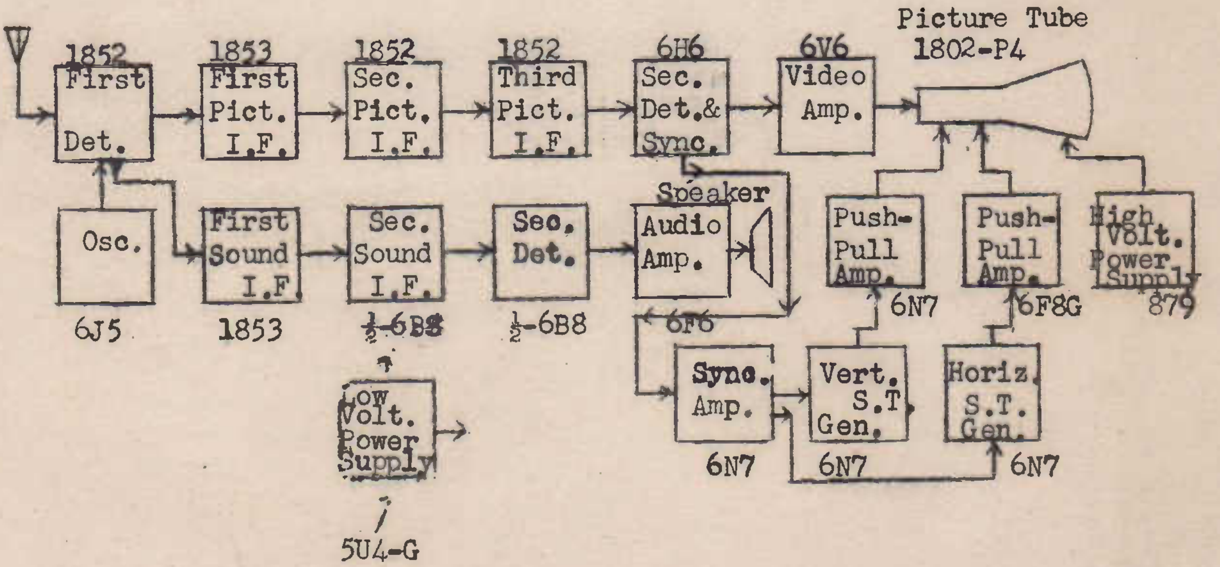


FIGURE 1.

We shall devote the first part of this lesson to a description of the circuits and controls of two modern television receivers. In this way the student will have an opportunity of visualising as a whole, the techniques involved in the latest black-and-white (as distinct from colour) sets. At the same time the descriptions will serve to gather up the "loose-ends", and provide a revision of the detailed explanations of particular sections which have been spread over several lessons in this series. We have no hesitation in spending considerable time over the circuits given, since it now appears that, for black-and-white transmission, the techniques and standards for transmission, modulation and receiver design have reached a fairly static state, from which very little fundamental deviation is to be expected for a few years.

We would qualify the above remarks on two scores. Firstly, the sound sections of the receivers whose circuit diagram are given in Figures 2 and 4, are for amplitude modulation (A.M.), whereas, in America, frequency modulation has been decided upon as standard practice. This practice is certain to continue there for some considerable time, and if replaced would give way to the sound-on-vision method, whereby some type of pulse modulation, (already briefly described) is superimposed on the picture carrier. It seems very probable however, that for quite a time to come sound will accompany the scene either as an amplitude or frequency modulated carrier slightly separated in frequency from the vision carrier. At this stage in the course, however, it is impossible to say more about the details of an F.M. sound section of a television receiver. The subject of F.M. will be covered in later lessons.

The other exception we would like to make to our general remarks on standardisation above, concerns colour television. The latter has made remarkable progress and has reached such a standard of definition and naturalness overseas that its commercial adoption seems a certainty in the immediate future. At the present moment it has passed the stage of laboratory development and has reached that of final "field" tests. These tests, to determine the best of the several systems which have been developed, and to provide data, on one or two doubtful points of performance, seem near completion. Colour television, then, is a thing which must not be ignored, even if we are content to consider only the immediate future.

As has been explained colour transmission requires a bandwidth at least three times as great as that required for black-and-white, and a very much higher portion of the frequency spectrum - 400 to 1,000 m.c. - has been chosen for its use. These extremely high frequencies have never before been used for civil or commercial purposes, and were only used extensively for the first time during the latter years of the war for improved operation of Radar devices. The use of such frequencies will, of course, mean considerable modification to techniques used in receiver design. This development of colour television will not, however have any immediate effect on the standards for black-and-white television. The plan, both in England and America, is, eventually, to introduce colour television as a separate and additional service, not materially affected the present standards decided upon for the black-and-white system.

A TYPICAL SMALL-TUBE TELEVISION RECEIVER.

Figure 1 shows a block diagram of a typical television receiver using a 5 inch-tube of the electrostatic type. Such a receiver would be representative of the mantel-models or less ambitious cabinet sets at present in use in America.

The full circuit diagram is given in Figure 2.

It will be observed that the receiver contains seventeen tubes, seven of these (6H6, 6B8, 6F8, and four 6N7's) being dual-tubes.

Referring to the circuit diagram of Figure 2, and commencing at the antenna, note that five signal channels are provided for. For each of these we have a separate input circuit and a separate oscillator circuit. The desired station is chosen by means of a switch. In passing it might be mentioned that in America sets are equip-

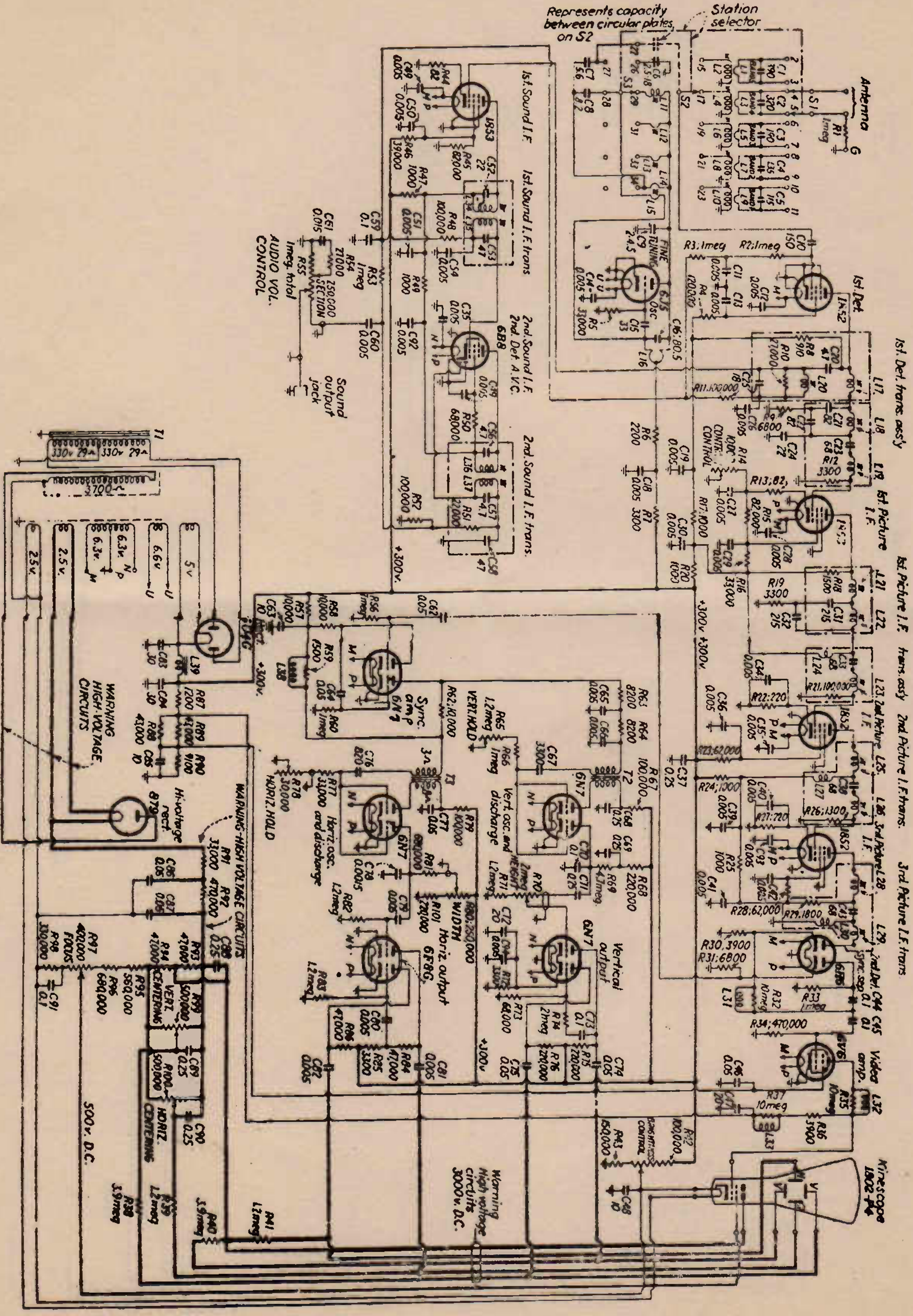

Antenna
Represents capacity between circular plates on S2
Station selector
1st. Det.
1st. Det. trans. ass'y
1st. Picture I.F.
1st. Picture I.F. trans. ass'y
2nd. Picture I.F.
2nd. Picture I.F. trans.
3rd. Picture I.F.
3rd. Picture I.F. trans.
2nd. Det. Sync. sep.
Video amp.
Kinescope 1802 P4
1st. Sound I.F.
1st. Sound I.F. trans.
2nd. Sound I.F. 2nd. Det. A.V.C.
2nd. Sound I.F. trans.
AUDIO VOL. CONTROL
Sound output jack
FINE TUNING
CONTRAST CONTROL
BRIGHTNESS CONTROL
Sync. amp
VERT. HOLD
Vert. osc. and discharge
HEIGHT
Vertical output
HORIZ. HOLD
Horiz. osc. and discharge
WIDTH
Horiz. output
Hi-voltage rect.
WARNING HIGH VOLTAGE CIRCUITS
WARNING-HIGH VOLTAGE CIRCUITS
Warning High voltage circuits 3000 v. D.C.
FOCUS
VERT. CENTERING
HORIZ. CENTERING
500 v. D.C.
+300 v.

Fig 2

ped for anything up to five channels, although, even there, at present no more than two or three stations are in operation in any one locality.

Each input circuit is broadly tuned to accomodate both vision and sound carriers of the signal. These, for any one transmission extend over a wave-band of about 6 megacycles.

The primaries of the input circuits each consist of but a single turn, this being usually a metal strap stamped from sheet, and intended to match the 75 ohms characteristic impedance of a transmission line from the antenna.

For frequency conversion a single mixer tube (frequency changer) is used for vision and sound, this being a 6AC7 (1852) of high mutual conductance -- about 9,000 microamps. per volt. A separate oscillator (6J5) produces an oscillation, which when injected into the mixer together with the two carriers develops the two desired I.F's. for vision and sound. This system has already been described. The separation of the sound and vision signals is then carried out by the respective I.F. tuned circuits.

The vision I.F. stages employ an 1853 valve followed by two 1852's. The 1853 is similar to the 1852 except that it is a remote cut-off (variable mu) tube while the latter have a sharp cut-off characteristic. It should be observed that manual gain control is operated upon the grid of this remote cut-off 1853. This provides a variation of the overall gain of the picture receiver, and is known as the contrast control.

The vision I.F. tuned circuits are of the band-pass type which have a "flat" characteristic over the wide frequency band representing the modulated vision signal.

The duo-diode 6H6 is used for vision detection and sync. pulse "clipper. The "detected" (demodulated) signal from the first diode section is passed to the final video amplifier (6V6) and also to the second diode section of the 6H6. R33 and C44 develop a negative bias on the plate of this diode of such value that the valve passes current only when the signal rises above the black level, i.e. only for sync. pulses. Positive pulses representing these sync. pulses are taken from the cathode of the sync. separator and applied to the grid of the 1st triode section of the sync. amplifier (a 6N7). This tube acts as an amplifier, each section reversing the polarity of the signal. Since the polarity of the pulses is positive on the 1st grid, the output from the second plate will also be positive.

Returning to the picture video signal, this is applied, from the detector, through a "peaking" coil to the grid of the 6V6. The latter tube is operated without bias. The grid circuit, together with the coupling condenser and leak, thus forms a D.C. Restorer for re-insertion of the D.C. component, as previously explained. The output of the 6V6 is directly coupled to the control electrode of the C.R.T. Thus no further loss in D.C. component is suffered. This direct coupling is made possible by operating the cathode of the C.R.T at a voltage of little more positive than the anode of the 6V6. This system has been discussed in the lesson on "power supplies".

Returning to the synchronising circuits the separation of the frame and line sync. pulses is brought about immediately following the sync. amplifier. The inductance L38 acts as a differentiating circuit developing high peaks of voltage on the sharp edges of the line sync. pulses. These voltage pulses, occurring at line frequency, are applied, for synchronising purposes, to the horizontal scanning generator. The series of broad sync. pulses, which occur between frames is applied to a double integrating circuit consisting of R63, C65, R64, and C66. The time constant of each of these R-C sections is long (comparatively), and the net effect is to integrate, or "add-up" the separate frame pulses into a single large pulse. These large pulses emerging from the integrator occur at frame frequency, and are used to "time" the vertical scanning generator.

Both scanning generators are of the blocking oscillator and hard-discharge tube variety. The first triode section, in each case, serves as the single-cycle blocking oscillator which produces sharp pulses of voltage at a frequency determined by the time constant of the R-C circuit consisting (in the case of the horizontal scan generator) of the condenser C76 and resistor R78. The latter is a rheostat which provides an adjustment to the frequency of pulse production. When the latter frequency is adjusted *approximately* to its correct value (i.e. line frequency) the line sync. pulses become effective in "locking" the oscillator *exactly* to line frequency. Thus horizontal lines will be traced out "in step" with the incoming signal information. If the control is far off adjustment the oscillator will operate at its own frequency, the sync. pulses having no chance of assuming control. When this occurs the C.R.T. will trace out horizontal lines at a frequency differing from that of the transmitter, and the effect is a movement, or drifting of the whole picture as a whole across the screen in a horizontal direction. Adjustment of the control has the effect of "holding" the picture stationary on the screen. The rheostat (R78) is therefore called the Horizontal Hold Control.

Vertical movement of the picture is prevented by adjustment to the rheostat R65. This acts in an exactly similar manner to the Hor. Hold Control, and is called, naturally, the Vertical Hold Control.

These two "Hold" controls require only rare adjustment and are usually only accessible at the back of the receiver.

The second triode section of each scanning generator tube (6N7's) serves to discharge the condenser which, together with its associated condenser forms an R-C charging circuit. This circuit consists (in the case of the horizontal scanner) of the C78 and R81. The condenser is charged through the resistor from the B+ supply: The triode section of the 6N7, "triggered" by the scan. generators' pulses, periodically discharges the condenser. In this way a saw-tooth voltage is developed across C78. The vertical scanning generator operates in a similar way.

The output amplifiers for the saw-tooth voltages are of interest. These consist of a 6N7 for the vertical output and a 6F8 for the horizontal output. Both valves have two triode sections, and act as "Paraphase" push-pull amplifiers. Consider the 6F8. The input voltage (saw-tooth) is applied to the first grid, and an amplified 180° out-of-phase voltage is developed across the plate-load, consisiting of R84 and R85 in series. The stage gain is about 15. Of this output voltage, that developed across R85 is applied to the second grid of the 6F8. Since R85 (3300 ohms) forms about $\frac{1}{15}$ of the total plate load (R84 + R85 = 47,000 + 3,300 = 50,300 ohms) about $\frac{1}{15}$ of the output of the 1st triode is applied to the second grid. Hence the signal voltage on the grid of the second triode will equal that on the grid of the first triode, but the two will be out-of-phase. Consequently equal, and out-of-phase voltages will appear on the two plates. These two output voltages are applied through condensers C81 and C82 to the horizontal deflecting plates, producing a push-pull deflection. The vertical output amplifier acts in a similar way. An important point about the paraphase amplifier is that the total peak-to-peak output is doubled that obtained from each tube section. This is an important consideration when large deflecting voltages are required with limited high-tension available for the amplifier tube plates.

The power supplies use but a single transformer operating a 5U4G (for the "low-voltage" supply) and an 879 (for the "high-voltage" supply). The circuits are of standard type explained in detail in the lesson on power supplies. The student should trace out the circuits in detail, noting particularly the operation of the controls for Horizontal and Vertical Centering (or Shift), and the method of obtaining bias for the C.R.T.

A LARGE SCREEN TELEVISION RECEIVER.

Figure 3 shows, in block form, the different sections of a larger receiver designed for operation of a 12" screen C.R.T. The full circuit diagram is given in Figure 4. This receiver employs electro-magnetic focusing and deflection. The magnetic tubes are becoming ever more popular for home receivers. They are cheaper than the electrostatic type, and may be made very much shorter in length. This allows of a tube of large diameter to be fitted into the confines of the radio cabinet.

The circuit involves 22 tubes in all (including the C.R.T.) many of these serve a dual purpose. The student should study the circuit noting how the various principles explained in previous lessons are applied in the complete receiver. The points discussed in the following paragraphs should be particularly noted.

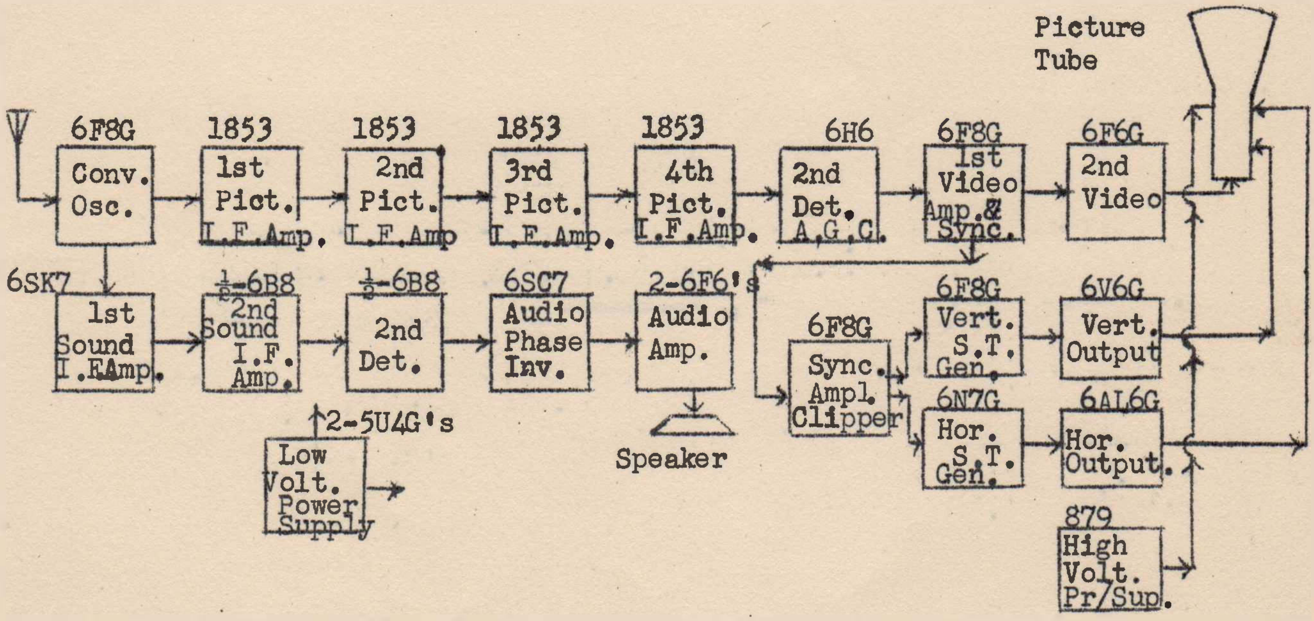


FIGURE 3.

The converter employs but one tube. This however is a 6F8, one triode section of which is used as oscillator. The other triode section serves as mixer. Thus the functions of generating the heterodyne oscillation, and mixing it with the incoming signal are kept separate.

Station selection is carried out by push-button operating in the input and the oscillator circuits. Vernier tuning, operating only in the oscillator circuit, allows the selected station to be finely adjusted. In practice this adjustment is carried out while listening to the sound. Since picture and sound carriers are separated in the television channel by a fixed frequency difference, correct adjustment of the sound will ensure accurate picture signal tuning.

Four stages of picture I.F. amplification are used. Automatic Gain Control, obtained from one diode section of the 6H6 video detector, operates on the grids of the first three I.F. amplifiers. The grid bias of these tubes may also be controlled manually (for gain control) by means of the potentiometer R67, which picks off a fraction of a 30V. negative potential developed in the "low-voltage" supply. This controls is, of course, the "Contrast Control".

Sync-pulse "clipping " is performed by the second triode section of the 6F8. the first section of which serves as first video amplifier. This clipper triode operates with a large automatically developed bias, grid-current flowing only on the tips of the sync. pulses.

D.C. Restoration is carried out at the control electrode of the C.R.T. itself. No direct coupling is employed between the final video amplifier and the control electrode. C.R.T. bias is applied by operating the control electrode slightly positive with respect to ground and tapping off a still more positive voltage, for application to the cathode, by means of R52 (Brightness Control) which operates in a resistor network connected between B+ and ground.

For scanning, a multivibrator type oscillator is used for generating the line (horizontal) saw-tooth wave. A Blocking Oscillator is used for vertical scanning. In each instance the output is amplified by a power output type valve, yielding saw-tooth currents, of sufficient amplitude to operate the deflection coils.

The Power Supplies employ separate transformers for "low-voltage" and "high-voltage". The low-voltage supply is of the full-wave type using a complete 5U49 for each diode. Note that the diode plates are connected together in each tube. This arrangement is necessary to yield the large current output consumed by the numerous tubes in the circuit. The R-C filter of the "high-voltage" supply consists of R80, C77 and C78. Notice that this filter follows the bleeder R81, R82, R83, R84, R85, R86. Six separate resistors rather than a single one of equivalent value, are used for the bleeder in order to obtain adequate power dissipation and to minimise surface leakage.

Focus of the beam is achieved by passing a fraction of the low-voltage supply current through the focusing coil. Adjustment is made to the focusing current by means of rheostat R75 (Focus Control).

TELEVISION RECEIVER CONTROLS.

At different points in these lessons we have described the various controls incorporated in a television receiver. The mode of operation of each control has been

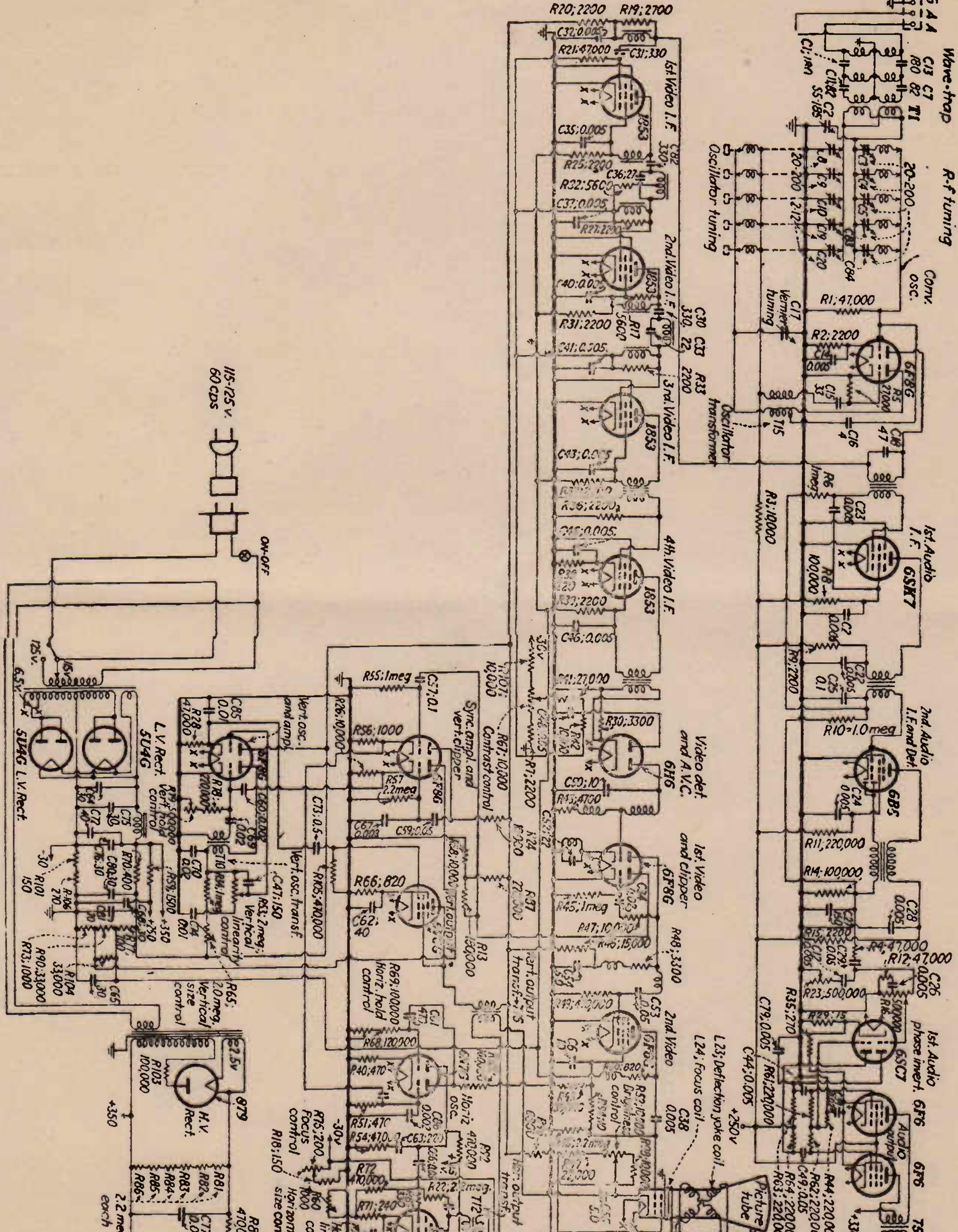

Wave-trap
R-f tuning
Oscillator tuning
Conv. osc.
6F8G
T1
Oscillator transformer
T15
C17 Vernier tuning
R1;47,000
R2;2200
R3;10,000
1st. Audio I.F. 6SK7
2nd. Audio I.F. and Det. 6B8
1st. Audio phase invert. 6SC7
Audio output 6F6
6F6
T5
Speaker
+330v
R10=1.0meg
R11;220,000
R14;100,000
R12;47,000
R23;500,000
R44;220,000
R62;220,000
R63;220,000
R64;220,000
C44;0.005
+250v
L23; Deflection yoke coil
L24; Focus coil
Picture tube
C56;0.04
R33 2200
1st Video I.F. 1853
2nd. Video I.F. 1853
3rd. Video I.F. 1853
4th. Video I.F. 1853
R20;2200
R19;2700
R21;47000
C31;330
C32;0.005
C35;0.005
R25;2200
R32;5600
C36;22
C37;0.005
R27;2200
C40;0.005
R31;2200
R17 5600
C41;0.005
C43;0.005
C46;0.005
Video det. and A.V.C. 6H6
R30;3300
C50;10
R43;4700
1st. Video and clipper 6F8G
R45;1meg
R47;10,000
R46;15,000
R48;3300
2nd. Video 6F6G
C38 0.005
Brightness control
Contrast control
R67;10,000
R7;2200
Vert. output transf. T5
Horiz. output transf.
T12
Sync. ampl. and vert. clipper 6F8G
Vert. osc. and amp. 6F8G
Vert. osc. transf.
R55;1meg
C57;0.1
R56;1000
R57 2.2meg
R26;10,000
C73;0.5
R105;470,000
R66;820
C62; 40
R69;100,000 Horiz. hold control
R68;120,000
R40;470
Horiz. osc.
R51;470
R54;47000
-30v
R76;200 Focus control
R18;150
R72 470,000
R71;240
Horizontal linearity control
Horizontal size control
6AL5G Horiz. output
C51;0.1
R22;2.2meg.
L.V. Rect. 5U4G
5U4G L.V. Rect.
Vert. hold control
Vertical linearity control
R65; 2.0meg. Vertical size control
R73;1000
R90;33000
R104 33,000
R101 150
-30
+350
H.V. Rect. 879
R103 100,000
2.5v
R80 470,000
R81 R82 R83 R84 R85 R86 2.2meg. each
C77 0.06
C78 0.06
6.3v
125v.
115-125v. 60 CDS
ON-OFF

Fig.4

explained when dealing with the particular section of the receiver involved. At this point the student will probably appreciate a summary of the various controls, and a statement of the present trend as to their incorporation in a modern receiver. They are:-

(1) Station Selector. A switch or set of push-buttons operating so as to bring into circuit sets of coils and/or condensers (aerial, r.f, oscillator) for the several channels for which the receiver is designed. In England, where sets are manufactured only for operation on the single B.B.C. broadcast this control is not provided. In America sets are manufactured to receive anything up to five or six different transmissions.

(2) Fine Tuning. This operates a trimmer condenser providing a small variation of oscillator frequency, and is provided principally so that the operation may ensure that the sound I.F. frequency falls within the narrow band-pass provided. Where the receiver is designed for but a single channel this control may or may not be provided.

(3) Contrast Control: This is really a gain control, operating upon the picutre I.F. amplifier. As has been explained variation of the gain principally affects the contrast between high-lights and dark sections of the picture. This is one control which is always to be found at the front of the cabinet.

(4) Brightness Control: Adjusts the bias on the C.R.T. control electrode. Although this control allows adjustment to the over-all brightness of the picture, only very little variation is permissable, because the C.R.T. bias must operate at or near the blanking level of the video signal applied to the tube so that black objects appear black or so that the "flyback" trace is not visable. Adjustment affects mainly the detail in the dark parts of the picture. The control is often of the pre-set type, available only at the back. of the receiver, or on the chassis. It has to be operated in conjunction with the contrast control.

(5) Horizontal and Vertical Centering Controls: Also called Picture Shift, Picture Position etc. Controls. They adjust the position of the picture on the screen in a horizontal and vertical sense respectively. In the case of the electrostatic type C.R.T. they operate usually in the bleeder network of the high voltage power supply. When electromagnetic tubes are used they are purely mechanical controls, allowing adjustment of the deflection coils on the tube's neck. These controls are almost invariably of the pre-set type.

(6) Picture Width and Picture Height Controls: These control the amplitudes of the horizontal and vertical saw-tooth (scanning) voltages or currents, and hence allow adjustment of the picture dimensions on the screen. They usually operate so as to vary the deflection amplifiers' gains. Usually "pre-set" controls. See R60 and R65 in Figure 4.

(7) Horizontal and Vertical "Hold" Controls: These allow some adjustment to be made to the horizontal and vertical scanning frequencies respectively. They operate on the scanning generators. Incorrect adjustment will mean that these generators are not operating close enough to the transmitter's scanning frequencies for the synchronising impulses to be effective. The result is a movement of the picture as a whole over the screen in a horizontal or vertical direction. They are of the "pre-set" type.

(8) Focus Control. Adjusts the C.R.T's electron beam focus, to produce a small bright spot on the screen. The adjustment determines the sharpness or clarity of the picture. The focus control is usually of the "pre-set" type, but in some receivers it is brought out to the front panel.

(9) Sound Volume and Tone Controls. Operate on the sound receiver as in ordinary broadcast practice.

PRESENT TRENDS IN TELEVISION RECEIVER CONTROL.

The present trend, particularly in England, is to reduce the number of controls available to the operator at the front of the receiver to a bare minimum. Some receivers in that country have only one television picture control available - the Contrast Control. Additionally, of course, there is the sound volume control. These are essential because their setting will depend upon the strength of the received vision and sound carriers at any one time. All other controls are then of the "pre-set" type, intended to be adjusted only be a technician when the receiver is first installed, or when component replacements are made.

In America the practice has been to provide more knobs for the operator to manipulate. Next in importance to Contrast Control are, of course, "fisic tuning" and "station selection", then "Focus" and "Picture Brightness".

TELEVISION RECEIVER TYPES.

Receivers in production overseas may be divided into the following types.

(1) Vision Receiver with Sound Converter. This type is the cheapest available and is intended for use in conjunction with an ordinary radio receiver having pick-up terminals. In this way the audio sections and speaker of the broadcast receiver may be utilised for the television sound reception.

(2) Television Vision and Sound Receiver. A self contained set for receiving the television vision and sound broadcasts. Will not pick-up sound transmissions from broadcast or short-wave stations.

(3) Complete Television and Broadcast Receiver. Incorporates vision and television sound receiver plus an ordinary broadcast (sound) receiver.

(4) Complete Television and World Range Receiver. This is the sames as (3), except that the purely sound receiver covers also the short-wave band. Often a phonograph motor and pick-up are also provided.

SCREEN PRESENTATION.

We may also classify receivers according to the method employed for viewing the screen. The smaller receivers universally use direct viewing of the C.R.T. screen. Most of the larger receivers (with screens up to about 12" or even 14" screens) also use this method. Figure 5 shows a"direct viewing" receiver incorporating television vision and sound receivers and an all wave radio receiver. Some receiver, employing the larger tubes, have a mirror in the cabinet lid which reflects the image from the screen of the C.R.T. which is placed in a vertical position. Figure 6 shows one of this type.

A large screen projection type receiver is shown in Figure 7. This employs a 3" projection type tube, operating at 25,000 V. The image is projected first on to a mirror, thence to the back surface of a ground-glass screen measuring 22" X 18". The screen rises automatically into position when the cabinet lid is opened. The receiver is intended for use in large rooms such as hotel lounges, clubs, small halls etc.

CARRIER-DIFFERENCE RECEPTION OF TELEVISION SOUND.

One of the chief obstacles to be overcome in introducing television into a country is that of producing a receiver of sufficiently low cost. The public will not, naturally, outlay a large sum for an extra receiver, particularly in the early stages of television when, perhaps, only several hours per week of television service is provided.

The higher cost of television receivers, compared with the ordinary broadcast sets, is largely due to the great number of components required. In the reception of a television signal we have two separate aspects of the signal to consider -- the vision "information" and the sound "information". In general, the two signals are dealt with independently within the receiver, i.e. separate channels are provided. In the standard type of black-and-white receiver in use overseas the only sections which are common to both vision and sound signals are the input circuits, the oscillator, and (usually) the mixer. Separate I.F. amplifiers, detector, and video or audio amplifiers are used. The result is a vary large number of valves (14 plus the C.R.T. is about a minimum), together with associated condensers, resistors, coils etc.

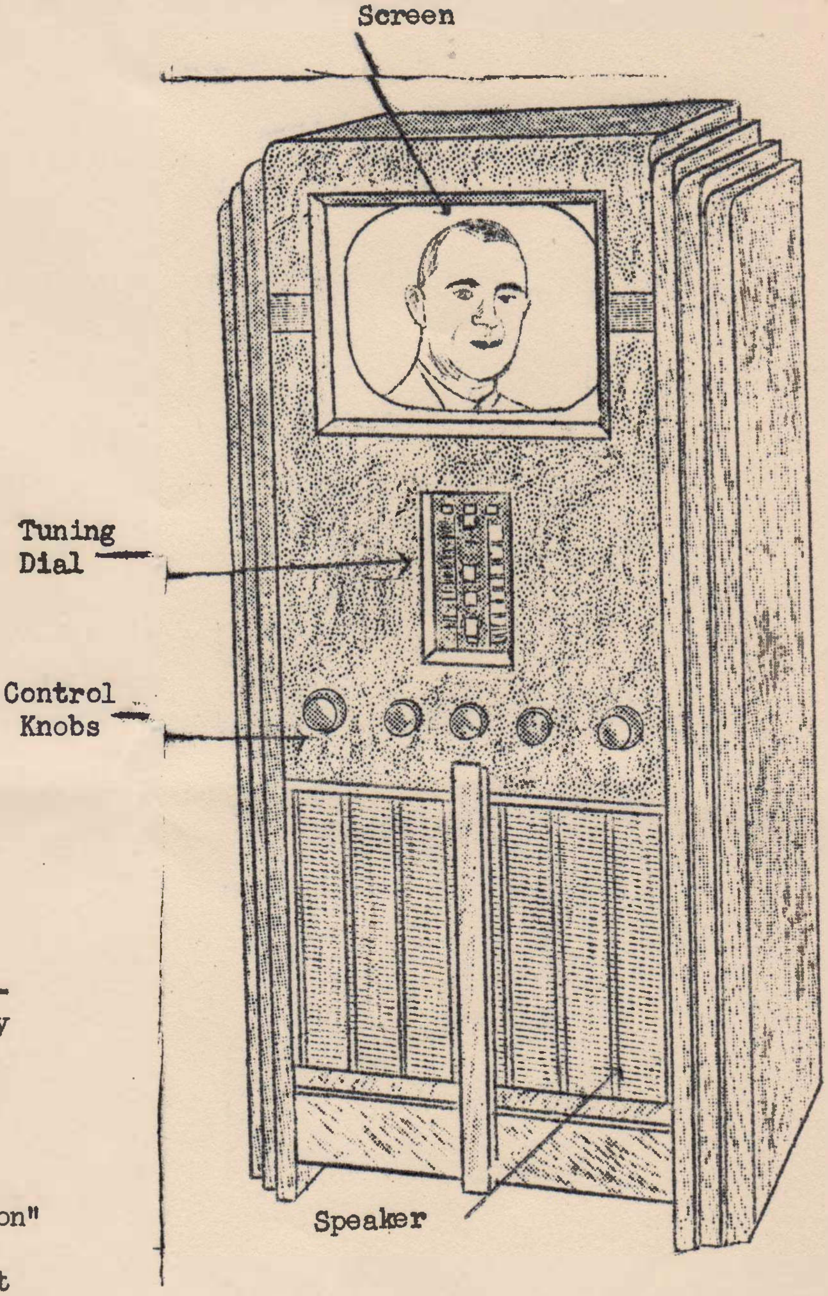


FIGURE 5.
A DIRECT VIEWING RECEIVER (PICTURE 10" X 8".)

The use of Pulse Modulation, explained in an early lesson, or "bursts" of sound sub-carrier (see lesson on Colour Television) have been suggested, and in some cases, used, to eliminate at the receiver, the separate I.F. channel. These, however,

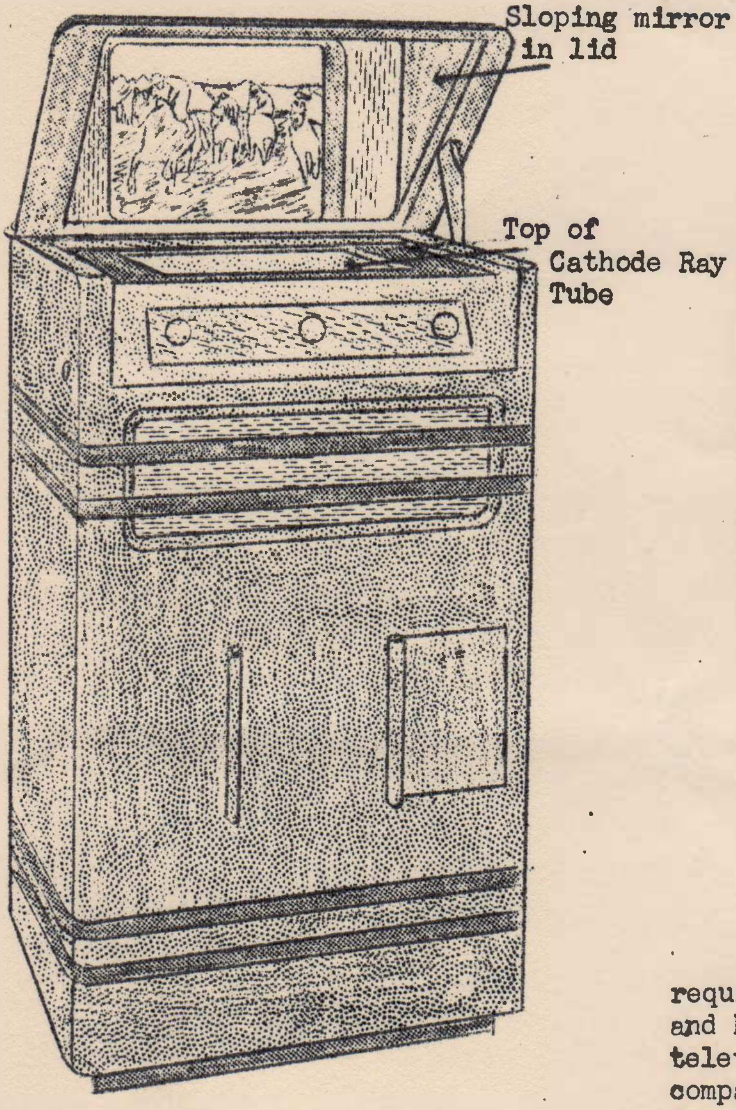


FIGURE 6.
RECEIVER EMPLOYING MIRROR VIEWING OF C.R.T. SCREEN.

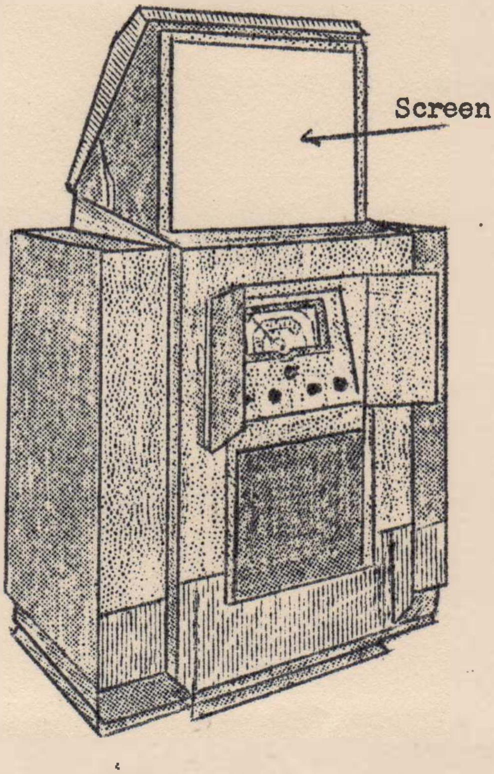


FIGURE 7.
A PROJECTION TYPE RECEIVER.

require an entirely new transmission system and have, so far, been confined to colour television. In addition they provide a comparatively poor signal-to-noise ratio for the sound, which is radiated only for a small percentage of the total time. Although improvements will undoubtedly be made in this respect.

The Carrier-Difference method of receiption will operate upon the standard television signals now in use in America. Such a signal (to refresh the student's memory) consists of a channel of total width 6 megacycles. The vision carrier is amplitude modulated, and, together with side-bands occupies a channel 4.mc. wide. The sound carrier is frequency-modulated and lies in frequency 4.5 m.c. below the vision carrier. The sound carrier is varied in frequqncy (by modulation) 25 kilocycles/sec. above and below the control frequency. Thus the sound carrier is 50 kilocycles/sec. in width. A receiver operating upon the Carrier-Difference Principle not only dispenses with a separate I.F. section for sound, but also requires little in the way of audio amplifiers. The saving in tubes and other components will therefore well be realised. Just how this rather amazing receiver operates will now be explained.

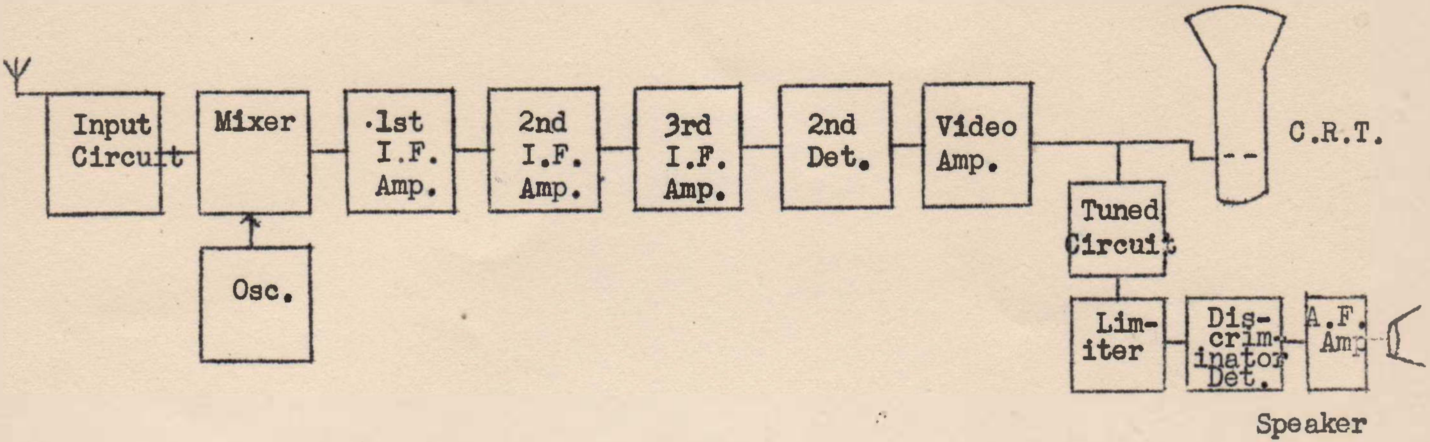


FIGURE 8.

A block diagram of the receiver is shown in Figure 8. As stated there are no sound I.F. amplifiers. The sections from input to C.R.T. grid follow along fairly conventional lines for a vision receiver. The converter (oscillator and mixer) "beats down" (heterodyne principle) both picture and sound signals to their intermediate frequencies. The I.F. amplifiers are sufficiently broadly tuned to cover the entire television channel vision and sound -- 6 megacycles/sec. wide.

Suppose after the converter stage the picture I.F. carrier is 12.75 m.c. and the sound carrier is 8.25 m.c. -- a frequency difference of 4.5 m.c. The sound carrier, frequency modulated, will have its frequency varied or "swung" (at an audio frequency rate) by anthing up to 2.5 kilocycles (.025 m.c.) above and below the centre frequency of 8.25 m.c. That is the sound carrier will continually be changing between maximum limits of 8.275 m.c. and 8.225 m.c. These frequencies, together with the picture carrier and its side-bands are applied to the detector stage.

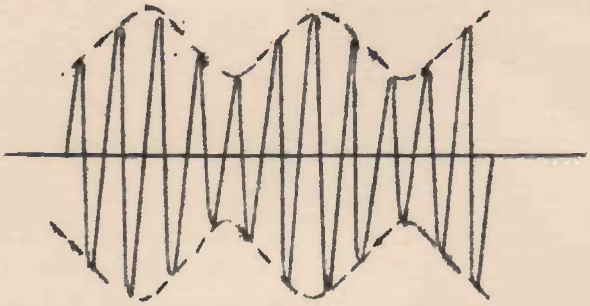
THE SECOND DETECTOR'S OUTPUT.

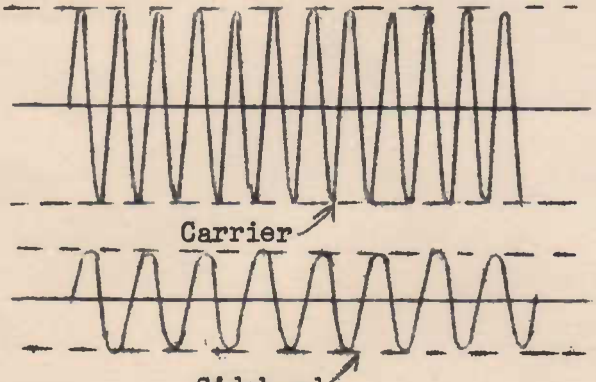
Let us now recall the action of an ordinary detector, such as a diode, upon an amplitude modulated wave. Figure 9 shows at A such a modulated wave. The "modulation envelope" is shown by the dotted lines. This wave may be regarded as consisting of the carrier wave and a sideband (both radio frequency) differing in frequency by an amount equal to the modulating frequency. These are shown at B (Figure 9). In other words we may say that the result of "adding" the carrier and sideband of Figure 9B is to produce the modulated wave of Figure 9A. Usually there are two side-bands for every modulating frequency, but one is sufficient (remember "single-band" transmission). The one shown in Figure 9B is the lower side-band, since it is lower in frequency than the carrier.

On detecting the modulation wave of Figure 9A the detector's output will contain a component as at C (Figure 9). This component is of the modulating frequency. Now instead of visualising the detector's input as shown at A, we may regard it as the carrier and sideband equivalent of Figure 9B. The output, of course, is still as at C.

From the foregoing discussion the following important point emerges. If we apply to a detector's input two frequencies f1 and f2 (both of constant amplitude) a frequency equal to their difference, f1 - f2 (or f2-f1) will appear in the output. This is apparent also in the case of a frequency converter in a superheterodyne receiver where the signal frequency and oscillator produce an intermediate frequency output equal to their difference.

Returning now to the television receiver. We have applied to the detector's input the picture carrier (frequency 12.75 mc), the side-band frequencies of the picture signal, together with a frequency varying around 8.25 m.c. going, at times up to 8.275 m.c, and down to 8.225 m.c. The latter, of course, represents the F.M. sound signal. The detector will act upon the picture signal side-bands together with the picture carrier, to produce the various video frequencies representing the picture detail.. Each of the latter, of course, will have a frequency equal to the difference between the carrier frequency and the particular picture side-band frequency. In addition, the detector will have no way of distinguishing between the sound signal frequency and a side-band of the picture signal. In other words the detector will treat the sound signal frequency just as though it were another side-band of the picture carrier wave.


(A) Amplitude Modulated Carrier



(B) Carrier and Lower Sideband.


(C) FIGURE 9.

For example at the moment when the sound carrier is at the central frequency 8.25 m.c. the detector output will contain a component equal to 4.5 m.c. (i.e. 12.75 m.c. -- 8.25, i.e. difference between picture and sound carriers). At a moment when the sound carrier has moved up to 8.275 m.c. (due to F.M.), the detector output will contain a component of 12.75 -- 8,275 = 4.475 m.c. Again, if the sound carrier is at 8.225 m.c. we will obtain a component of 12.75 - 8.225 = 4.525 m.c.

Thus the detector output contains, in addition to the video frequencies representing the picture detail, a frequency which varies about 4.5 m.c. (Difference between the two carriers). This frequency may go up to 4.525 m.c. or down to 4.475 m.c. -- a variation of .025 m.c. or 25 kilocycles on either side of the central frequency. The rate at which the frequency varies up and down represents, of course, the audio frequency. Hence the detector produces a 4.5 m.c. sound carrier, frequency modulated at audio frequency.

This sound signal is amplified together with the video frequencies proper, by the video amplifier(s) of the receiver. Hence the video amplifier(s) must be "flat" up to, at least, 4.525 m.c.

The sound signal is separated from the video signal right at the C.R.T. control electrode as shown in Figure 8. This is achieved, as shown, by means of a circuit tuned to 4.5 m.c. This part of the circuit is shown in detail in Figure 10. The circuit L1 C1 forms a parallel resonant circuit (rejector circuit) tuned to 4.5 m.c. This circuit will offer a large dynamic impedance to frequencies in

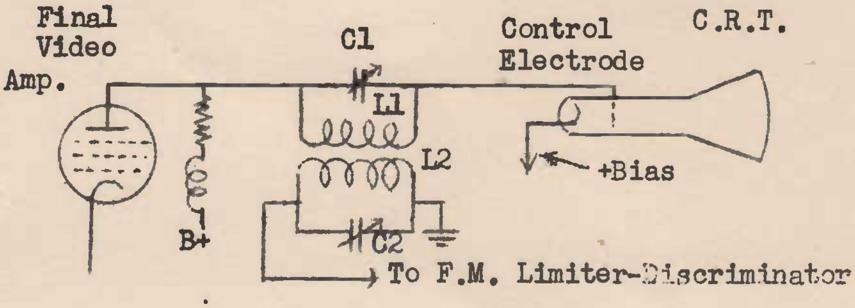


FIGURE 10.

the vicinity of 4.5 m.c. In this way the frequencies representing the sound signal will be blocked from the C.R.T. control electrode. At the same time a large "circulating" current of frequency 4.5 m.c., or thereabouts, will flow around L1 C1 (this is a characteristic, remember, of a parallel tuned circuit). This current will induce a large voltage in L2 (tuned by C2). The latter voltage, representing a sound carrier or intermediate frequency of 4.5 m.c, frequency modulated with the audio frequencies, is from this point passed to a "limiter" stage, thence to the "discriminator". The operation of the latter circuits will be explained in detail under the section on "Frequency Modulation". It might be mentioned here, however, that the "discriminator" is really a F.M. detector. The audio frequencies emerging from the discriminator are then passed through audio amplifiers of conventional design to the speaker. Not much audio amplification will be necessary, because the sound signal, in the form of the 4.5 m.c. F.M. "carrier" has been amplified by the video amplifiers of the receiver.

OTHER ADVANTAGES OF THE "CARRIER-DIFFERENCE" SYSTEM.

In addition to simplicity and low cost of the carrier difference type of receiver, the system confers other important advantages. All these advantages depend upon the fact that the sound "carrier" frequency finally applied to the discriminator-detector is *fixed* at the *difference* between the original picture carrier and sound carrier radiated by the transmitter, viz: 4.5 m.c. This cannot be altered by, say, variations of local oscillator frequency, as in the conventional system.

If the oscillator frequency changes or drifts in a conventional receiver due to B+ changes caused by heating up etc. the sound I.F. frequency will change by an equal amount. This may move the frequency of the signal (which is F.M.) sufficiently far away from the operating point for which the discriminator-detector is designed to cause the sound to fade out or become distorted. If the power supply voltage changes are rapid (due, for example, to a ripple voltage at power frequency) the sound I.F. is caused to change at the same rate. In other words the sound I.F. is frequency modulated at ripple frequency. The result is a power supply hum in the speaker.

These effects are not present in a receiver designed for carrier-difference reception. Any change in sound I.F. due to oscillator frequency changes are counterbalanced by an equal change in picture I.F. In all cases, as stated previously, the F.M. signal applied to the discriminator has a centre frequency equal to the difference between vision and sound carriers -- and this is fixed at the transmitter.

Microphonics, due to oscillator changes caused by vibration of the electrodes, are similarly avoided.

A further advantage is that the tuning of the receiver is simplified. In the conventional receiver the tuning is carried out on the sound. The tuning (which controls the local oscillator frequency) is accurately adjusted for maximum sound. This automatically gives the approximate correct adjustment for the picture. The tuning involves careful adjustment of the control so that the sound I.F. produced falls within the narrow I.F. amplifier channel provided for it. It is quite possible to have the picture roughly tuned in, yet the sound is inaudible. This is due to the fact that the picture I.F. channel is so much wider (approx. 50 times) than that provided for the sound. In the case of the carrier-difference receiver, on the other hand, the operator may tune for the clearest picture possible. The picture fades, as the tuning control is turned away from the correct point, long before the sound does. This is a feature unavailable in the conventional receiver.

The art of television is rapidly advancing and improving, almost every month we see some new idea, perhaps an improvement to an existing system, perhaps a simpler and cheaper way of performing some task or perhaps some substantial change, but the principles set down in the foregoing lessons may be taken as fundamental. With the tremendous amount of money and effort spent bringing television to its present high state of development, it is inconceivable that the fundamental principles of scanning a scene into individual picture elements which are used to modulate a carrier wave and thus are transmitted one by one to be reassembled at the receiver into complete pictures at a rate exceeding 20 times per second, will be superceded for many years, if ever. Of course, there will continue to be improvements and advancements and new systems which will carry out the fundamental principles mentioned above, more efficiently, but the information contained in these lessons will form a sound foundation upon which an understanding of future developments can be based.

We do not know as yet how long it will be before a television service is established in Australia nor the exact technical nature of the service but it will certainly be based on the principles explained in the foregoing lessons and consequently a thorough familiarity with the contents of these papers will place the student in a position which will enable him to easily understand and appreciate the technicalities of whatever system is ultimately introduced.

T.FM & F. LESSON NO. 13.

EXAMINATION QUESTIONS.

(1) If the horizontal centering control (R100) of Figure 2 were moved towards the top of the page, in which direction would the picture on the screen move (viewed from the front of the screen)?

(2) State 2 advantages of a "Paraphase" amplifier for deflection voltage amplification compared with a single tube output.

(3) Why must C74 and C81 (Figure 2) have a very high voltage rating?

(4) Why are electro-magnetic tubes preparable to electrostatic types when a large screen is required?

(5) Why is it essential to provide a knob on the front of a receiver for Contrast Control whereas most other controls may be of the "pre-set" type?

(6) What is the chief advantage of the carrier-difference method of reception?

(7) Why is very critical adjustment of the oscillator frequency unnecessary in a "carrier-difference" receiver?

(8) Explain how you would proceed to adjust the fine-tuning control (a) in the case of a conventional receiver (b) in the case of a "carrier-difference" type of receiver.

(9) At what point in a "carrier-difference" receiver is the sound signal extracted from the vision signal?

(10) Why is it absolutely essential that the video amplifiers of a conventional carrier difference receiver be approximately "flat" up to about 4¾ mc/sec? What would happen if these amplifiers had an upper frequency "cut-off" of, say, 3 mc/sec?

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T.FM & F. LESSON NO. 14.

GENERAL CHARACTERISTICS OF FREQUENCY MODULATION.

We now take up the detailed study of the transmission of sound by Frequency Modulation (F.M.) of the carrier wave. The nature of F.M. was explained in Lesson 1, and its main advantages over A.M. were stated. Section B of that lesson should now be re-studied.

THE NATURE OF F.M.

As has been explained an F.M. wave remains of constant amplitude, but its frequency is varied above and below the mean carrier frequency. The amount that the frequency is increased above or decreased below this mean frequency for the loudest sound being handled is called the Frequency Deviation. Hence the total frequency "swing" is twice the frequency deviation. For example if in any one system a carrier of 50 m.c/sec. and a deviation of 75 Kc/sec. (.075 mc/sec) is chosen, the frequency swings between 50 + .075 = 50.075 mc/sec. and 50 - .075 = 49.925 mc/sec. when the loudest sound is being transmitted. This is a total swing of .15 mc/sec or 150 kc/sec, i.e. twice the deviation. It should be clearly understood that for weaker sounds (i.e. modulating voltages of smaller amplitude) the frequency variation is less than this. The amount of frequency change of the carrier is directly proportional to the amplitude of the modulating voltage, and therefore depends upon the varying loudness of the sounds being transmitted.

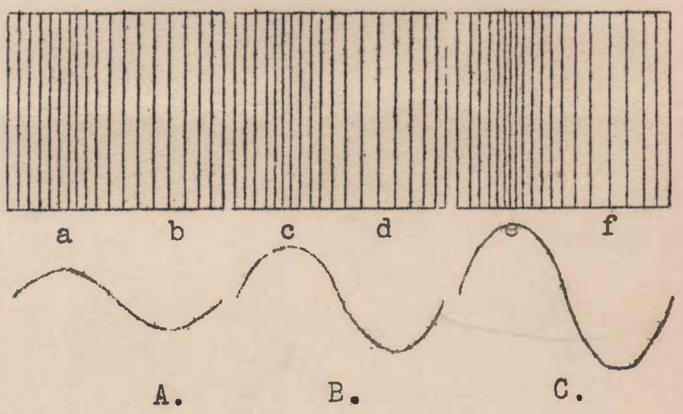


FIGURE 1.

The pitch of the sound note being transmitted, and therefore the frequency of the modulating voltage is represented by the rate at which the carrier frequency is changed between its upper and lower limits.

These points should be made quite clear by reference to Figures 1 and 2. In Fig. 1 a wave with a single cycle of each of three modulating voltages having identical frequencies but different amplitudes. (Note:- for simplicity in both Figures 1 and 2 the r.f. cycles are represented by straight vertical lines instead of sine curves. When these lines come closer together an increased radio-frequency is indicated, when the lines move apart the frequency of the radiated wave is decreasing). At A. Fig.

1 we have a modulating voltage of small amplitude (weak sound). At B a stronger modulating voltage is shown. C shows a voltage which we will suppose has the greatest amplitude which can be handled (giving a frequency variation equal to the maximum deviation).

Note that when the modulating voltage is at its positive peak the frequency of the wave is increased to a maximum (points a,c,e Figure 1). When the modulating voltage is at its negative peak the wave frequency is a minimum (points b,d,f. Fig.1). The point we wish to stress, however, is that the frequency "swing" is greater in the case of the larger amplitude modulating voltage. The maximum frequency reached in Figure 1C is at "e", and this is higher than that of Figure 1, at "a". Similarly the lowest frequency in the case of 1C (at "f") is lower than the lowest frequency in the case of 1A (at "b").

Consider now the periods in which the frequency of the wave is "swung" in the three cases of Figure 1. It will be noted that the time of frequency swing is the same in every case. In Figure 1A the wave's frequency changes from its maximum to its minimum in a time equal to ab. In 1B the time taken is cd, and in the case of 1C it is ef. All of these time intervals are equal one to the other, because each equals the half-period of the modulating voltage -- and remember the three modulating voltages are identical in frequency, therefore their periods are equal.

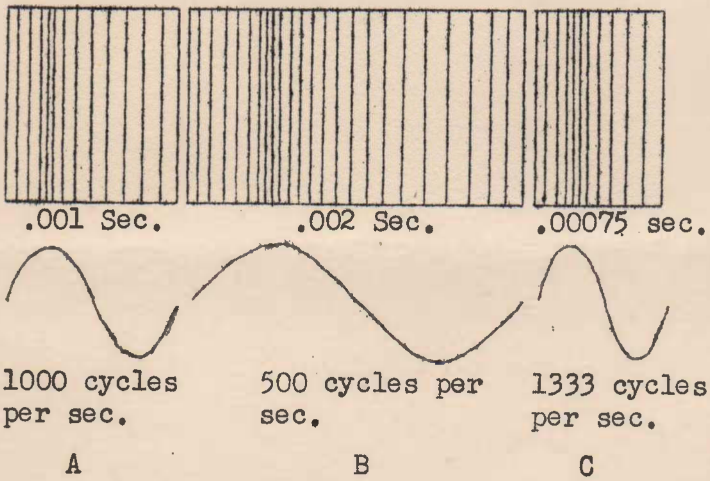


FIGURE 2.

Now consider Figure 2. Here we show a low frequency modulating voltage at B, a higher frequency voltage at A, and a still higher frequency one at C. The three voltages, however, all have the same aplitudes. The graphs show that the frequency deviations (above and below the mean frequency of the wave) are equal in all cases. The rate of frequency change between the maximum and minimum limits, however, is slow in case B, faster in case A, and still faster in case C. The rate of frequency swing, thus depends upon the modulating frequency.

BAND-WIDTHS REQUIRED.

It was pointed out in Lesson 1 that in the early stages of the history of F.M. it was thought that by choosing a small frequency deviation, say 2 Kc/sec, the bandwidth of a transmission could be limited to 4 Kc/sec (twice the deviation) without any restriction upon the modulating frequency which could be super-imposed upon the wave. Thus it was hoped to "compress" within a narrow band of several Kc/sec in width (or even less) a modulated wave carrying all the audio frequencies up to the upper limit of audibility, about 15 Kc/sec. This possibility was exploded in 1922 by Carson, who showed that a frequency band at least double the highest audio frequency is required, no matter how small the maximum deviation was made, Let us see why this is so.

The reason is due to the fact that when the carrier is frequency modulated, the variation in frequency brought about prevents the individual cycles being of exact sine-wave shape. In other words the separate cycles are distorted. This is illustrated in an exaggerated form, in Figure 3, where a single cycle of the wave is shown when the frequency is being increased (by modulation). Curve number one represents a pure sine-wave for comparison purposes.

Now it is a well known fact that when an A.C. is distorted from the pure sine-wave shape, extra frequencies called harmonics are generated. In other words it may be stated that an A.C. having a non-sine-wave shape may be produced by combining two or more sine-wave frequencies. In general, the greater the difference between the wave-form, the greater the number of extra frequencies involved.

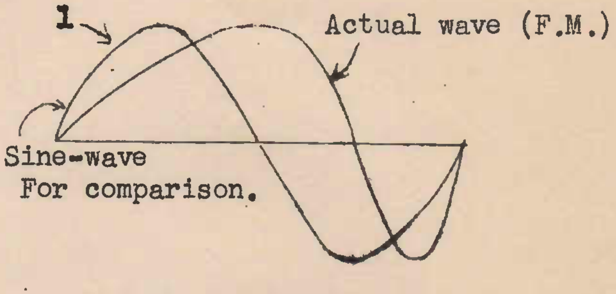
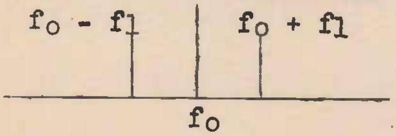


FIGURE 3.
SINGLE CYCLE OF F.M. WAVE FOR INSTAN
WHEN FREQUENCY IS INCREASING.

An exact mathematical analysis shows that an F.M. wave contains all the side frequencies of an A.M. wave, plus additional ones. If a carrier of frequency fo is amplitude modulated with a pure note of frequency f1, two side frequencies having frequencies fo + f1 (the higher side frequency) and fo - f1 (the lower side frequency) are produced in addition to the carrier. This is represented diagramatically in Figure 4A.

If the same carrier is <u>frequency</u> modulated with the same note, these two sidebands f0 + f1 and f0 - f1 are generated as before. In addition, however we have extra side-bands fo+ 2f1, f0 - 2f1 and fo + 3f1 and fo - 3f1 etc. This is shown at B, Figure 4.



A.M. - carrier + side frequencies for single modulating frequency f_1

FIGURE 4A.

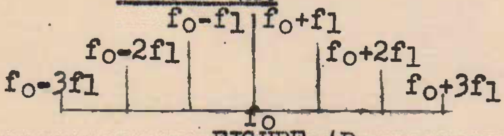


FIGURE 4B
F.M. CARRIER AND SIDE-BANDS FOR SINGLE MODULATING FREQUENCY f1.

In the case where the range through which the frequency is varied is less than the audio frequency of modulation, the higher order side-bands are negligibly small. It should be clearly observed, however, that no matter how small the deviation frequency, a band-width of about 30 Kc/sec. is required if all audio frequencies up to 15 Kc/sec. are to be handled, for we shall have first-order side-bands extending 15 Kc/sec above and below the carrier frequency.

For wide frequency deviations, the higher order side-bands, fo + 2f1, f0 - 2f1, fo " 3 f1, f0 - 3f1, etc. become important, extending up to the limits of the frequency deviation involved. Hence for deviations like, say 75 kc/sec, we may take the band-width to be identical with the total frequency swing-in this case 150 Kc/sec.

Assuming we require the highest fidelity transmission (i.e. incorporation of the complete range of audio frequencies up to 15 Kc/sec), we may summarise the question of band-width thus: There is a lower limit below which the band-width of the channel may not be reduced, no matter how small a frequency deviation is used. This is of course 30 Kc/sec, the same as would be required for A.M. For wide deviation systems the band-width may be taken to be twice the deviation employed. This, of course, may be many times the audio-frequency range, viz: 15 Kc/sec.

THE NATURE OF STATIC.

By "Static" we mean interference to a carrier wave produced by sudden electrical discharges in the aether. These electrical discharges may occur naturally (the so-called "atmoshperics") or they may be man-made, occurring in electrical machines of different varieties. In all cases the electrical discharges are really "sparks", i.e. discharges of electricity through the air between two points. In the case of "atmospherics" the discharges occur between cloud and cloud, or cloud and earth, and are called "lightning". In the case of man-made static the discharges are of smaller magnitude, but occur, usually, closer to the receiving aerial.

OSCILLATORY NATURE OF AN ELECTRICAL DISCHARGE.

An electrical discharge (spark or lightning) takes place through air when the latter's natural insulating properties break down.

Consider Figure 5 at A we have a simple circuit containing an air-gap of sufficient width to prevent a flow of current. Suppose now the e.m.f. "E" is increased until the electrical "strain" across the air-gap causes the air molecules to become ionised, i.e. broken into "free" electrons and positively charge particles. The air in this state forms a conducting path of low resistance, and a large current flows (Fig. 5B). The current however does not simply flow in one direction, as may be expected. For some appreciable time after the discharge commences, the current surges back and forth in an alternating or oscillatory fashion. This is due to the fact that the circuit contains small amounts of self or distributed-capacity and inductance, these forming the equivalent of an oscillatory or resonant circuit, as shown at C, Figure 5. The oscillatory discharge will, of course, eventually die out, due to "damping" of it by the resistance in the circuit.

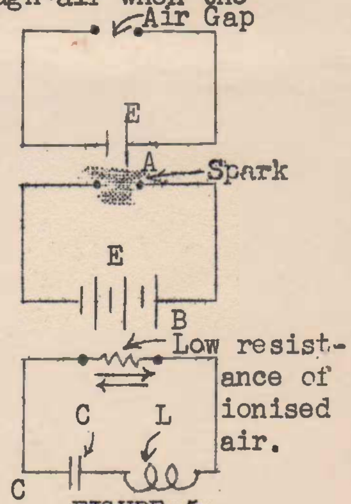


FIGURE 5.

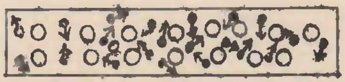
The obvious effects of electrical discharge of light and sound. There is, however, another most important effect. This is an electromagnetic wave generated and sent out into space. The alternating current associated with any sudden electrical discharge is usually of high-(radio) frequency, since the values of inductance and capacity associated with the circuit are usually small. Now we know that the flow of a high frequency current always produces an aether wave of the radio type.

The above considerations hold for sudden electrical discharges whether occurring naturally (lightning) or by man-made machines (car ignition, electric motor commutators, diathermy machines etc). The frequencies of the waves produced may cover all conceivable values.

CIRCUIT "NOISE" AND VALVE "HISS".

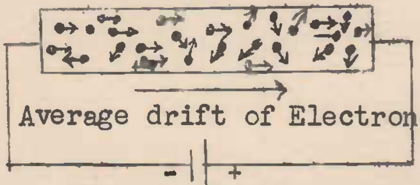
It is well known that even in the absence of external static a low hiss is to be heard in an ordinary receiver. This is caused principally by "thermal agitation" in the input circuit of the receiver, and "shot effect" occurring in the r.f. value (if any) and the converter valve.

Thermal agitation refers to the random vibratory motion of the molecules and free electrons in a substance. This motion goes on continually within any substance, and its average value depends upon the temperature of the body. In Figure 6A the small circles represent the fixed molecules and the dots the free electrons. As indicated by the arrows these electrons are continually darting about in all directions, with very varied velocities. Suppose now a current (D.C.) is forced to flow through a conductor. The current takes the form of a general drift of the free electrons in one direction, say to the right, as in Figure 6B. Here the fixed molecules have, for simplicity been omitted. Superimposed on this average drift we have the rapid and random motion, due to thermal agitation. At any one moment it might so happen that more electrons are darting to the right than the average number. When this occurs the current is increased a little above average. A moment later the opposite state of affairs might exist, and the current may be reduced a little. The point is that no current is absolutely steady, but has very minute fluctuations, due to "thermal agitation" superimposed upon it. These fluctuations occur at all possible frequencies (including radio-frequencies). Such fluctuations in current, flowing through impedances, develop corresponding voltages, which are amplified by the valves in the receiver.



Thermal Agitation of Free Electrons in Conductor.

A.



B. Current flow in conductor.

FIGURE 6.

Voltages due to thermal agitation are very minute, but when they occur before the first amplifying tube in the receiver they are amplified by all the stages in the receiver. For this reason, in designing a receiver, we usually have to consider only those occurring in the input circuit.

The "shot" effect referred to results from the fact that the stream of electrons flowing from cathode to plate is made up of a series of particles rather than a continuous flow. As a result the electron flow to the plate is somewhat irregular, resembling hailstones striking a surface, and this gives rise to slight irregularities in the plate current of the tube. A further irregularity is due to the fact that the emission itself from the heated cathode is subject to haphazard variations. Those fluctuations in plate current are minute, but they occur over an almost unlimited and continuous range of frequencies.

HOW "NOISE" VOLTAGES BECOME AUDIBLE:

Thus we have seen that in the early stages of a receiver there will exist, in addition to the r.f. signal voltage, voltages representing almost every conceivable frequency. Of these latter some are due to waves in the aether caused by static (and which induce corresponding e.m.f's in the aerial), and others are generated within the circuits and valves themselves due to the several phenomena we have described. All of these latter interfering voltages we describe as "noise".

It should be clearly understood, however, that the "noise" voltages which result in actual sounds in the speaker are not in the first place, of audio frequency. This will be realised if it is remembered that the tuned circuits of the I.F. stages will not pass audio frequencies. These stages will block all but a narrow band of frequencies around the I.F. for which the receiver is designed. (Note:- random voltages, occurring at audio frequencies after the detector can generally be neglected because there is insufficient amplification in the remaining valve stages to bring them up to audible level). The question then arises is how are these "Noise" voltages carried through the stages (including "tuned" stages) of the receiver to appear as audio frequency voltages in the output to the speaker?

Assuming, for the moment, a conventional A.M. receiver, we shall consider only the state of affairs when a station carrier is being received, since this is the only case which really interests us here. Together with this carrier frequency there will be present "noise" voltages of all conceivable frequencies. Some of these noise frequencies will be adjacent to the carrier frequency, i.e. they will differ from the latter by an amount equal to an audio frequency. To all intents and purposes such a noise frequency will appear to the carrier, just as though it were one of the latter's own side-band frequencies. Consequently, in the detector's output there will appear an audio voltage equal to the difference between the "noise" frequency and the carrier frequency. Putting this in a different way we may say that each noise frequency which differs from the carrier frequency by an audio frequency amount will modulate the carrier at this audio frequency rate.

This point may be further clarified by referring to Figure 7 where "a" represents carrier frequency, surrounded by "noise" frequencies of varying amplitudes, and differing from the carrier frequency by varying amounts. In this figure cd represents the receiver band-width, which we shall suppose is double the audio-frequency range. It is obvious from the diagram that only those noise frequencies lying within this band (cd) will give rise, by modulating the carrier, to a "difference" frequency which lies within the band-pass of the receiver, and which will be audible. A "noise" frequency like "x" will certainly "beat" with the carrier, modulating it at a frequency equal to the difference between its own frequency and that of the carrier. This modulation frequency, however, even if passed by the receiver's amplifiers, will be too high to be audible. The noise heard in the speaker will be due to the sum total of all those voltages in the detector's output produced by frequencies lying in the range cd (Figure 7) around the central carrier frequency.

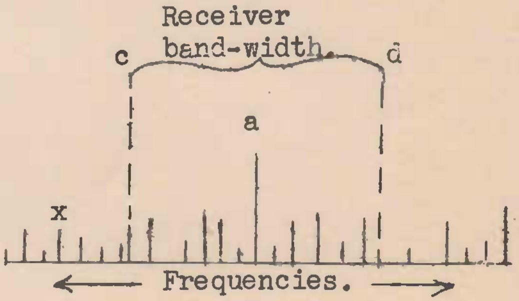


FIGURE 7.

HOW FREQUENCY MODULATION REDUCES NOISE.

We have seen that interfering voltages present in the early stages of a receiver and due to static, thermal agitation, valve hiss etc, produce audio voltages which operate on the speaker, by modulating the carrier wave. Now this modulation is mainly of the amplitude type. A noise voltage, if lying adjacent to the carrier in frequency, alternately works into and out of step with the latter. Thus the amplitude of the carrier is increased and decreased at a rate depending upon the difference between the two. This is amplitude modulation.

Now an F.M.receiver does not respond to amplitude modulation. It employs a type of detector (the "discriminator") which is sensitive mainly to frequency modulation. In any case we usually have preceding the discriminator a "limiter" stage, whose purpose it is to "level off" any undesired A.M. It would appear, therefore, that F.M. should eliminate all noise. This is not quite the case however.

Mathematicl analysis, as well as practical experiment, have shown that the "noise" voltages do cause some phase or frequency "flutter" of the carrier. In other words a small amount of frequency modulation by "noise" voltages occurs. This will appear as noise in the speaker. If we compare the performances of an A.M. system and an F.M. system employing the same band-widths (this would be classified as a narrow band F.M. system) we find that the F.M. system displays distinct advantages over the A.M. systems as far as noise performance is concerned.

HOW INCREASING THE F.M. BAND-WIDTH REDUCES NOISE.

The reduction in noise interference, which is characteristic of an F.M. system, becomes really important when large deviations, and therefore wide band-widths are employed. The greater the deviation used for full modulation, the more negligible the noise effects become. When the modulating signal (A.F.) is made to cause large variations of carrier frequency the comparatively small deviations caused by an interfering r.f. "noise" voltage become virtually "swamped out".

A simple numerical example should make this point clear. Suppose we have an r.f. noise voltage which, by interaction with the r.f. carrier, causes a frequency change of say, 1.5 k.c/sec. Consider first a "narrow band" F.M. system having a deviation (max) of 7.5 Kc/sec. (note: the latter is the deviation for maximum modulation, i.e., for the loudest sound being transmitted). The "noise"voltage in the detector output will be $\frac{1.5}{7.5} = \frac{1}{5}$ of the signal voltage representing the loudest sound. This gives a signal-to-noise power ratio of 25 to 1. Such a noise would cause some interference to the signal. Now consider an F.M. system employing a deviation of 75 Kc/sec. (again for maximum modulation). In this case the noise voltage in the detector's output will be only $\frac{1.5}{75} = \frac{1}{50}$ of the maximum signal voltage. The signal-to-noise power ratio in this case is $\left(\frac{50}{1}\right)$ = 2,500 to 1. Thus, by increasing the deviation and therefore the band-width used by 10 to 1, the noise, on a power basis, will be reduced relative to the signal by the ratio of 2,500 to 25, i.e. 100 to 1.

Summarising, we may state that, as between two F.M. systems of different band-widths, the signal-to-noise power ratio in the rectified output will vary directly as the square of the deviation and band-width. The advantage of using large deviations and band-widths thus becomes obvious.

For "Wide-Band" F.M. the frequency deviation has been fixed at 75 Kc/sec. This, of course, is the frequency swing on either side of the centre carrier frequency, for maximum modulation, i.e. for the loudest sound handled. Weaker sounds will result in smaller frequency swings than this. The band-width required is thus 150 Kc/Sec. Compare this figure with a band-width of 20 Kc/sec. as used by A.M. broadcast stations

REQUIREMENTS OF HIGH FIDELITY REPRODUCTION.

The special prov of F.M. has become that of high fidelity. It should be understood, however, that high fidelity is not a natural characteristic of a F.M. system.

The requirements of high fidelity are:-

(1) The system should be capable of handling at both transmitter and receiver the full range of audio frequencies, say from 30 cycles/sec. up to about 15,000 cycles/sec.

(2) The system should reproduce the full "dynamic range" of the original sound. "Dynamic range" refers to the range of sound volume (depending upon amplitude of the A.F. voltage). In other words the difference between the maximum sound level and the minimum sound level in the speaker should equal that of the original sound.

(3) The high degree of "naturalness" obtained when (1) and (2) are satisfield should not be marred by electrical interference or noise. It is found that the advantages of wide A.F. response and wide dynamic range are only really appreciated by the ear in the absence of any interfering back-ground noise.

It is possible to satisfy condition (1) above in a typical F.M. system because the band-width is used (150 Kc/sec) is many times the range of audible frequencies. In the case of a conventional A.M. system, however, where the band-width is limited to 20 Kc/sec, the maximum audio frequency which can be handled is 10 Kc/sec. (half the band-width). The higher audio frequencies from 10,000 c/sec. up to 15,000 c/sec. or so are lost.

With reference to the dynamic range of the reproduction, an A.M. system is somewhat limited in this respect. Conventional broadcast stations have been limited to a certain minimum sound volume because at low levels random noise voltages in the transmitter's circuits "drown out" the desired signal. In addition, the peaks of the sound signal must be prevented from causing over-modulation, and hence distortion. To satisfy both conditions an appreciable amount of"volume compression" is used, whereby the dynamic range is considerably limited.

In the case of F.M, on the other hand, there is no need to limit the low volume levels, because the system, as we have seen, is particularly free from back-ground noises. In this way a much wider dynamic range is achieved.

Thus a wide-band F.M. system with its wide A.F. response, and large dynamic range, together with the absence of distracting noise, is capable of extremely natural reproduction. The improvement is particularly noticeable when reproducing large orchestras, where great variations in sound frequency and amplitude occur.

THE CAPTURE EFFECT.

Another important advantage of F.M. over A.M. is that which has been described as the "Capture Effect". This is an effect which occurs as a result of a peculiar combined action of the Limiter and Discriminator stages of the receiver, whereby when two signals are received, the stronger one takes complete control of the receiver, thus eliminating entirely the weaker signal. The effect is 100% complete when the stronger signal is only twice the strength of the weaker. In the case of A.M., interference from a weaker signal is not virtually "swamped" until the stronger signal is 100 times as powerful as the weaker.

This Capture effect means that when F.M. is used interference between adjacent signal channels, and, in most cases even interference between signals occupying the same channel, is practically unknown. The reasons for this effect will be fully explained in a later lesson on Receivers.

TYPICAL CARRIER-FREQUENCIES.

As a result of the wide frequency band used the ultra-high frequencies must be used for F.M. Any frequency above about 40 mc/sec is suitable but, of course, large sections of the spectrum above this figure are already in use for television.

Formerly in America F.M. transmissions were confined to the band 42-50 mc/sec. Latterly, however, the band between 88 and 108 mc/sec. has been assigned for F.M. The first channel has a central carrier frequency of 88.1 mc/sec, the second at 88.3, and so on at intervals of .2 mc/sec (= 200 kc/sec) up to 107.9 mc/sec. Thus 100 separate channels are available. In Australia, so far, the <u>only</u> band allocated for F.M. is this 88 -- 108 mc/sec. band.

DISTANCE LIMITATIONS.

As we have already explained in the television lessons, frequencies above about 40 mc/sec. have a very limited coverage. Reception is limited to a distance a little beyond the line of sight. The "line of sight" is shown by the heavy line in Figure 8. The actual path of the received wave is shown by the dotted line. The extra distance (over and above the line-of-sight distance)is obtained as a result of a bending of the wave by an effect known as "diffraction" due to the presence of the earth.

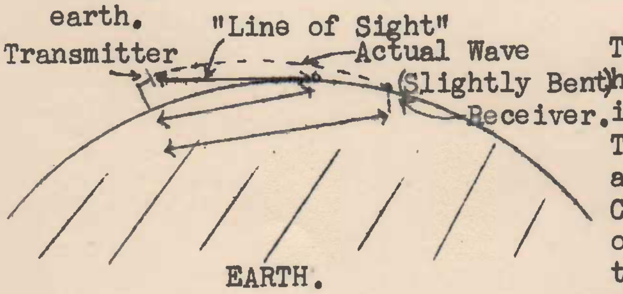


FIGURE 8.

The coverage may be extended by increasing the height of the transmitter antenna (also by increasing the height of the receiver aerial). The distance reached by the wave is, of course, also affected by the nature of the terrain. Certain areas may be "shielded" by the presence of mountains or hills. Under average conditions the range may be taken to be about 50 miles.

COVERAGE OF WIDE AREAS BY UNATTENDED RELAY STATIONS.

The fact that the area which can be covered by a wide-band F.M. system operating on U.H.F. is severly limited might at first suggest that the system is not suited for a countrly like Australia of large areas and small population.

The F.M. system, however, is peculiarly adapted for the use of unattended, low-power, automatic relay stations. These relay stations would be situated at high points (e.g. on mountain tops) over the country-side. They could operate on exactly the same frequency as the main station. Such a system is impracticable with an A.M. system because of interference between 2 or more signals coming from different transmitters of the relay network. One effect which would occur would be heterodyne "howls" due to the interaction of two different carriers. It is an impossibility to synchronise exactly the frequency of the carrier of a relay station with that of the main transmitter. Such interference effects do not occur with F.M.

due to the "capture effecte". Experiments in America have shown that it is a practical impossibility to obtain interference between 2 transmitters operating on the same frequency. In one experiment a car was fitted up with a receiver and attempts were made to find a point between 2 transmitters operating on the same frequency (but sending different programmes) where interference occurred. Theoretically it should be possible to find such a point, e.g. where the ratio of the signal strengths was less than two to one. However no such point was found, even though a point was picked out where simply opening the door of the car resulted in the receiver "switching" from one programme to the other.

It should be clear from the foregoing discussion that if a large area were covered by a number of relay stations, then a receiver at any given point would simply respond to whichever transmitter was producing the strongest wave at that point.

Another factor to remember is that the relay stations would be comparatively cheap to install and operate. Each need by only of very low power as a consequency of the freedom from static interference peculiar to F.M. Further, the cost of maintaining permanent staffs for each relay station does not occur.

It might be mentioned that such a system has been very successfully tried out on large highways in America, for providing complete coverage for patrol cars.

FREQUENCY MODULATION FOR TELEVISION SOUND TRANSMISSION.

As has been pointed out in the Television lesson frequency modulation of the sound carrier is now universally employed. F.M. is particularly suited for this purpose, as an ultra-high frequency sound carrier must be used, in order that it might lie adjacent to its companion vision carrier. By using F.M. the attendant advantages of freedom from noise and high fidelity are obtained.

In America a standard deviation of 25 Kc/sec.(instead of the usual 75 Kc/sec deviation) is used. This involves a band-width of 50 kc/sec. The deviation has been restricted somewhat, compared with that used for other F.M. purposes, mainly in order to limit the over-all width of the composite television channel (vision and sound).

VECTOR TREATMENT OF ALTERNATING CURRENTS AND VOLTAGES.

At this stage it will be necessary to explain a simple graphical method of representing alternating quantities (currents and voltages) whereby the latter may be readily compounded together. This theoretical work will be absolutely necessary for a proper understanding of the work which follows in subsequent lessons. In addition the student will find that this "vector" treatment of A.C, as it is called, will give him a better understanding of A.C. theory in all its applications to radio generally.

WHAT IS A VECTOR?

For our purpose a vector may be regarded as a line of <u>given length</u> and drawn in a <u>given direction</u>. The <u>direction</u> of the vector is of equal importance to its length or magnitude. More strictly a vector is a quantity which may be represented (in magnitude and direction) by such a line. For example consider a force of, say, 5 lbs weight. In considering the effect of such a force acting on a body its direction of action is of equal importance to its magnitude (51 lbs. weight). For example if we Have a force of 51 lbs acting in a northerly direction its effect on a body would be quite different from that of another 51 lb. force acting in, say, a north-easterly direction. These two forces, though of the same magnitude (51 lbs) must be regarded as different; for they have different directions.

Force is only one example of a Vector; there are many other quantities however, which possess both magnitude and direction (e.g. velocity).

Consider Fig. 9. At A we have an example of equal vectors. The two lines representing them have identical lengths and directions. In all other cases (B, C and D) the pairs of vectors are unequal; for in every case the 2 vectors differ either in magnitude or direction or both.

COMPOUNDING VECTORS.

The process of finding a single vector which is equivalent to, or has the same effect as, two vectors is called "compounding" the vectors, or finding the "vector sum", or finding the Resultant of the vectors.

TWO VECTORS ACTING IN THE SAME DIRECTION.

The Resultant, or Vector Sum of two vectors acting in the same direction is the simple arithmetical sum of the two. The resultant acts in the same direction as the two original vectors.

Identical vectors
equal magnitudes
same directions.
Figure 9A.

Different vectors
unequal magnitudes
same directions.
Figure 9B.

Figure 9C

Different vectors.
Equal magnitudes
Different directions.

Figure 9D

Different vectors.
unequal magnitudes
and directions.

Suppose we have two vectors acting in the same direction as shown by "a" and "b" Figure 10A. The resultant is a vector acting in the same direction (viz. towards the top of the page) equal in the magnitude to a + B. This may be seen clearly by considering the net effect of two forces, say of 3 lbs. and 5 lbs. weight respectively, acting in the same direction. The net or resultant force is one of 8 lbs acting in this direction. Thus at A, Figure 10, the resultant of the two vectors may be obtained by placing the two "end to end" AB represents vector "a" and BC represents vector "b". The resultant is represented by the line AC.

TWO VECTORS ACTING IN OPPOSITE DIRECTIONS.

In this case the Resultant is a single vector having a magnitude equal to the simple difference of the two original vectors, and acting in the direction of the larger. Refer to Figure 10B. The two vectors "a" and "b" act in opposite directions, and "a" is larger than "b". The resultant is obtained by placing vector "b" at the arrow end of vector "a". Thus AB represents vector "a", BC represents vector "b" and the difference AC represents the resultant. The resultant equals "a" minus "b", and acts in the direction of the larger vector "a". Note that if the two vectors were equal magnitude and opposite direction the resultant would be zero, i.e. the two vectors cancel each other.

RESULTANT OF VECTORS NOT ACTING IN THE SAME STRAIGHT LINE - THE PARALLELOGRAM OF VECTORS.

If the vectors do not act in the same straight line their resultant is neither the simple arithmetical sum nor the arithmetical difference of them. Neither does the Resultant act in the same direction as either of the original vectors.

We find the Resultant in this case by a simple graphical method, known as the parallelogram of Vectors, illustrated in Figure 11. Here we have two vectors "a" and "b" acting in different directions. To find the resultant we draw the vectors starting from a common point O, as shown to the right of Fig. 11. Here OA = "a" in magnitude and direction. Similarly OB = "b" in magnitude and direction. Now

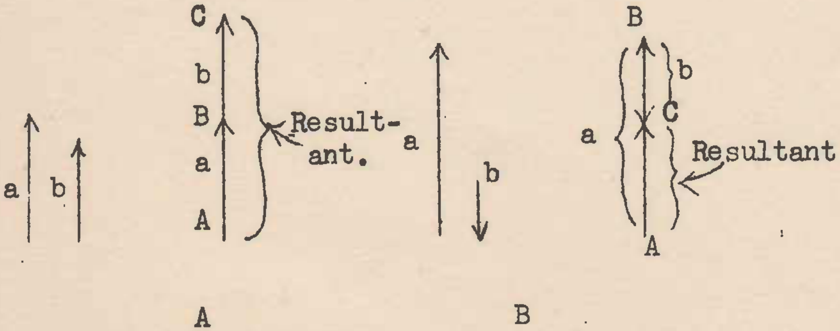


Figure 10.

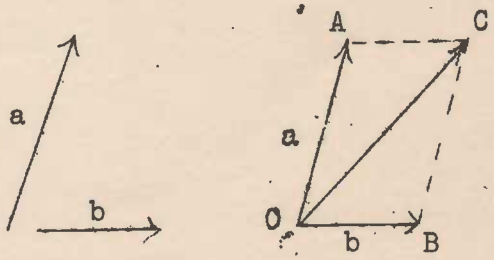


Figure 11.

complete the parallelogram OA CB by drawing AC parallel to OB and BC parallel to OA. Then the resultant is represented by the diagonal OC of the parallelogram. OC represents a vector which would have the same net effect as "a" and "b" acting together. For example if OA and OB represented <u>forces</u> acting on a body in the directions shown, these forces being proportional in magnitude to the lengths of the lines OA and OB, then the two forces would be equivalent to a single force acting in the direction OC, and having a magnitude proportional to the length of OC.

HOW AN ALTERNATING VOLTAGE OR CURRENT MAY BE REPRESENTED BY A VECTOR.

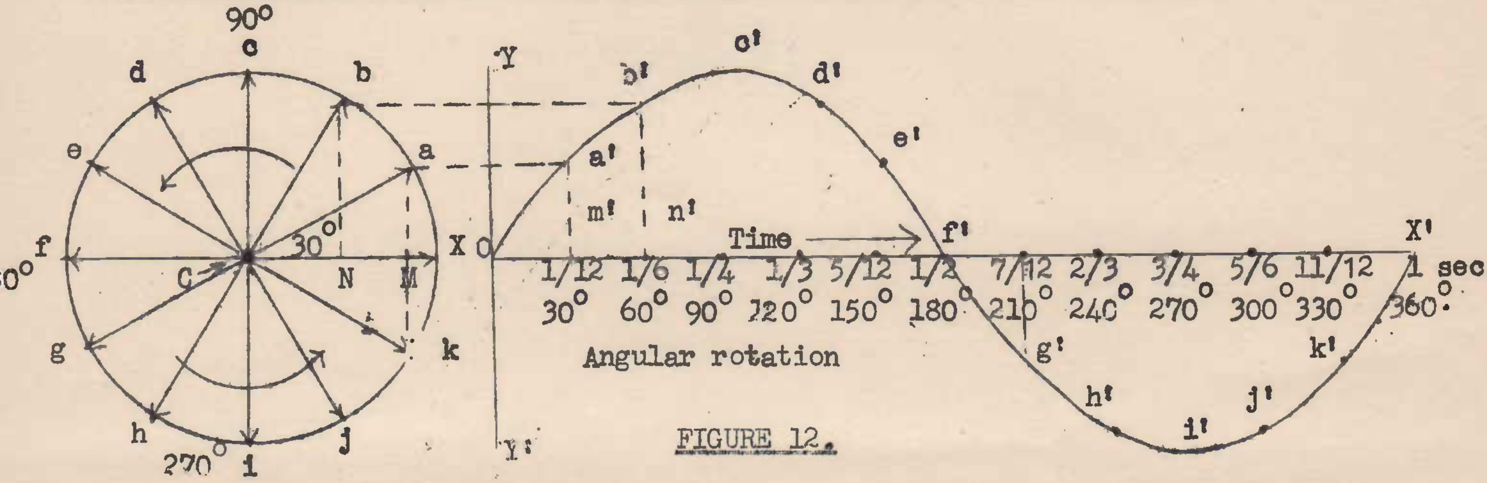


FIGURE 12.

Referring to Figure 12, on the right we have a "sine curve" representing an alternating current or voltage. This curve may be considered to be traced out in the following manner. Take a circle whose radius CM is equal to the <u>peak value</u> or amplitude of the A.C. (shown on the left of Figure 12). We shall call this circle the "circle of reference". Let the radius rotate around the circle, at a constant rate, in a counter-clockwise direction as shown, say at a rate of 1 complete revolution per second. In the figure, [illegible] Ca, Cb, Cc etc. represents <u>twelve</u> positions of the rotating radius. Each position is separated from the next by an angle of $\frac{360^\circ}{12} = 30^\circ$. Now on the right of the circle take two axes OX' and YOY', representing <u>time</u> <u>or</u> angular rotation in degrees along OX', and amplitude, or instantaneous value along the vertical axis YOY'. In this way, on the horizontal axis m' corresponds to the instant of time when the rotating radius has passed through an angle of 30°, and is in the position Ca. Hence M' is marked $\frac{1}{12}$ sec. or 30°. Similarly n' represents the instant of time (or the corresponding angle) when the rotating radius is in position Cb.

Now the graph is traced out by plotting points each of whose vertical distances from the horizontal axis is equal to the perpendicular from the end of the rotating radius to the line fCX in the circle. For example when the radius is in position Ca, the point a' is plotted on the graph making a'm' equal to aM, at the point m' = $\frac{1}{12}$ S or 30°. Similarly b'n' equals bN and represents the height of Cb, and so on. If all such points are plotted, the sine curve Oa' b' c' etc. is traced out.

Note that one complete revolution of the radius Cx traces out one cycle of A.C. Hence in the case chosen the cycle will occupy 1 second. That is the frequency in this case is 1 cycle/sec.

Thus we may imagine the A.C. sine curve to be traced out by a straight line of constant length (equal to the peak value of the A.C.), rotating at a constant rate (equal to the frequency of the A.C). This line referred to (the rotating radius of the circle in Figure 12) has, at any particular moment of time a given length (or magnitude) and a given direction. Hence it may be regarded as a vector.

Certainly the direction of the vector is continually changing. For example at zero time its direction is Cx (Figure 12). One-twelfth of a second later (30° later) its direction is Ca, etc. Such a vector is called a rotating vector.

Summarising, we may state: Any alternating quantity (e.g. current or voltage) may be represented by a rotating vector, whose length or magnitude equals the peak value of the A.C, whose rate of rotation equals the frequency of the A.C, and whose direction, at any moment, represents the "phase" angle of the A.C. (see below).

PHASE OF AN A.C.

The term "phase" refers to the particular point on the A.C. curve at any moment of time. The term "phase angle" means the difference, in degrees, between any point and the zero point, the latter being usually taken when the A.C. is rising from zero in the positive direction. For example, in Figure 12 the phase angle of the point b' on the curve is 60°, relative to the zero point O. Note that the phase angle is also given by the angle between the position of the rotating vector, at the given moment, and the zero position of that vector. In Figure 12, for example the phase angle of the point b' on the curve is given by the angle between CX and Cb, in the circle of reference, viz. the angle bCX.

PHASE ANGLE BETWEEN TWO A.C's OF THE SAME FREQUENCY.

Consider now the two A.C's shown in Figure 13. These having the same frequencies (since each completes a cycle in the same time as the other). They have, however, different amplitudes and phases. The A.C's are represented by rotating vectors on the left of the figure. The radius of OX of the large circle is the vector representing the A.C. marked A. The radius OX_1 of the small circle is the vector representing the A.C. marked B . When the vector OX for curve A is in the position OX, the vector for curve B is in the position Oa, i.e. 30° ahead of OX. As the vectors continue to rotate, at constant and equal speeds, the angle between them will remain at 30°. For example when current A is at position b' (peak value) its vector is in the position Ob in the circle. At this same instant of time current B has passed its peak, and is at c'. Its vector is now in the position Oc in the circle, still 30° ahead of the larger current, the phase angle being the angle bOc.

The important point to note is that, although the directions of the vectors are continually changing, the angle between them remains constant. Thus we may adequately represent the phase angle between two A.C's by showing their vectors for one instant of time only. From the points of view of amplitude and phase the two

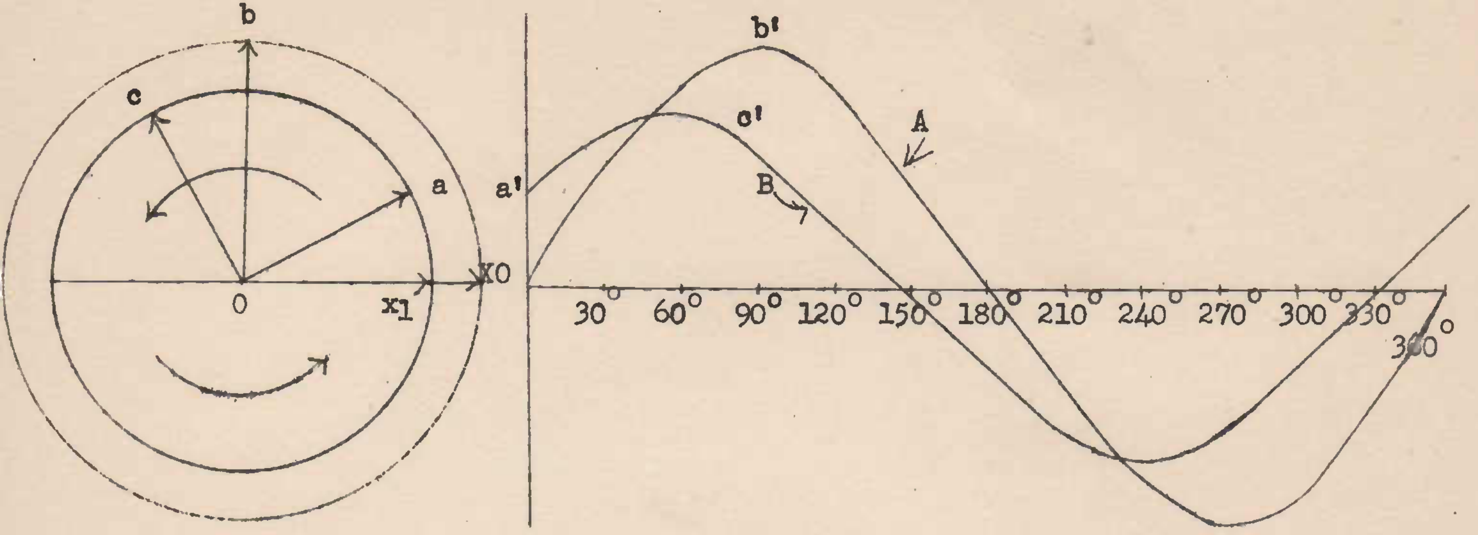


FIGURE 13.

A.C's shown in Figure 13 could be represented by the simple vector diagram of Figure 14. The current B would be said to be "leading the current A", because it is in advance from the point of view of phase with respect to A (vectors are always considered as rotating in a counter-clockwise direction). Conversely, current A is "lagging the current B".

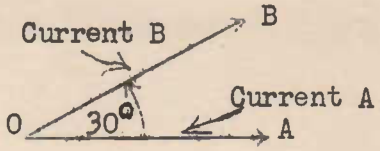


FIGURE 14.

VECTOR SUM OF ALTERNATING CURRENT OR (VOLTAGES) OF THE SAME FREQUENCY.

Two out-of-phase A.C's may be compounded into a single A.C. by laboriously drawing their curves with the correct phase difference, and for a large number of points plotting their sums of differences, depending upon whether they are, at the moment considered, aiding or opposing. The new curve obtained will be their vector sum or Resultant.

If the A.C's have the same frequency, this job may be much more readily obtained by compounding their two vectors.

Figure 15 A(i) shows two currents I_1 and I_2 in phase (vectors in same straight line). The Resultant current is obtained by placing the 2 vectors "end-to-end" as shown at A(ii). The resultant is then the simple sum of the two, and is in phase with the original currents. The length of the vector marked R, gives, of course, the peak value of the resultant current.

If the two currents are 180° out pf phase (i.e. exactly opposing) their vectors are as at B(i) Figure 15. The Resultant is obtained by placing the vectors as shown at B(ii), the resultant then being the simple difference. Note that the resultant current is in phase with the larger of the two original currents (viz. I_1).

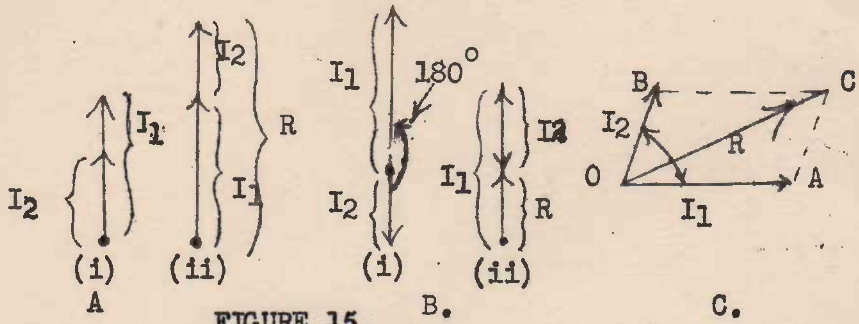


FIGURE 15.

If the two currents have any other phase difference, we make use of the parallelogram of vectors. For example at C, Figure 15 the two current I_1 and I_2 have a phase difference equal to the angle AOB. Their resultant is obtained by completing the parallelogram AOBC, and taking the diagonal OC. Note that the resultant OC is not in phase with either I_1 or I_2. The resultant "leads" I_1 in phase, but "lags" I_2. In other words the resultant lies in phase somewhere between I_1 and I_2.

In all cases of Figure 15 the lengths of the vector lines I_1 and I_2 were taken to represent the peak values of the currents, and the length of the vector line R obtained then represented the peak value of the resultant current. If, however, I_1 and I_2 were represented by lines proportional to the R.M.S, or Effective Values of the currents, then the line representing the resultant R would give the R.M.S. value of the resultant.

PHASE ANGLE BETWEEN AC's OF DIFFERENT FREQUENCY.

If two A.C.'s have different frequencies, the phase angle between them does not remain constant, but continually varies. At certain instants they will be in phase; at other instants they will be 180° out-of-phase. In fact the phase angle between them takes up all possible values. This can be seen if it is remembered that the frequency of an A.C. is given by the rate of rotation of its vector. If the two A.C.'s have different frequencies, their vectors therefore rotate at different speeds.

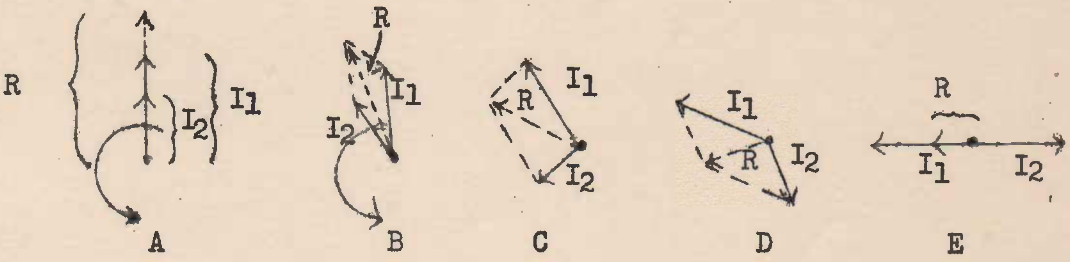


FIGURE 16.

For example, suppose the two A.C's I_1 and I_2, start off in phase as shown at Figure 16A. Further, suppose I_2 has a higher frequency than I_1. The I_2 vector, rotating faster than that of I_1, will draw away from the latter, as time goes on, as shown in the subsequent diagrams. At E the vectors are 180° out of phase, i.e. the A.C's are exactly opposing each others. As time proceeds further the phase angle will be reduced, and eventually they will be in phase again, as at A.

Since the resultant of the two vectors depends upon the phase angle between them (as well as the amplitudes) it is obvious that the amplitude of such a current will vary with time. The resultants are shown by the dotted lines in Figure 16.

Note that the magnitude of the resultant (i.e. the length of the line) varies between a maximum when the currents are in phase at A, and minimum when the currents are 180° out-of-phase at E. An example of this continual variation of phase angle between two currents (or voltages) and continual variation in amplitude of their resultant is when two r.f. currents "beat" together, giving a resultant current whose amplitude varies between a maximum equal to the sum of the two, and a minimum equal to their difference. The rate of variation of the amplitude is the rate at which they get into and out of step, and this is equal to their difference in frequency. The resultant is an amplitude modulated wave, having a modulation frequency equal to the difference frequency.

PHASE ANGLE BETWEEN VOLTAGE (E) AND CURRENT (I) IN A CIRCUIT.

When a source of A.C. voltage (E) is applied to a circuit containing resistance only (see Figure 17A) the current and voltage are in phase. This is obvious, for when the voltage is zero, the current will also be zero; when the voltage is at its peak in any one direction, the current is also at its peak in that direction. The fact that E and I are in phase is shown by the vector diagram in Figure 17A.

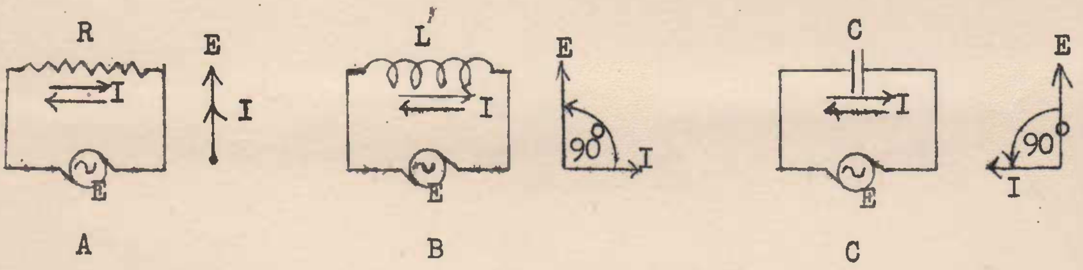


FIGURE 17.

Consider now a circuit containing pure inductance (L) (i.e. resistance of coil negligible). The opposition to the applied e.m.f. (E) in this case takes the form of a counter e.m.f. of self-induction. This is an e.m.f. induced in the coil by the magnetic field due to the current continually expanding and contracting as the current changes in value. The moving lines of magnetic force thus cut the coil inducing an e.m.f. in it. Now we know that such an induced e.m.f. always opposes the applied e.m.f. (E). In other words the induced e.m.f. is 180° out of phase with the applied e.m.f.

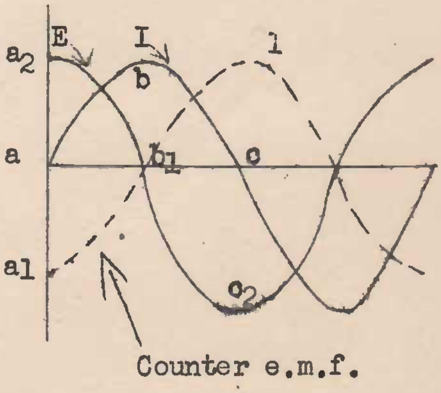


FIGURE 18.

Consider Figure 18, where a.b.c. etc. represents the current flowing. As the current increases from a to b the magnetic field expands. The rate of expansion of the field depends upon the rate of increase of the current. Now the current is increasing at its maximum rate at "a". As the current becomes larger, the rate of increase falls off, as shown by the steepness of the curve ab. Hence at "a" the field will be expanding rapidly, cutting the coil, and inducing a maximum cohnter e.m.f. in it. This e.m.f. will oppose the current increase, and hence will be negative (current increasing in positive direction). Hence when the current is at "a", the counter e.m.f. will be at its negative peak a_1. When the current reaches its peak at b, the rate of change of current is momentarily zero, the field is not moving, and the induced counter e.m.f. is zero, shown at b_1. Now as the current begins to fall off, the magnetic field contracts, cutting the coil in the opposite direction, thus inducing an e.m.f. which acts in the same direction as the current, thus tending to oppose the latter's decrease. Hence as current goes from b to c, the counter e.m.f. rises positively from b_1 to c_1.

This counter e.m.f. of self-induction, represented by curve a_1 b_1 c_1 (Figure 18), remember, is always 180° out of phase with the applied voltage E. Hence E will be represented by curve a_2 b_1 c_2 etc.

Comparing now the curve for the applied e.m.f. E and the current I it will be observed that the current "lags" the voltage by 90° -- since I reaches its peak at b (say) $\frac{1}{4}$ cycle (= 90°) later than E reaches its peak at a_2.

The Vector diagram showing current I, counter e.m.f. of self-induction (E_1) and applied voltage E is shown in Figure 19. Note that the current (I) lags the applied e.m.f. by 90°, but leads the counter e.m.f. (E_1) by 90°. E and E_1 are equal and opposite.

Finally consider the case of an e.m.f. (E) applied to a circuit which is purely capacitive, as in Figure 17C. As the applied voltage (E) (Figure 20) rises from zero the current I will at first be large. The reason for this is that even when the voltage is only a minute fraction of a volt a large current will flow, due to the fact that there is no resistance in the circuit and no opposing charge in the condenser. (Remember $I = \frac{E}{R}$, hence I may be large even if E is small, provided that R is negligible). Hence as the e.m.f. first rises from point "a" the current (I) will be a maximum at a_1. As the applied e.m.f. rises further towards b the current falls off (see a_1 b_1). This is due to the fact that the condenser is now acquiring a charge, and developing an e.m.f. which opposes the charging current. By the time that E has risen to b, the condenser has become fully charged, i.e. the P.D. across its plates is equal to the applied e.m.f. Hence, at this instant the net e.m.f. in the circuit is zero, and the current is zero at b_1. As the applied e.m.f. falls off towards zero (see bc) the condenser begins to discharge against this weakening e.m.f. Hence the current around the circuit is now flowing in the negative direction, as shown by b_1c_1. If this argument is continued, the curve for I will be obtained for a full cycle, as shown in Figure 20. Note that the current leads the voltage by 90°, for the current peaks occur $\frac{1}{4}$ cycle (= 90°) before the corresponding voltage peaks. The vector diagram, illustrating this phase relationship between voltage and current in such a circuit was shown at C in Fig. 17.

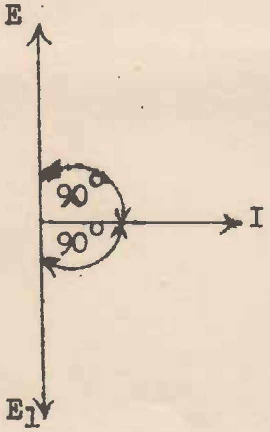


FIGURE 19.

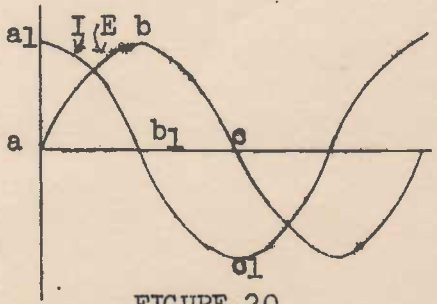


FIGURE 20.

PHASE MODULATION.

Having covered sufficient elementary vector theory we now are in a position to return to modulation methods, and to carry the theory of this subject a little further in preparation for the next lesson.

A third method of modulation is that known as Phase modulation. This is a method whereby the phase of the carrier is continually varied above and below that of an unmodulated voltage. The amplitude of the wave remains constant, and the amount of phase deviation is proportional to the A.F. modulating voltage amplitude. The rate of phase change depends only upon the frequency (A.F.) of the modulating voltage.

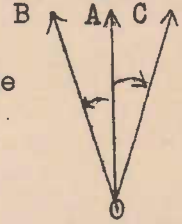
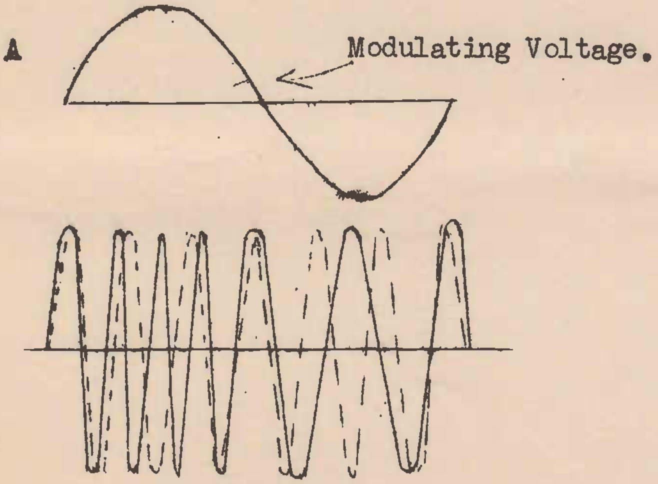


FIGURE 21.

In Figure 21 OA is a vector representing the amplitude and phase of the carrier r.f. voltage. To phase modulate this carrier the phase is first advanced by the angle AOB, and then retarded as shown by the angle AOC. These angles are equal and represent the phase deviation. The size of the angles will, of course, depend upon the amplitude of the modulating voltage at any instant. In Figure 22 we have shown at A the modulating voltage, at B the r.f. wave, which remains at constant amplitude, but whose phase is continually varied (an unmodulated carrier is represented by the broken line) and at C. the phase of the wave for the positive peak of modulation, for zero amplitude of modulating voltage, and also for the negative peak of the modulation. Note that when the modulation voltage goes positive, the phase angle is advanced (i.e. rotated in the counter-clockwise direction), and when the modulation voltage goes negative the phase angle is retarded (i.e. rotated in the clockwise direction).



B. Phase Modulation Carrier.

C. Showing Phase variation.

FIGURE 22.

HOW PHASE MODULATION CAUSES AN EQUIVALENT FREQUENCY MODULATION.

To advance the phase of an A.C. we must rotate its vector at a faster rate. A faster rate of rotation of the vector means an increase in frequency. This may be seen by referring back to Figure 16, where the phase of current I_2 was continually advancing in respect to the phase of I_1, due to the fact that I_2 had the higher frequency. In a similar manner, if the phase of a current is, for a certain period of time, retarded, the frequency of the current while the retardation of phase is continuing, must be decreasing. Hence if the phase of a carrier swung backwards and forwards by modulation, there will be a certain "equivalent" swing of frequency.

The above point may be further elucidated by considering the following example. Suppose a certain modulating voltage "swings" the phase of the carrier backwards and forwards through a total angle of 36°. This will be the phase change brought about by each cycle of the modulating voltage. Suppose this modulating voltage has a frequency of 50 cycles per second. The phase of the carrier is varied by 36° every $\frac{1}{100}$th second, i.e. in the time from the positive peak of one half cycle to the negative peak of the succeeding half cycle. Therefore the average rate of phase change is 36° for every $\frac{1}{100}$th sec. This is 36 X 100 = 3,600° per second. Since 360° = 1 cycle this rate may also be expressed as $\frac{3,600}{360}$ = 10 cycles / sec. Hence a phase swing of 36° at a modulation frequency of 50 cycles/sec. will involve an average equivalent frequency swing of 10 cycles/sec. of the r.f. carrier. This is an important point and will be referred to again in later lessons.

DIFFERENCE BETWEEN FREQUENCY & PHASE MODULATION.

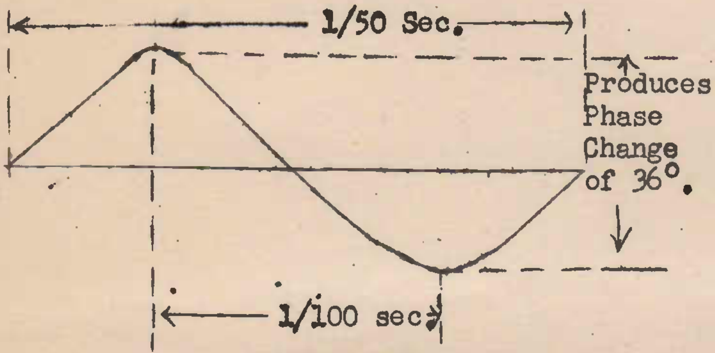


FIGURE23.

Since Phase Modulation causes a frequency change, how does it differ from Frequency Modulation? The difference may be explained by taking another example similar to that given above, but one in which the modulation frequency is, say 500 cycles per sec. In this case the phase will be varied 36° in every $\frac{1}{1,000}$ sec. (i.e. in the time occupied by each half cycle of the modulating voltage). This is a phase change at the average rate of 36,000 per sec. or $\frac{36,000}{360}$ = 100 cycles per sec.

Thus the average change in carrier frequency becomes 10 times as great when the modulating frequency is increased 10 times, even though the amplitude of the modulation voltage remains constant. Now for pure F.M. we stressed the point that the frequency deviation should depend only on the amplitude of modulation, and not upon the frequency of modulation.

Summarising we may say that phase modulation involves an "equivalent" frequency modulation (not a true F.M.) whereby the frequency deviation depends upon both the amplitude and frequency of modulation. The deviation is directly proportional to each of these factors.

True F.M. will, of course also involve an "equivalent" phase modulation (P.M.). The phase deviation involved, however, will vary with the modulation frequency. Hence the P.M. produced is not true P.M, the latter involving a phase deviation which is independent of frequency, depending only upon the amplitude of modulation.

True phase modulation is not used, as such, for communication purpose. The above discussion of it, however, is necessary, because one of the main methods of frequency modulating a transmitter is first to phase modulate it, and then to convert the "equivalent" F.M. obtained into true F.M. by employing a correcting circuit. It might also be mentioned here that random noise r.f. voltages cause a small phase modulation of an incoming carrier. It is the "equivalent" frequency modulation caused by this phase modulation which results in some noise interference in an F.M. receiver.

This will be discussed in a later lesson.

T.FM & F. LESSON NO. 14.

EXAMINATION QUESTIONS.

(1) In an F.M. transmitter an audio modulating voltage of amplitude 50V, and frequency 1,000 cycles per sec. causes the frequency of the carrier to vary between 50.05 mc. per sec. and 49.95 m.c per sec. What would be the amplitude and frequency of an audio voltage causing a carrier swing between 50.01 mc/sec and 49.99 mc/sec and back to 50.01 mc/sec 500 times per second ?

(2) Upon which property of the modulating voltage does the instantaneous band-width of an F.M. signal mainly depend (consider only wide-band systems ?)

(3) Name three types of "noise" voltages whose effects are greatly reduced by F.M.

(4) Place the following systems in order of merit from the point of view of signal-to-noise ratio : (a) A.M. system of band-width 12 kc/sec. (b) F.M. system of Band-width 150 kc/sec, (c) A.M. system of bandwidth 20kc/sec, (d) F.M. system of band-width 50 kc/sec.

(5) What is meant by the "Capture Effect ?"

(6) Why it is possible to obtain a wider Dynamic Range in the case of an F.M. system compared with an A.M. system.

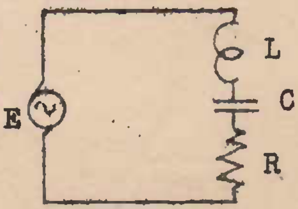
(7) An A.C. voltage of 4V leads one of 3V (peak values) by a phase angle of 60°. Draw an accurate vector diagram to obtain their Resultant. What is the peak value of the resultant voltage ? What is its phase compared with the 3V e.m.f. ?

(8) Draw rough vector diagrams showing the phase relationship between voltage (E) and current (I) in each of the following cases :-

(a) Circuit containing pure resistance. (b) Circuit containing pure inductance.
(c) Circuit containing pure capacity.

(9) In the case of a phase modulated carrier, the phase is varied through a total angle of 24°, what is the equivalent frequency swing, if the modulating voltage has a frequency of 750 C/sec ? What would be the frequency swing for a modulating voltage of the same amplitude but whose frequency is 150 C/sec.

(10) Assume in this circuit that the reactance of L equals the reactance of C, and that the current (I) is in phase with the applied voltage E. Draw a rough vector diagram representing (a) the counter e.m.f. across L (EL), (b) the counter e.m.f. across (C) Ec and (c) the voltage across R (Er).



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T. FM & F. NO.15

FREQUENCY MODULATED TRANSMITTERS.

Any F.M. transmitter system may be divided in four main parts or sections.

(1) The section which frequency-modulates the primary or master frequency.
(2) The frequency-multiplier section.
(3) The power step-up section.
(4) The radiating antenna.
(5) The Power Supply units.

These are shown in block form in Figure 1.

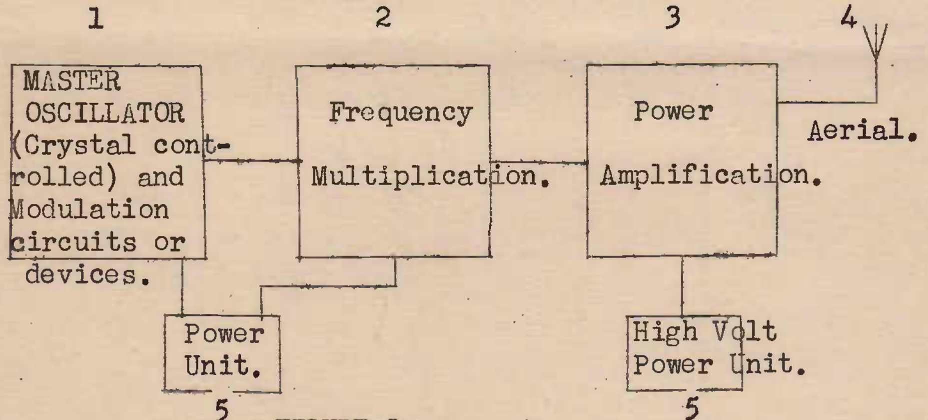


FIGURE 1.

Unlike the usual practice in A.M. transmitters, Figure 1 shows that most of the essential operations in F.M. transmitters are accompanied at low-power levels. As a matter of fact the operations carried out in blocks (1) and (2) of Figure 1 are carried out with power levels as customary as in receiver tubes. This greatly simplifies the transmitter design. By the time the signal has passed through the frequency multiplication stages (Block 2, Figure 1) it is completely formed, i.e. it is already in the form required for radiation. It now requires only to subject this signal to power amplification the exact amount of which depending upon the power output desired from the station. It may, therefore, be said that a low-power transmitting station (say 250 watts) is more or less the same as a high powered one, of, say 50 kilowatts. The only difference would be in the number and power rating of power-amplifier stages.

METHODS OF MODULATION.

Frequency modulation methods may be divided into two main classes. (1) Direct F.M. methods. These bring about a direct frequency modulation of the master oscillator's frequency. They include (a) the condenser-microphone method, and (b) the reactance tube method. (2) The Indirect F.M. Method, in which the audio modulating voltage first amplitude modulates the r.f. signal. The amplitude modulation is then transformed to Phase Modulation, which in turn is converted to true Frequency Modulation. This is the Armstrong method, used in the experimental work of the latter gentleman prior to the presentation of his famous paper on F.M. in 1935 to the Institution of Radio Engineers (America).

These methods of frequency modulating an r.f. carrier will be dealt with in turn.

THE CONDENSER MICROPHONE METHOD OF MODULATION.

This method is based upon two main facts:-

(1) The capacity of a condenser depends upon the distance separating its plates; and

(2) The resonant frequency of a tuned circuit depends on the total capacity used in conjunction with its inductance.

In this system one plate of a condenser acts as a diaphragm of a microphone. The sound waves vibrate this plate causing the distance between it and the fixed plate to vary in sympathy with the sound. In this way the capacity of the condenser varies at a rate dependant upon the frequency of the sound, and by an amount which depends upon the strength of the sound.

The Condenser-microphone forms part of the tuned circuit of the transmitter's primary oscillator, as shown in Figure 2. The variations in capacity of the tuned circuit LC result in a corresponding variation of the latter's frequency. Thus frequency modulation of the r.f. current generated results.

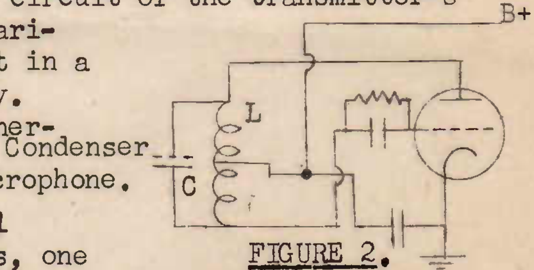


FIGURE 2.

The condenser-microphone system is not in general practical use. It suffers from many disabilities, one being the difficulty of obtaining sufficient capacity, and sufficient capacity variation while at the same time having a sufficiently light diaphragm to respond faithfully to the sound waves.

THE REACTANCE TUBE.

By this term is meant a valve which acts in a circuit just as though it were an inductance. In order to understand how a valve may act in this unusual manner - it first will be necessary to consider the phase relationship between current and voltage in a circuit which contains both resistance and reactance in series.

We have already seen that in the case of a circuit which contains only resistance the current and voltage are in phase. We have further seen that if the circuit contains only reactance (i.e. the opposition presented to an A.C. by capacity, or inductance) then the current and voltage are 90° out of phase. If the reactance is capacitive (i.e. due to a condenser) the current leads the voltage by a phase angle of 90°. If the reactance is inductive (due to inductance) the current lags the voltage by 90°. These three cases are shown for revision purposes in Figure 3. Here Xc stands for capacitive reactance, and X_L for inductive reactance.

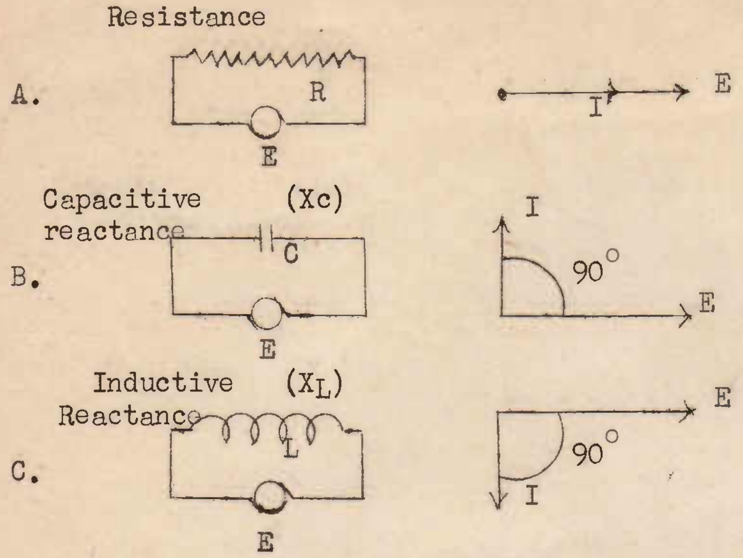


FIGURE 3.

These reactances are, of course, measured in ohms, as in the case of resistance. The question now arises, what happens if the circuit contains both reactance and resistance in series, as in Fig. 4 at (A)? Here we are considering capacitive reactance in series with the resistance, but a similar argument would apply for inductive reactance.

The first thing to realise is that there is only one current in this circuit, since the components are in series. The current through the resistor will be identical with that through the condenser, since the total circuit current flows through each. What then, is the phase relationship between this current and the voltage applied across the circuit?

Consider Figure 4A, where we have an applied voltage Ea (A.C.) applied across a condenser in series with a resistor. The reactance of the condenser is represented by Xc, and depends not only upon the capacity of C but also upon the frequency (f) of the applied e.m.f. (Ea), being given by the formula

$$X_c = \frac{1}{2\pi fc}$$ where π = 3.1416 and C is capacity in farads.

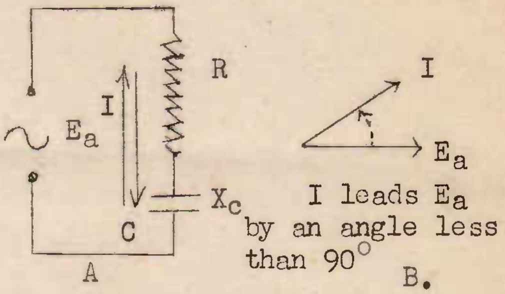
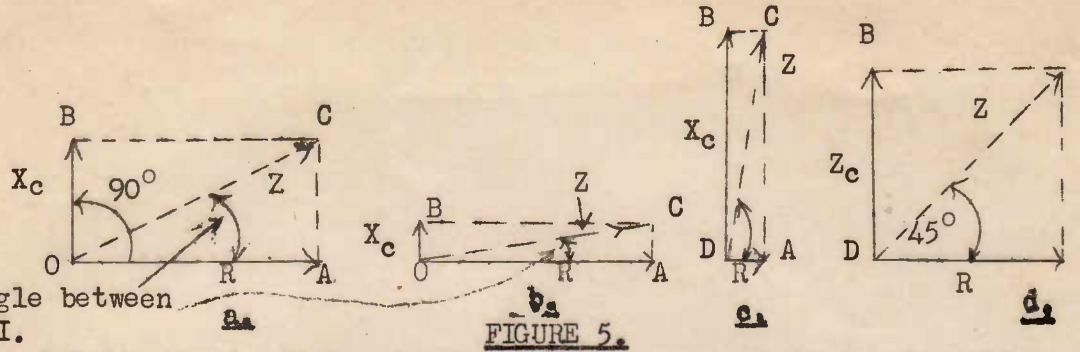


FIGURE 4.

The resistance (R) in the circuit will tend to maintain the current (I) in phase with the applied voltage (Ea). The effect of the reactance (Xc) of C, on the other hand, will be to tend to cause this current to lead the voltage by 90°. Obviously the same current cannot be both in phase and 90° out of phase with voltage. The net result will be that current will lead the voltage by some phase angle having a value between 0° and 90° (see Fig. 4B). The exact phase angle will depend upon the relative magnitudes of the resistance (which tends to maintain E and I in phase) and the reactance (which tends to produce a phase angle of 90° between E and I). For example if R is very large compared with Xc (circuit nearly purely resistive) E and I will be very nearly in phase. If Xc is very large compared with R, I will lead E by a phase angle nearly, but not quite, equal to 90°. If Xc and R have equal values (for the frequency of the applied e.m.f.) the phase angle will lie mid-way between 0° and 90°; i.e. I will lead E by 45°.

Figure 5(a) shows a simple graphical method of obtaining the phase angle between E and I, when the resistance and reactance of the circuit are known.

Here we treat resistance, reactance and total circuit impedance as vectors. Drawing OA having a length depending upon the value of R (in ohms), we draw OB at right-angles to OA, and make this line a length depending upon the reactance



Phase Angle between E_a and I.

FIGURE 5.

(Xc) of C (in ohms). Note, further, that we draw OB in the direction of a leading phase angle (i.e. counter-clockwise direction from R (OA). The reason for this is that Xc tends to advance the phase-angle of the current by 90°. We then complete the parallelogram OBCA, as for the parallelogram of vectors when finding the vector sum of two A.C. voltages. Joining the diagonal OC, the angle AOC then represents the phase angle between voltage (Ea) and current (I) in the circuit. The fact that the vector OC is leading the vector OA (resistance) in this diagram indicates to us that the current is leading the voltage by the angle quoted.

Actually this diagram will give us, in addition to the phase angle between E and I, the value of the total circuit impedance (Z), For, since we have regarded R (OA) and Xc (OB) as vectors, the diagonal of the parallelogram OC must represent the resultant of these two circuit components, viz, the impedance (Z) of the circuit.

Diagrams (b), (c) and (d) show several other cases for various values of R and Xc. Notice at (b) where R is large compared with Xc the phase angle between E and I is small (i.e. E and I nearly in phase). When Xc is large compared with R (at (c)), the current leads the voltage by nearly 90°. When Xc and R are equal, I leads E by 45° (i.e. E and I $\frac{1}{8}$ of a cycle "out-of-step").

Incidently, we might mention here that a circuit containing inductive reactance (XL) and resistance (R) in series, could be treated in a similar way, as shown in Figure 6. Here the inductive reactance vector (XL) is shown lagging the resistance vector (R) by 90°, because XL tends to cause the current to lag the voltage by 90°. The net effect is that I lags E by an angle given by AOC. We are now in a position to understand the "reactance tube", as used for modulation purposes in some F.M. transmitters.

"I" lags "E" by this angle.

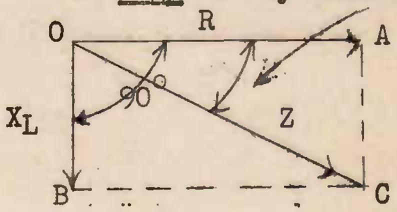


FIGURE 6.

In the schematic of Figure 7, V_1 and the tuned circuit LC form an r.f. oscillator of the Hartley type. Normally this oscillator would produce oscillations whose frequency depends only upon L and C of the tuned circuit. The r.f. voltage developed across the tuned circuit LC by these oscillations is applied across the series combination RC_1. Here LC may be regarded as a source of A.C. e.m.f. Now the value of R is made very large compared with the reactance (Xc) of C_1 at the frequency of operation. This means that for practical purposes the current through RC_1 will be in phase with the voltage across it. (see Figure 5B). This current through Rc_1 will develop an alternating potential difference across C_1. This voltage across C_1, which we shall call Ec lags the voltage applied across the combination RC_1 by almost 90°.

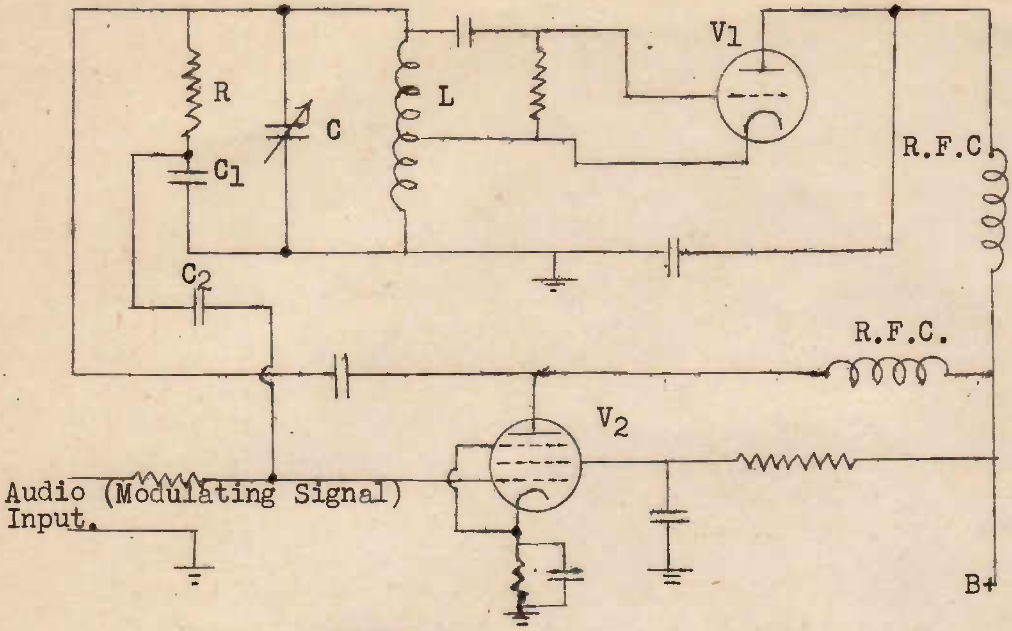


FIGURE 7

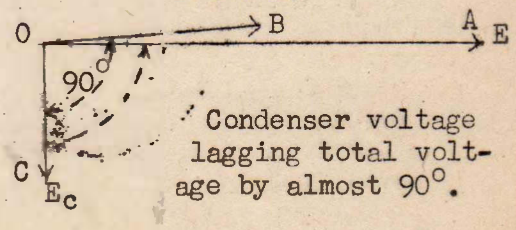
The reason for this may be understood by referring to Figure 8. Here OA is a vector representing the total A.C. voltage (E), applied across the RC, combination (Figure 7). This voltage, of course, is that developed across the LC circuit of that figure by the oscillation produced. The current flowing through R and C will be <u>nearly</u> in phase with E. This current is represented by OB. (Figure 8) the small leading phase angle being BOA. Now, as we have seen at an earlier stage in these lessons, the current through a condenser leads the voltage applied it by 90° . This is the same as saying that the voltage across the condenser <u>lags</u> the current by 90°. Hence, in Figure 8, since OB represents the current through C_1, the voltage across this condenser will be represented by the vector OC, lagging by 90° the vector OB . For practical purposes the angle COB may be taken as 90°. Hence we may say that the voltage across C_1 (Fig.7)) lags the voltage across the RC_1 combination (that is that of the tuned circuit LC)by practically 90°.

Referring again to figure 7, the voltage across C_1 is applied to the grid of V_2, through the condenser C_2. Now remember that the plate current through a valve is <u>in phase</u> with its grid voltage, i.e. plate current and grid voltage rise and fall in step. Hence plate current of V_2 is in phase with voltage across C_1 (Ec). But since Ec <u>lags</u> the voltage across the tuned circuit LC by 90°, this means that the plate current of V_2 also lags this voltage (E) by 90°.

Now note that the voltage across V_2 (i.e. voltage between its plate and cathode) - its plate voltage - is identical with that across LC (E)., for V_2 is connected directly across this tuned circuit. Hence we arrive at the important conclusion <u>that the current through V_2 lags by 90° (practically) the voltage across it</u>. This fact is illustrated by the vector diagram of Figure 9.

Now we know that in a circuit containing only inductive reactance the current lags by 90° the voltage. The vector diagram for such a circuit would be identical with that of Figure 9. To all intents and purposes, therefore, the <u>valve V_2 of Figure 7 acts as though it were a pure inductance</u>. A valve acting in this manner is described as a <u>Reactance Tube</u>.

Negligible Phase Angle Between E and I.



Condenser voltage lagging total voltage by almost 90°.

FIGURE 8.

HOW THE REACTANCE TUBE CAUSES FREQUENCY MODULATION.

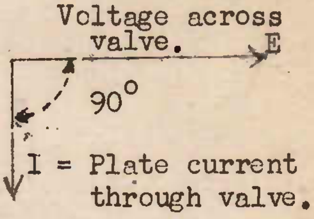


FIGURE 9.

The oscillator consisting of V_1 and LC of Figure 7 could be the primary oscillator of an F.M. transmitter. The tube V_2 (as far as its plate circuit is concerned) is connected in parallel with the inductance L of the tuned circuit. Hence the effective inductive (which together with condenser C determines the frequency of oscillation is made up of the inductance of the coil (L) together with the "inductance" of the reactance tube V_2, <u>in parallel</u>. The effective inductance of two inductances L_1 and L_2, say, in parallel is calculated in a similar manner as for resistances, thus

$$\text{Effective inductance} = \frac{L_1 L_2}{L_1 + L_2}$$

Any variation of either of the inductances (L_1 or L_2) will therefore affect the effective inductance, and so vary the frequency of oscillation of any tuned circuit of which they form part.

If, then, we can vary the inductance effect contributed by the reactance tube V_2 of Figure 7 we will vary the frequency of oscillation of the tuned circuit. This variation of reactance tube's inductance can be brought about by alteration of its grid bias. Such an alteration would change the tube's amplification, and hence alter the magnitude of the r. f. component of the plate current. For example if the grid bias is changed in the positive direction the r.f. current in the tube's plate circuit will increase. This is equivalent to a decrease in the "inductance" of the reactance tube. The effect of such a positive voltage on the grid will therefore be to decrease the total effective inductance of the tuned circuit consisting of C, L and V_2 in parallel (Figure 7), and therefore to <u>increase</u> the frequency of oscillation.

Conversely, a more negative voltage on the grid of V_2 will cause an increase in the effective inductance of the tuned circuit, resulting in a decrease in frequency.

Suppose now we apply the audio modulating voltage to the grid of V_2, as shown in Figure 7. During the positive half-cycles of A.F. the tube's grid potential is made less negative, resulting, as explained above, in an increase in the <u>frequency</u> of oscillation generated by V_1. Similarly the negative A.F. half-cycles will cause a decrease in this frequency. In other words the r.f. oscillation is frequency modulated by the A.F. signal. Of course, it will require careful design of the various circuit components of Figure 7 if the frequency deviations obtained are to be <u>proportional</u> to the amplitudes of the varying audio frequencies voltages.

A block diagram of a commercial F.M. transmitter using a reactance tube modulation is shown in Figure 10. Blocks 1 and 2 comprise the primary oscillator and reactance tube modulator, and together would comprise a circuit similar to that shown in Figure 7. This primary oscillator operates at one-half the radiated frequency. The F.M. modulated output from Block 2 (Figure 10) is doubled in <u>frequency</u> by Block 4. This puts the signal into its proper channel. The frequency doubler will also double the frequency <u>deviation</u> representing the modulation. Block 5 consists simply of power amplifiers to raise the power of the radiated

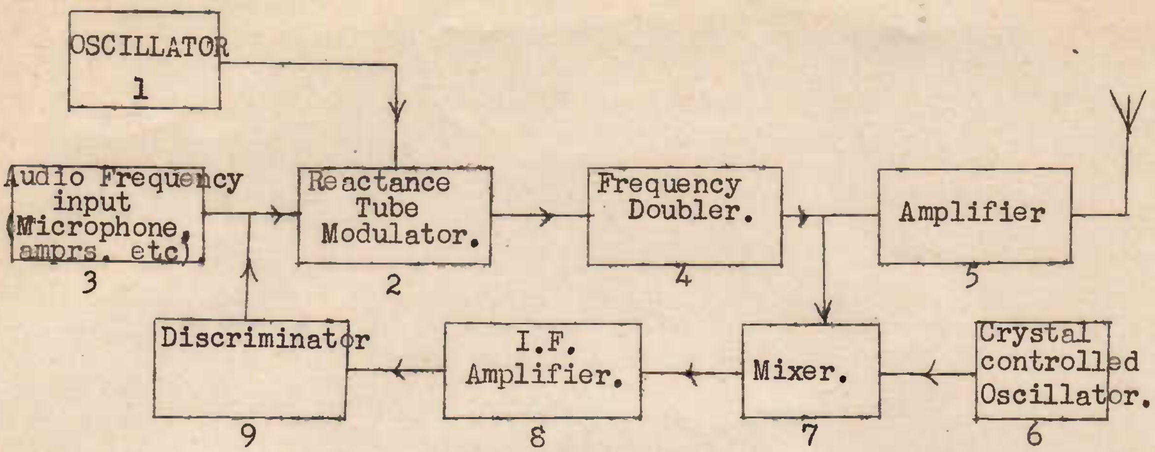


FIGURE 10.

signal to the desired level.

The remaining Blocks - 6, 7, 8 and 9, - of Figure 10 are solely for the purpose of maintaining frequency stability. The primary oscillator (Block 1) does not produce a particularly stable frequency. Direct crystal control of the oscillator is generally not practicable when the output from the latter is modulated by a reactance tube. In this transmitter an ingenious method to hold the centre frequency of the output steady is used. Block 6 is a stable crystal-controlled oscillator operating near the frequency of the transmitted signal. A portion of this signal from the doubler output is fed, together with the crystal oscillator's output into a mixer which produces an "Intermediate Frequency" of comparatively low value. Any variations in the frequency of the primary oscillator (Block 1) will cause the frequency of this I.F. to alter likewise. Block 6 is a circuit which gives a D.C. voltage output proportional to any variation of the I.F. away from its correct central frequency. This D.C. output is applied to the reactance tube's grid with such polarity that it corrects the original frequency drift. Remember that altering the bias on this grid causes a variation in the primary oscillator's (Block 1) frequency. Block 6 is called a "discriminator" and is similar to the discriminator detector in an F.M. receiver. The detailed operation of this device will be dealt with in the lesson on Receivers. Actually this discriminator is used here exactly in the same manner as in an ordinary automatic frequency control equipped receiver.

THE INDIRECT F.M. SYSTEM - OR ARMSTRONG SYSTEM.

This method as stated earlier involves the production of amplitude modulation first, then in effect, the transformation of this A.M. into Phase modulation. The equivalent F.M. produced by this P.M. is then "corrected" to ensure "true" F.M., i.e. where the frequency deviation is proportional only to the amplitude of the modulating voltage, and not to the audio frequency of this modulating voltage.

In order to understand how A.M. may, in effect, be transformed into P.M. and F.M. we must delve a little more deeply into the differences between these several forms of modulation, particularly from the point of view of their side-bands.

SIDE-BAND DIFFERENCES BETWEEN A.M. AND P.M. OR F.M.

It was stated briefly in the previous lesson that F.M. involved the production of side-band frequencies just as in the case of A.M. If the frequency deviation is large, however, we may have a whole series of side-bands for every modulating voltage. The "first-order" pair of side-frequencies are similar to those produced by A.M., as they differ from the carrier frequency (one above, the other below) by a frequency equal to the audio modulating frequency. For example if f_o is the carrier frequency and f_1 represents one particular audio modulating frequency, then the "first-order" pair of side-frequencies have frequencies $f_o + f_1$ (the upper side-frequency) and $f_o - f_1$ (the lower side-frequency). In addition to these, however, we have (for F.M.) a "second-order" pair of side-frequencies which differ from the carrier (or central) frequency by twice the audio frequency modulation voltage. These second-order side-frequencies will therefore have frequencies $f_o \pm 2f_1$, where f_o and f_1 are as stated above. Similarly the "third-order" pair of side-frequencies will have frequencies $f_o \pm 3f_1$, and so on.

The relative importance of the various pairs of side-frequencies depends upon the frequency deviation used. More accurately it depends upon the ratio of the frequency deviation to the modulating frequency. This ratio is called the "Modulation Index", i.e.

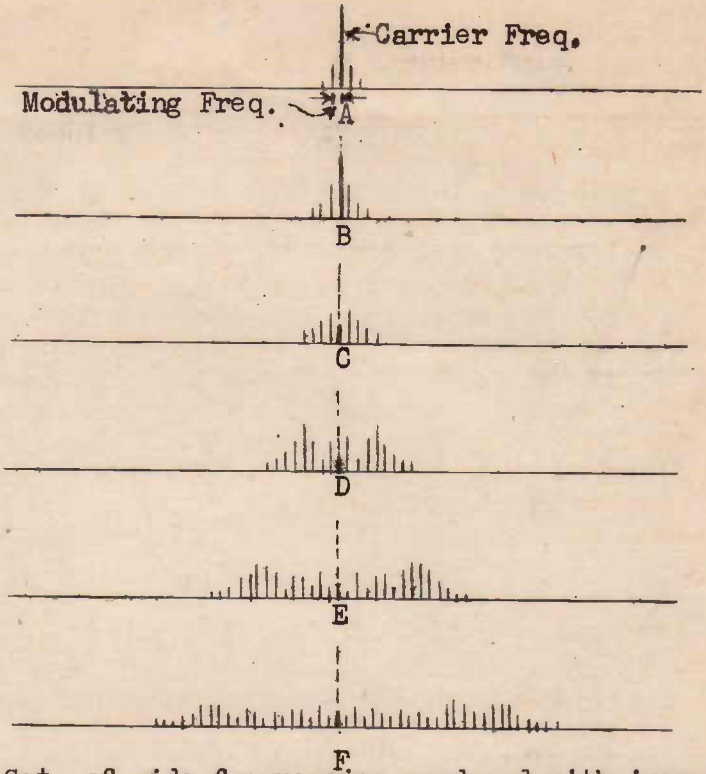
$$\text{Modulation Index (M)} = \frac{\text{Change in Carrier Frequency (Deviation).}}{\text{A.F. Modulating Frequency.}}$$

For example if an A.F. of 7,500 C./sec. is producing a deviation (change in carrier frequency) of 37.5 K.C./sec. (= 37,500 C./sec.), the modulation index (M) equals

$$\frac{\text{Deviation}}{\text{Modulating Frequency}} = \frac{37{,}500}{7{,}500} = 5.$$

Figure 11 shows the side-frequencies (with their relative amplitudes) produced for various values of modulating index (M). It will be seen that, as at A in this figure, when M is small (i.e. small deviation) all side-frequencies may be neglected except the two "first-order" ones. For small deviations (relative to the modulating frequency), therefore, the situation as regards side-bands is identical with that produced by A.M. Remember that in the case of the latter form of modulation, only a single pair of side-frequencies is formed for any given modulating frequency. Returning to Figure 11, we see that as the deviation (for a given modulating frequency) is increased more and more higher-order side-frequencies become important. It should, of course, be understood that, in these diagrams the first-order side-frequencies are those closest to the carrier (or centre) frequency - one side-frequency on either side of the latter. The second-order side-frequencies are represented by the next pair of lines moving outwards from the carrier frequency, and so on. Further, remember that the gap between any pair of lines representing side-frequencies is equal to the modulating frequency (A.F.).

The important point brought out by Figure 11 and which we wish to stress at this stage is that if M. is 0.5 or less, i.e. for small deviations an F.M. wave may be adequately represented by a carrier wave and a single pair of side-bands, just as in the case of A.M. The omission of the higher-order side-bands, under these conditions, will not materially affect the result. The same applies for P.M., since both P.M. and F.M. involve a continual variation of carrier frequency.



Sets of side frequencies produced with increasing deviation and constant modulating frequency, i.e. for different values of "M".

FIGURE 11.

The question now arises: If an F.M. (or P.M.) wave and an A.M. wave each involve a carrier frequency and the same pair of side-bands, how can they differ? The answer to this question involves the phase relationship which exists between the side-bands and the carrier in each case. In the case of A.M., the side-band frequencies are in phase or 180° out-of-phase with the carrier at the instants when the audio modulating voltage is at its peaks. For F.M. (or P.M.) the side-band frequencies are 90° out of phase with the carrier when the audio modulating voltage is at its peaks, (positive or negative).

PHASE RELATIONS BETWEEN CARRIER & SIDE-BANDS FOR A.M.

First let us see how the addition (vector addition) of a carrier frequency, and two side-band frequencies (all of constant amplitude) will produce an amplitude modulated wave (i.e. one of constant frequency but of varying amplitude). Consider Figure 12, where at A is shown the A.F. modulating signal. Suppose, for the sake of argument the frequency of this signal is 10,000 cycles/sec. Then the time represented by a.e. on the graph (i.e. time for one cycle is $\frac{1}{10,000}$ sec. At B we have the unmodulated r.f. carrier (I_o). Since there are 10 r.f. carrier cycles in the time a.e., i.e. $\frac{1}{10,000}$ sec., the carrier frequency must be 10 x 10,000 = 100,000c./sec. (= 100 K.C./sec.). Note that the amplitude (peak value) of the modulating voltage at A is one-half the carrier amplitude. This will give 50% modulation, so that the modulated carrier's amplitude (shown at E) will rise to twice its mean value (on the positive peaks of modulation) and fall to one-half its mean value (on the negative peaks of modulation). Note that the frequency of the modulated carrier I_m (at E) is identical with that of the unmodulated carrier I_o (at B) - since in both graphs we have the same number of cycles (viz. 10) in the time a.e. This, of course, is in agreement with what we already know, i.e. amplitude modulation causes no change in carrier frequency. Our aim at the moment, however, is to investigate how the three radio frequencies represented by graphs B, C and D, all of constant amplitudes and constant (but different) frequencies may com-

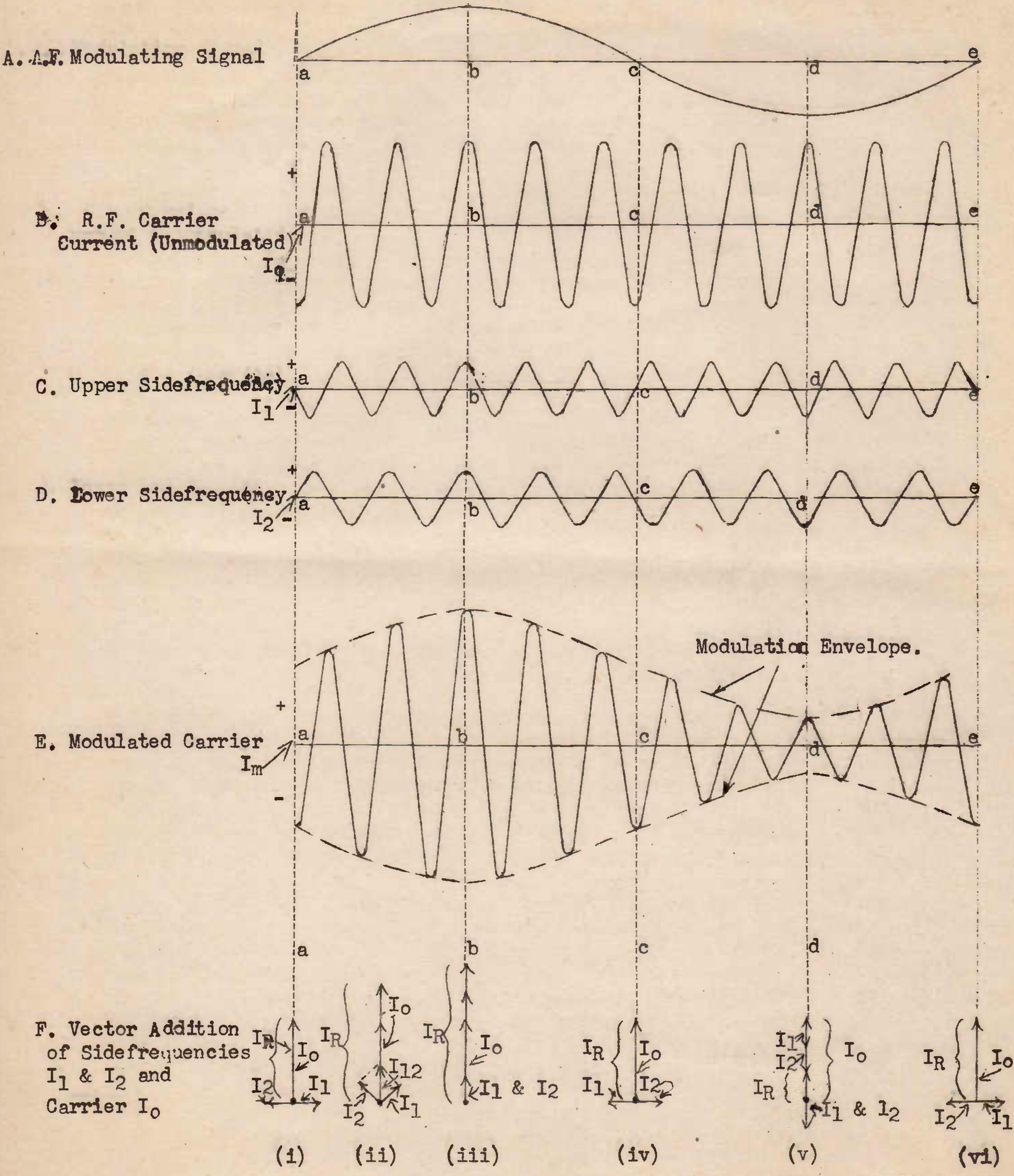

A. A.F. Modulating Signal
B. R.F. Carrier Current (Unmodulated)
I0
C. Upper Sidefrequency
I1
D. Lower Sidefrequency
I2
E. Modulated Carrier
Im
Modulation Envelope.
F. Vector Addition of Sidefrequencies I1 & I2 and Carrier I0
a
b
c
d
e
+
-
IR
I0
I1
I2
I12
I1 & I2
(i)
(ii)
(iii)
(iv)
(v)
(vi)

Fig. 12.

bine to give the modulated result shown at E.

At C. we have an upper side-frequency. Here are shown 11 complete cycles in the time a.e.($\frac{1}{10,000}$ sec.), so that the frequency is 11 x 10,000 = 110, 000 C./sec. (= 110 K.C./sec). Note that this frequency lies above the carrier frequency (100,000 C./sec.) by an amount equal to the audio frequency of the modulating signal (10,000 C./sec.). Graph D shows the <u>lower</u> side-frequency of 90,000 C./sec. (9 cycles in $\frac{1}{10,000}$ sec.). This also differs from carrier frequency by an amount equal to the modulating frequency.

Note that, for the 50% modulation shown, the amplitude of <u>each</u> of the side-frequencies is one-quarter of the amplitude of the unmodulated carrier.

Now let us consider the relative phase relationships between the carrier and its two side-frequencies shown in graphs B, C and D (Figure 12). At the instant marked "a" in the graphs the upper side-frequency is just commencing to go negative. At this same instant the carrier has already reached its negative peak. This means that the upper side-frequency (I_1) is, at this instant lagging by $\frac{1}{4}$ cycle or 90° the carrier. This is shown in the vector diagram F (i) (Figure 12) where the vector representing the carrier is drawn in a direction up the page. I_1 is drawn towards the right of the page making an angle of 90° with I_o. This represents a lagging phase for I_1 compared with I_o. (Remember that the conventional direction of vector rotation is counter-clockwise). Now look at the lower side-frequency graph (D). At instant "a" the wave is just beginning to go positive whereas the carrier does not begin to go positive till $\frac{1}{4}$ cycle later (see graph B). This, of course, means that side-frequency I_2 is <u>leading</u> the carrier by $\frac{1}{4}$ cycle or 90_o. Now since I_1 lags I_o by 90° and I_2 leads I_o by 90° this also means that I_1 and I_2 (the 2 side-frequencies) are 180° out of phase. This may also be seen by direct comparison of the graphs (C and D) of I_1 and I_2. At instant "a" I_1 is just beginning to go negative. At the same instant I_2 is just beginning to go positive. This shows that they are of opposite phase (phase angle = 180°).

These additional phase relationships are also shown by vectors at F (i). I_2 is drawn to the left showing a leading phase angle relative to I_o. The vector diagram shows clearly that, at this instant "a" I_1 and I_2 are 180° out of phase; for their vectors are drawn in <u>opposite</u> directions.

The lengths of the vectors I_o, I_1 and I_2 are of course equal, respectively, to the peak values of the currents I_o, I_1 and I_2.

Adding the vectors of Figure F(i) we notice that the vector sum of I_1 and I_2 is zero (equal and opposite vectors). This leaves as the resultant of I_1, I_2 and I_o a vector equal to I_o, <u>and in phase with I_o</u>, as shown by I_R on the diagram. This agrees with graph <u>E, where at "a" the</u> instantaneous amplitude of the modulated carrier equals vector I_R which is equal to the amplitude of the unmodulated carrier (I_o).

Now the phase relationships shown at F (i) do not persist indefinitely. The vectors, it must be remembered, are continually spinning counter-clockwise with speeds representing the <u>frequencies</u> of the currents they represent. Since I_1 represents the highest frequency it will be rotating counter-clockwise at a faster rate than I_o. Hence the angle between these two vectors will be diminishing as time goes on. Now in the subsequent vector diagram of Figure 12 F we have shown vector I_o in a fixed direction (vertically) and have represented only the <u>relative</u> rotations of I_1 and I_2 in respect to I_o. This is done because we are interested only in the <u>relative</u> phase relationships of I_1 and I_2 in respect to I_o. Thus at a moment later, <u>F(ii)</u>, we have shown a diminished angle between I_o and I_1 compared with that shown at F(i). The vector I_1, initially lagging I_o by 90° is now "catching up" in phase on I_o.

In a similar manner the angle between I_o and I_2 vectors will be diminishing, since I_2 (initially ahead of I_o) is rotating counter-clockwise at a slower rate than I_o. In effect I_o is "catching up" on I_2. We have shown this at F(ii) by imagining that vector I_o has remained fixed, and vector I_2 has rotated <u>clockwise</u> at a rate equal to the <u>difference</u> between the rates of actual rotation of I_o and I_2.

Concentrating now on vector diagram F(ii), we obtain the vector sum of I_1 and I_2 by completing the parallelogram giving the vector marked I_{12} as the resultant. The resultant of all three vectors is then obtained by adding I_{12} to the end of I_o, giving I_R. This of course will represent the modulated carrier in amplitude and phase. Note: (1) the amplitude of the resultant wave (length of I_R) is increasing as the side-frequencies move more and more into phase with I_o, and (2) the phase of the resultant is still identical with that of the unmodulated carrier (this follows since vector I_R(Fii) is still in the same direction as I_o). The latter point, of course, means that the modulation produces <u>no change in carrier phase</u>, and therefore no phase or frequency modulation.

Figure 12 F(iii) gives the state of affairs a little later at an instant of time (marked "b") when the wave is at a modulation peak. Vector I_1 rotating less rapidly than I_o and vector I_2 rotating more rapidly than I_o are now both in phase with I_o, and the resultant (I_R) is, at this instant a maximum. (See also points marked "b" on graphs B, C, D and E.)

As time goes on I_1 continues to rotate counter-clockwise with respect to I_o and I_2 continues to rotate clockwise (relative to I_o). As shown in Diagram **iv** (figure 12F) the side-frequencies are once again 90° out of phase with I_o, and 180° out of phase with each other (see points "C" on the graphs). Later still, as the vector rotation continues the vector I_1 and I_2 will be in the same direction downwards as shown at **12 F(v)**.The side-frequencies are now in phase with each other, but 180° out of phase with I_o (carrier). To obtain the resultant in Figure 12 F(v) vectors I_1 and I_2 have been placed at the "arrow end" of vector I_o, and their sum is subtracted from the latter. The resultant is I_R as shown. Here the modulated wave has a minimum amplitude.

Summarising, the important points to note from the foregoing discussion are:-

(1) The side-band frequencies are <u>in phase</u> with the carrier at the positive peaks of the modulation voltage (i.e. when the modulation envelope is at a peak). See points "b" in the graphs (Figure 12).
(2) As time continues the upper side-band vector rotates counter-clockwise, and the lower side-band vector rotates clockwise in respect to the carrier vector. These rates of relative rotation are equal, each depending upon the difference between side-band frequency and carrier frequency.
(3) As a result of (2) the angles between the side-band vectors and the carrier are always equal (see Figure 12 F(ii). Hence the resultant of the side-

bands (I_{12}) is always in line with carrier vector (I_o). This means that the side-bands do not change the phase of the modulated carrier (I_R is always in phase with or 180° out of phase with I_o).

(4) Since there is no change in carrier phase due to the side-band vectors (i.e. due to modulation) no frequency modulation results.

(When only one single audio frequency is modulating the carrier, there will simply be one single upper side-frequency and one single lower side-frequency as in the examples just quoted. When complex tones, especially music, are being broadcast there may be simultaneously a number of upper and lower side-frequencies. The groups of side-frequencies then are called "side-bands".)

PHASE RELATIONS BETWEEN CARRIER AND SIDE-BANDS FOR P.M.(OR F.M.).

Suppose now that the graphs representing the side-frequencies of Figure 12(C and D) are moved bodily towards the left of the page through a distance equal to $\frac{1}{4}$ cycle. This is equivalent to advancing the phase of the side-frequencies by 90° relative to the carrier, and the situation is shown in Figure 13, at C and D. Note that the upper side-frequency I_1 (figure 13C) is now in phase with the carrier, and the lower side-frequency I_2 (Figure 13D) is 180° out of phase. These phase relationships are shown in the vector diagram at F(i). The side-frequencies being equal and 180° out of phase cancel each other and have no effect upon the carrier (vector I_o).

Remember that the side-frequency vectors are rotating at equal and constant speeds relative to I_o, I_1 rotating anti-clockwise and I_2 clockwise. The situation is shown for an instant about $\frac{1}{8}$ cycle later at (ii) (Figure 13F). The side-frequency vectors I_1 and I_2 now have a resultant I_{12} as shown. The vector representing the modulated carrier is obtained by obtaining the vector sum of I_o and I_{12}, and is I_R as shown. Note that the effect of the side-bands has been to advance the phase of the carrier through an angle equal to that between I_o and I_R in this diagram.

A little later still the situation is as shown at (iii) (Figure 13F). This diagram shows the conditions for the instant of time marked "b" on the graphs, i.e. for the positive peak of the modulating voltage, I_1 and I_2 are now in phase with each other, and 90° out of phase (leading) with the unmodulated carrier (I_o). The resultant of I_o, I_1 and I_2, representing the modulated carrier is I_R. Note that the angle through which the carrier phase has been advanced (marked "A") has increased still further.

As I_1 and I_2 continue to rotate this phase angle "A" will now begin to decrease, becoming zero at time "C". This is shown at Figure 13F (iv) where I_1 and I_2 are 180° out of phase with each other, and therefore cancel. The carrier is thus simply I_o at this instant.

A quarter of a modulating voltage cycle later I_1 will have rotated anti-clockwise and I_2 clockwise, so that both vectors are pointing to the right of the page (see Figure 13F (v)). The resultant I_R of I_1, I_2 and I_o again represents the instantaneous value of the modulated carrier. Note now that the effect of the side-frequencies has been to retard the carrier phase of the carrier by an angle "A". (I_R lags I_o by "A").

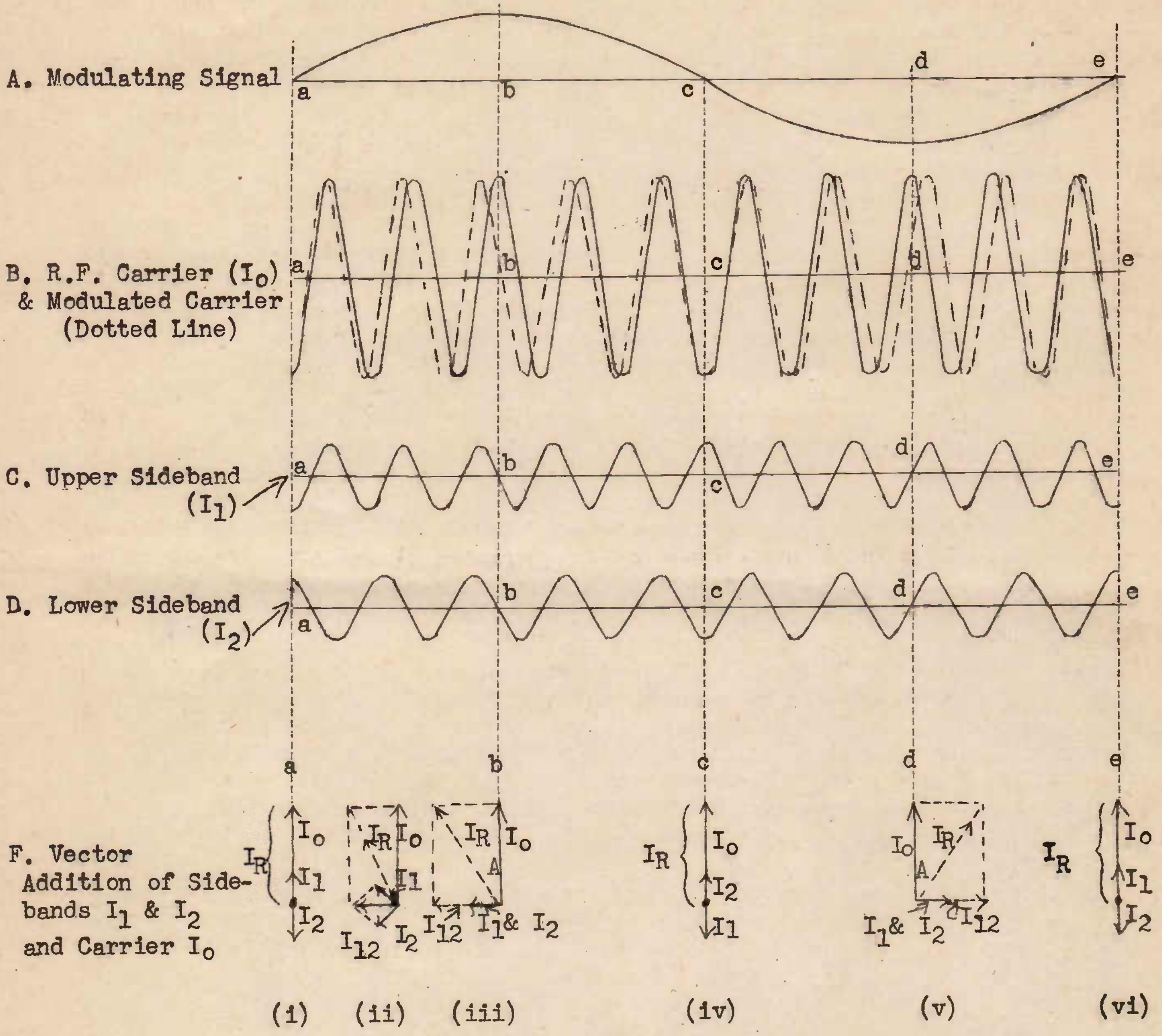

A. Modulating Signal
B. R.F. Carrier (I_o) & Modulated Carrier (Dotted Line)
C. Upper Sideband (I_1)
D. Lower Sideband (I_2)
F. Vector Addition of Sidebands I_1 & I_2 and Carrier I_o
a
b
c
d
e
I_R
I_o
I_1
I_2
I_{12}
I_1 & I_2
A
C
(i)
(ii)
(iii)
(iv)
(v)
(vi)

Fig. 13.

As time continues from this point the angle between I_R and I_o will commence to decrease. At point "e" the phase of the modulated carrier (I_R) is identical again with that of the unmodulated carrier (I_o).

Note carefully the net effect of the side-frequencies acting upon the carrier. The modulated carrier vector I_R oscillates back and forth about the mean position I_o, through a total angle equal to 2A. In other words the phase of the carrier is alternately advanced and retarded at modulation frequency. This is phase modulation, which, as we have seen produces an equivalent frequency modulation.

Observe the effect on the frequency of the carrier. Between points "a" and "b", when the phase of the carrier is being advanced (i.e. vector I_R rotated <u>anti-clockwise</u>) as shown at (iii) Figure 13F, the carrier frequency has been increased, as shown by the dotted line at B between points "a" and "b". Between "c" and "d" as the phase is being retarded (vector I_R rotating clockwise) the carrier frequency is below the mean value. This can be clearly seen by counting the number of dotted line cycles between "c" and "d" Figure 13B, and comparing with the number of full-line cycles between the same two points.

A further important point brought out by Figure 13 is that the amplitude of the carrier remains fairly constant. The vector I_R, representing the modulated carrier in amplitude and phase (at F) remains practically of constant length. This is only true if the angle A representing the <u>maximum</u> phase deviation is comparatively small. This is so because we have considered only the first-order pair of side-frequencies. Longer deviations would involve additional higher-order side-frequencies which we have neglected.

CONVERTING A.M. TO P.M.

Figures 12 and 13, and the accompanying discussion have thus shown that the only difference between A.M. and P.M. (for small deviations) is in the phase relationship between the pair of side-bands and the carrier. In the case of A.M. the side-bands are <u>in phase</u> with the carrier at the instants corresponding to modulating signal peaks; in the case of P.M. the side-bands are <u>90° out of phase</u> with the carrier <u>at the same instants</u>.

If, then, we can take the side-bands produced by A.M., and electrically shift them in phase through 90° relative to the carrier the result will beP.M. The "equivalent " F.M. thus produced may then be connected to yield "true" F.M. This is the principle of the Armstrong method.

THE ARMSTRONG "INDIRECT" METHOD OF F.M.

Figure 14 shows, in block form, the principal sections in the Armstrong Modulator. Here block (3) is an <u>amplitude</u> modulator so designed that it balances out the carrier voltage, its output containing only the two side-bands produced by the modulation. Into this modulator we feed the audio modulating signal (from the microphone) together with a part of the carrier signal from block (1). The remainder of the carrier signal is amplified (block 4) and passed to the frequency multipliers.

The two side-bands, produced by amplitude modulation are fed to block (5) where

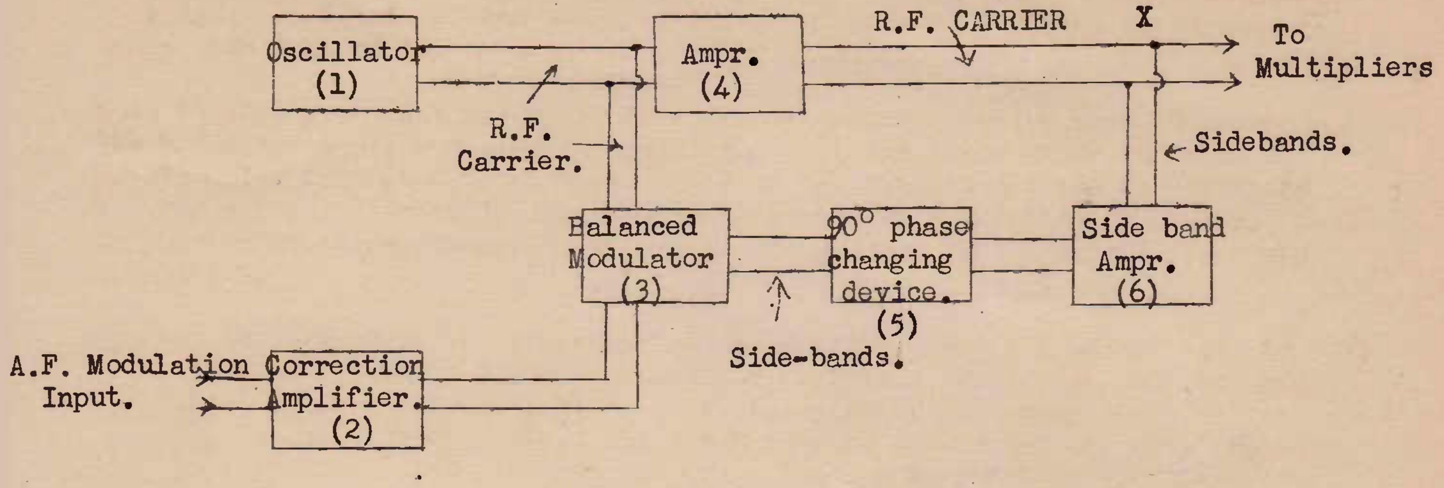


FIGURE 14.

their phase is shifted through 90°. The side-bands are now recombined with the carrier signal coming from block (4). These side-bands immediately after leaving the modulator were <u>in phase</u> with the carrier at the instants of modulating voltage peaks (since they were produced by A.M.). After phase-shift they will therefore be 90° out of phase with the carrier at modulation peaks. The effect of the 90° phase changing device may be visualised by comparing graphs C and D of Figure 12 with C and D of Figure 13. The vectors at F in these two figures also show the change produced. The phase relationship between the side-bands and carrier is now such that phase modulation would result.

As we have earlier explained phase modulation involves an "equivalent" frequency modulation, but the frequency deviation is proportional to the modulating (audio) frequency as well as to the amplitude of the modulating signal. This means that the frequency variations will double if the audio modulating frequency is doubled even though the amplitude of the latter signal remains unchanged.

To counter-act this effect the modulating signal is put through a correction circuit included in block (2) Figure 14 before being used for modulation. This correction circuit acts in such a manner that the amplitude of the modulation signal is inversely proportional to its frequency. This will exactly off-set the effect of phase-modulation whereby the frequency deviations in the final output are directly proportional to A.F. signal frequency. The output from the transmitter will be therefore true F.M.

THE MODULATION SIGNAL CORRECTION CIRCUIT.

The correction circuit which does this job of changing the output from true P.M. to F.M. consists simply of a resistor and condenser in series, the microphone signal being applied across the two, while the output is taken from across the condenser only, as shown in Figure 15. The value of resistance is made large compared with the reactance of the condenser even for the lowest audio frequency. This means that the impedance of the circuit remains sutstantially constant for all audio frequencies of modulation. Thus the alternating current through R.C. (figure 15) does not alter with frequency. Now the reactance (X_c) of C varies inversely with the frequency ($X_c = \frac{1}{2\pi fc}$)

The voltage across C is given by $E = I \times X_c$ where I is the current (A.C.) through R and C. Since I remains practically constant for all frequencies, but since X_c varies inversely with the frequency E will also vary in the latter manner.

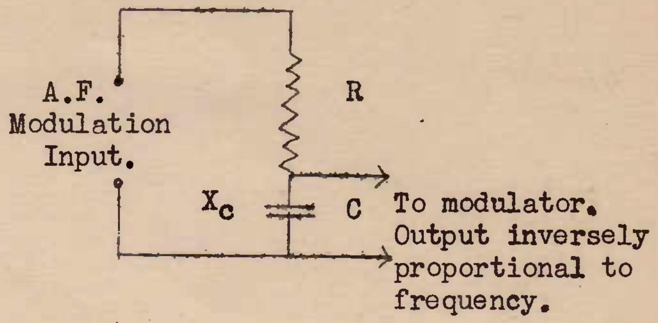


Fig. 15

THE BALANCED MODULATOR.

The balanced modulator (block 3, Fig. 14) used for A.M. with carrier suppression is more or less a push-pull amplifier as shown in Fig. 16. The carrier frequency is applied to the grids of the two tubes in phase. Hence, by using a transformer output in the plate circuits, with a centre-tapped primary, voltages of this frequency will cancel out in the output.

The modulating voltage is applied in opposite phase to the two screen-grids by means of a centre-tapped transformer. Now remember that out-of-phase voltages applied to the grids (or screen grids) of a push-pull amplifier will produce signals in the plate circuits which add in the secondary of the output transformer. In addition the A.F. modulation signal and the r.f. carrier signal will combine in the valves as in ordinary modulation theory, to produce amplitude modulation. The resultant output will therefore be an A.M. signal from which the carrier frequency has been suppressed. In other words the output will contain the side-bands, representing the modulation, only.

PRODUCTION OF THE 90° SIDEBAND PHASE-SHIFT.

The changing of the phase of the sidebands by 90°, necessary to convert the A.M to F.M is usually carried out in the output transformer of the balanced modulator of Fig. 16.

The principle involved may be stated thus:- "The A.C. voltage induced in the secondary winding of a transformer is 90° out of phase with the current flowing in the primary".

Consider Fig. 17. The current I_p in the primary sets up a magnetic field which expands and contracts in step with this current. This moving magnetic field, cutting the secondary will induce an e.m.f. (E_s) in

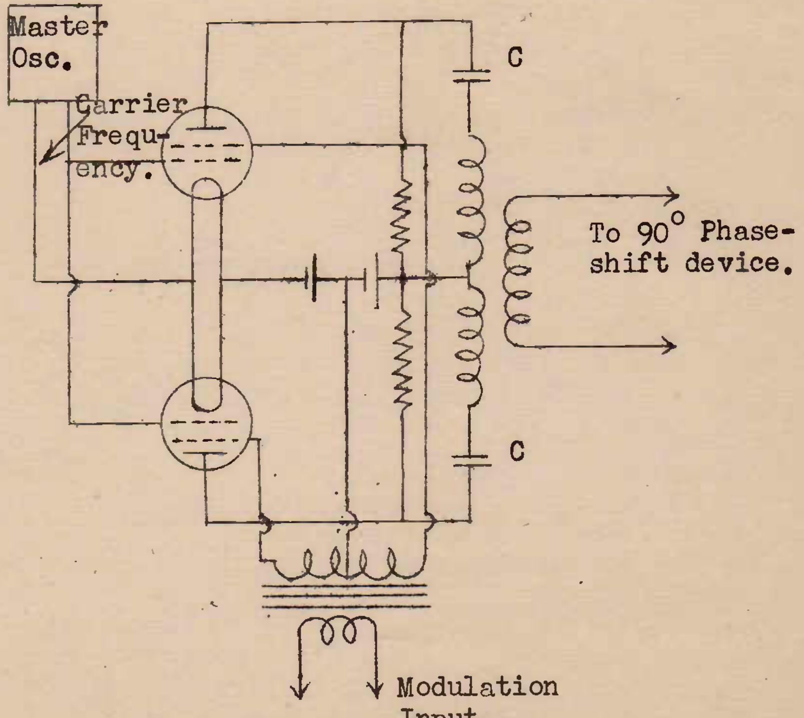


Fig. 16.

the latter. The instantaneous value of this voltage at any moment will have a value depending upon the rate of movement of the magnetic field, and therefore on the rate of change of primary current. Referring to Fig. 18, at points a and e the current, although small in value, is changing at a maximum rate. At these instants the magnetic lines of force will therefore be moving at a maximum rate across the turns of the secondary coil, and the induced e.m.f. will have a maximum value, as shown at b and f. At points c, and g on the other hand, the current is momentarily neither increasing or decreasing, the magnetic lines of force are therefore stationary and the induced e.m.f. (E_s is zero - see points d and h.

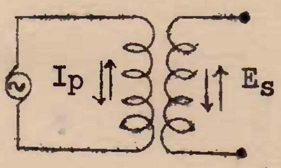


Fig. 17.

The induced e.m.f. in the secondary (E_s) will therefore be represented by the dotted curve of Fig. 18. Note that this is 90° out of phase with Ip. This phase relationship is also illustrated by the vectors of Fig. 18.

Referring back, now, to Fig. 16, the currents in the primary of the output transformer, representing the sidebands, will induce corresponding e.m.f's in the secondary, with a 90° phase-shift. These secondary voltages are then applied to the grid of the side-band amplifier, without further phase change. The side-band signals are then re-combined with the unmodulated carrier as shown in Fig. 14.

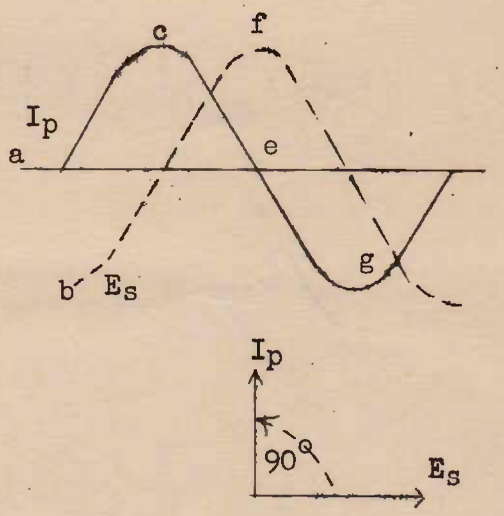


Fig. 18.

The condensers marked "C" in Fig. 16 are for the purpose of preventing any phase shift in the plate circuits of the valves. A valve's plate current will be in phase with its grid voltage only if there is no reactance due to inductance or capacity in the plate circuit. Now the inductances marked "L" in the plate circuits will tend to cause the A.C. component of plate current to lag by 90°. If we place capacities in series with the inductances in these circuits such capacities will tend to cause the current to lead by 90°. If the reactances of "C" and "L" in each circuit are equal, therefore, the two phase effects will off-set each other and the current will suffer no change in phase. In effect "L" and "C" form a series resonant circuit. The consequence of this action of the condensers "C" is that the sidebands represented by the currents in the primary of the output transformer of Fig. 16 have a phase relationship (relative to the unmodulated carrier) which corresponds to amplitude modulation. The side-band signals in passing from primary to secondary of this transformer then suffer a phase shift of 90°, and when recombined with the unmodulated carrier at "X" (Fig. 14) their phase is correct to produce frequency modulation.

FREQUENCY MULTIPLICATION.

The amount of frequency deviation obtainable with the Armstrong method in particular is quite small. The phase shift produced in the manner explained in connection with Fig. 13 must, for the reasons given, be kept small say 30°.

Now in a previous lesson it was explained how the equivalent frequency modulation produced by a certain phase shift depended upon the modulation frequency as well as the angular phase change itself. In that discussion we calculated the average frequency deviation (measured over half a cycle of modulation) by dividing the total number of cycles by which the frequency was varied by the time taken, i.e for half a cycle. It must be remembered, however, that when the frequency is swung backwards and forwards the rate of frequency change is not constant over the cycle of modulation, and therefore the average frequency change will be something less than the peak deviation (in the same way as the average value of an alternating current is less than its peak value).

A formula which will give the peak equivalent frequency deviation knowing the phase deviation, and the modulating frequency is :

$$\Delta F = \frac{\Delta A \times f}{57.3} \qquad \text{where :-}$$

ΔF = the peak value of the frequency deviation.
ΔA = the peak value of the phase modulation, measured in angular degrees.
f = modulating frequency.
(Note: the symbol Δ is the Greek letter "Delta", meaning here a small change in ...."
Thus ΔF means a small change in the carrier frequency, and represents the deviation.
Note that this formula brings out clearly the point made in an earlier lesson, viz. that for a given phase change the equivalent frequency deviation is directly proportional to modulating frequency.

Returning to the Armstrong modulator we saw that the maximum phase deviation was limited to 30°. The amount of frequency modulation produced at, say, the lowest frequency of modulation, 50 cycles per. sec. will be given by the formula above thus :

$$\Delta F = \frac{\Delta A \times f}{57.3}$$

$$\text{where} \quad \Delta A = 30^{\circ}, \quad f = 50.$$

$$\text{Therefore} \quad \Delta F = \frac{30 \times 50}{57.3} = \frac{1500}{57.3} = \text{26 cycles per sec. approx.}$$

But for wide-band F.M., we require a deviation of 75,000 cycles per sec. !

The required frequency swing is obtained by using a series of frequency doublers or triplers. These were described briefly in the lesson papers dealing with Television. A frequency multiplier, it will be remembered is simply an amplifier producing distortion (and therefore harmonics of the input frequency) and containing a resonant circuit in its plate loadtuned to one of these harmonics.

A frequency doubler will double all the frequencies applied to its grid. Hence if an F.M. signal is applied not only is the mean carrier frequency doubled, but also the frequency deviation.

In the case cited above, where we wish to increase the frequency deviation 26 cycles per sec. a total frequency multiplication of $\frac{75,000}{26}$, or nearly 3,000 times would be required. Now if straight out frequency multiplication were used, and the radiated wave were to have a frequency of, say, 93 m.c. per sec., the primary frequency at which modulation occurs would required to be $\frac{93,000,000}{3,000} = 31,000$ c. per sec. - only about double the highest audio frequency of modulation.

The difficulty is overcome by operating the primary oscillator at about 100 K.c per sec., stepping up the frequency (and deviation) by several multipliers, to, say 1,200 K.c per sec. or higher, and then reducing the frequency (without reducing the deviation) to a low value again, before using additional multipliers. This reduction in carrier frequency is achieved by heterodyning the carrier with an oscillator to produce a kind of intermediate frequency. This heterodyning action, although reducing the mean (carrier) frequency of the F.M. wave will leave the deviation (increased by multiplication) unchanged. By carrying out this process of successive multiplication and frequency "division" over and over again, the final deviation of 75 Kc per sec. may be obtained.

THE POWER AMPLIFIERS.

These are no different in general principle from those used in A.M. transmitters. There is one important point to note, however, Since the amplitude of the F.M. signal remains constant, the cmplifiers may be operated continuously at their full rated power output. In the case of an A.M. transmitter the power amplifiers must be designed to handle a peak power output 4 times that of the unmodulated carrier. On the peaks of amplitude modulation (for 100% modulation) the carrier voltage is twice the unmodulated value. This means that the power for maximum modulation amplitude is four times that for the unmodulated carrier, since power is proportional to the square of the voltage (or current). Hence the amplifiers are working at low efficiency. When F.M. is used the power amplifiers are working at saturation continually, and maximum power efficiency is obtained.

TRANSMITTING AERIALS.

As for television, operating at the ultra-high frequencies, resonant aerials, usually dipoles or "stacks" of dipoles, are used. The aerial system is designed so that very little signal is radiated sky-wards, since a sky-wave would not be reflected back to earth, but would be lost in space. The aim is to get maximum field-strength into the direct-wave. The lesson on transmitting antennas in the television section may well be referred to here.

LESSON 15 - QUESTIONS.

(1) Why would it be a comparatively simple job to redesign an F.M. transmitter for a different level of radiated power ?

(2) A resistance of 5,000 ohms is connected in series with a condenser whose reactance (at the frequency of the applied voltage) is 4,000 ohms. Draw an accurate vector diagram to find the phase angle between applied voltage (E_a) and current I.

(3) Refering to Fig. 4, draw a vector diagram showing vectors for applied voltage (E_a), current (I), voltage across R (E_r), and voltage across C (E_c).

(4) Under what conditions may an F.M. wave be considered as consisting of a carrier and a single pair of side frequencies ?

(5) What is the phase relationship between sidebands and carriers in the following cases :

a. A.M. - positive peaks of modulating voltage.
b. F.M. - positive peaks of modulating voltage.
c. A.M. - zero points of modulating voltage.
d. F.M. - zero points of modulating voltage.

Illustrate with vector diagrams.

(6) State the principle involved in converting A.M. to P.M.

(7) Why is frequency multiplication absolutely necessary in the Armstrong system of modulation ?

(8) What is the purpose of the modulating signal connection circuit in the Armstrong system ?

(9) Why is an F.M. transmitter more economical from the point of view of power consumption compared with an A.M. transmitter ?

(10) In a transmitter an F.M. signal of carrier frequency 5 m.c per sec., and deviation 10 Kc. per sec., is heterodyned with an oscillator frequency of 4 m.c per sec. (for frequency "division") what are the frequency limits of the resulting F.M. signals ?

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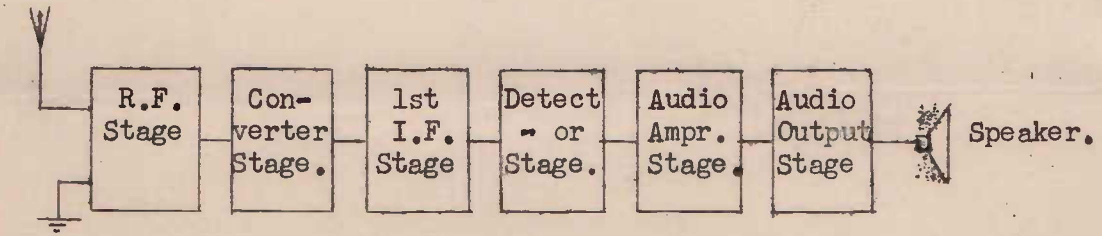
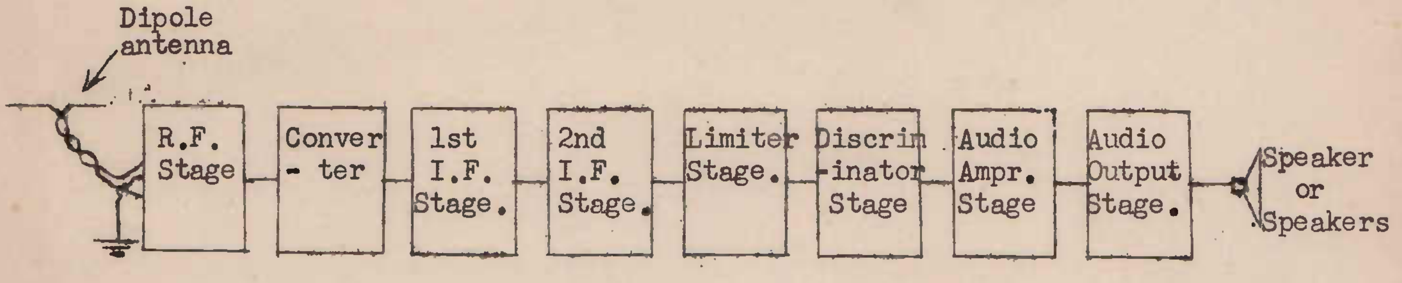
FREQUENCY MODULATION RECEIVERS.

GENERAL COMPARISON OF F.M. AND A.M. RECEIVERS.

Although F.M. and A.M. receivers are required to operate on signals which differ greatly in nature and operating characteristics there is no very great difference in the general over-all structure of these two pieces of electronic apparatus. The similarity in the sequence and functions of the various stages of the two types of receivers will be realised by a comparison of the two block diagrams of Fig.1.



A. BLOCK DIAGRAM OF TYPICAL A.M. RECEIVER.



B. BLOCK DIAGRAM OF TYPICAL F.M. RECEIVER.

Figure 1.

Here each receiver shown posses an R.F. amplifier, converter stage, I.F. amplifiers, audio amplifier and power output stage. All of these stages follow in the same order in the two types of receivers, and perform the same functions. It must be understood, however, that in order to realise the full potentialities with regard to signal-to-noise radio and fidelity (including A.F. frequency response and dynamic range) of the F.M. system the receiver must be designed to satisfy more stringent specifications than those to which we have been accustomed.

The only radical differences between the F.M. receiver and the more humble A.M. type are seen to be (Fig. 1) - the incorporation of a Limiter Stage and the use of a special type of detection, called the Discriminator Detector. The Limiter has no counterpart in the A.M. receiver, and the Discriminator is made necessary in order to convert the frequency modulation into amplitude changes before separating the audio from the radio signal in - more or less - the ordinary way. Actually a very recent development has made it possible to dispense with the Limiter stage by the use of a special type of F.M. detector known as the Ratio Detector. These points, however, will be discussed in detail in due course as we proceed.

Despite the similarities in the general lay-out of the two types of receivers, the advent of F.M. has necessitated a somewhat different approach towards the problem of receiver design. In the past we have always regarded high sensitivity and freedom from noise as desirable but antagonistic qualtities in a receiver. For example in the case of the A.M. system we have had to compromise between these two properties; an increase in sensitivity (over-all amplification), while increasing the output from a weak signal, also increases the total amount of noise. Similarly selectivity has always been a compromise between inter-channel inference and fidelity. An increase in band-width beyond 10 K.C. per sec. while improving the audio-frequency range, has invited "monkey-chatter" and other signs of interference from an adjacent channel. On the other hand, reducing the band-width to less than 10 K.C. per sec., while increasing the selectivity, and, incidentally, the signal-to-noise ratio, has cut off more of the high notes from a signal already trimmed to 5,000 cycles.

Frequency modulation lessens, or entirely eliminates, these compromises. An important characteristic of the F.M. receiver is that an increase in sensitivity not only improves the response to weak signals but actually, in general, reduces the noise level. Hence considerable sensitivity is desirable from all points of view.

Some degree of compromise between selectivity and adequate handling of the signal band is still required in the F.M. receiver. However it is a much easier job to obtain adequate selectivity without band-cutting. This advantage derives largely from the fact that providing the desired signal is more than twice as strong as the interfering signal at the detector (discriminator), interference cannot occur. The reason for this will be fully explained later in the lesson. However, if a weak signal is tuned in on a receiver having too broad a selectivity curve, it might be possible for a strong signal, operating on an adjacent channel, to take control whenever the latters frequency gets within the band-pass of the tuned circuits. Even this possibility is remote because of the line-of-sight limitation of the u.h.f. waves, coupled with the fact that it is the practice to assign adjacent channels only to stations whose service areas do not overlap. Nevertheless it is considered good design practice to attempt to obtain a fairly sharp cut-off in the receivers selectivity characteristic on either side of the pass-band of 150 K.C. per sec.

Let us now consider each section of an F.M. receiver, starting from the aerial and working through to the F.M. detector. The audio sections of the receiver, including power-output stages and loud speakers will be deferred until the next lesson. Here we shall discuss the special problems which relate to each stage or section and which arise from the use of an u.h.f. signal and the use of the new system of modulation.

Many of the principles involved in the operation of frequency converters and I.F. amplifiers are, of course, identical with those to be found in A.M. receivers, and are already well known to the student.

F.M. RECEIVER AERIALS.

In the past we have been accustomed to locating the receiver antenna anywhere it would fit, and making it of any convenient length. The lead-in has been simply a single length of wire connected to one side of the input circuit, the other side of the latter being earthed.. Such a type of aerial may be more or less satisfactory for F.M. work in certain localities where the signal field-strength is high, and man-made static is low. In general however, the tuned or resonant aerial connected by a properly matched transmission line should be used.

Actually the technique of F.M. antenna design and installation is practically identical with that for Television work. The lesson on "Antennas" in the Television section of this course should, at this stage, be re-read.

THE R. F. AMPLIFIER STAGE.

The functions performed by the R.F. stage in an F.M. receiver are for the most part similar to those in an A.M. type. The more important of these are :-

(1) To increase the receivers sensitivity.
(2) To reduce the signal-to-noise ratio.
(3) To increase selectivity.
(4) To keep r.f. signals at the I.F. frequency from entering the I.F. stages.
(5) To discriminate against the image frequency and to prevent "double-spotting".

In the case of a F.M. receiver Nos. (3), (4) and (5) of these are relatively unimportant. The r.f. tuned circuits, due to strong capacities and high r.f. losses cannot be made very selective. Again the I.F. frequency has been fixed at a value - 10.7 megacycles - which will not be used for other transmissions - hence (4) above is unimportant. Again the high valve of I.F. chosen in relation to the width of the F.M. band (88 to 108 m.c., i.e 20 m.c.) will render function (5) above unnecessary.

This leaves functions (1) and (2) as the important ones. In the case of A.M. reception these are quite separate functions. In F.M. receivers, on the other hand they are closely inter-related. As stated early in this lesson anything which increases the sensitivity before the limiter stage will improve the signal-to-noise ratio in an F.M. receiver. Since sensitivity is such an important factor in an F.M. receiver, therefore, and because of the difficulty of obtaining a high stage gain (on account of the high I.F. employed), anything which adds to the over-all amplification before detection is to be encouraged, For this reason an R.F. stage is almost invariably incorporated in an F.M. receiver, although seldom in an A.M. receiver.

The use of an R.F. stage improves the signal-to-noise ratio in another quite different way. The main source of random tube noise in any receiver - A.M. or F.M. - is in the converter. This is particularly the case when operating at u.h.f.'s. The use of an R.F. stage, before the converter, raises the signal level without amplifying the "noise" from the latter tube, and thus the signal-to-noise ratio is improved by a factor equal to the r.f. gain. The same action, of course, occurs in the case of the A.M. receiver.

Ordinary tubes with which we are familiar would be practically useless at frequencies of about 100 m.c. per sec. Special miniature tubes, having low inter-electrode capacities and high mutual conductances - 3 or 4 times normal - have been developed for F.M. receivers. With such tubes an R.F. stage gain of 5 and greater can be realised. It might also be mentioned here that a voltage gain of a similar amount may be obtained from the resonant dipole aerial. Thus a total R.F. gain, before the converter, of 25 and upwards is possible. Such a gain, for the two reasons given above, is of the greatest consequence.

THE CONVERTER STAGE.

The function of the converter stage is similar to that in A.M. receivers. It is required to convert the F.M. signal in the 88 - 108 m.c. band into the I.F. of 10.7 m.c. It is of great importance to maintain this I.F. very close to the centre of the band-pass of the I.F. transformers. Hence the oscillator associated with the converter must be made extremely stable to prevent frequency drift.

A typical converter stage is shown in schematic form in Fig. 2.

Many precautions not shown in Fig.2 are taken to prevent frequency drift. These include mechanical placement of the components, the size factor, and special design of the coils. In addition temperature compensating condensers are used. One of these is shown near the 47 ohm resistor. This resistor is placed very close to the condenser in order to warm it up very rapidly to the maximum operating temperature. Without this resistor the set might drift off the station before the temperature inside the chassis rose high enough to affect the condenser.

STATION SELECTION AND TUNING.

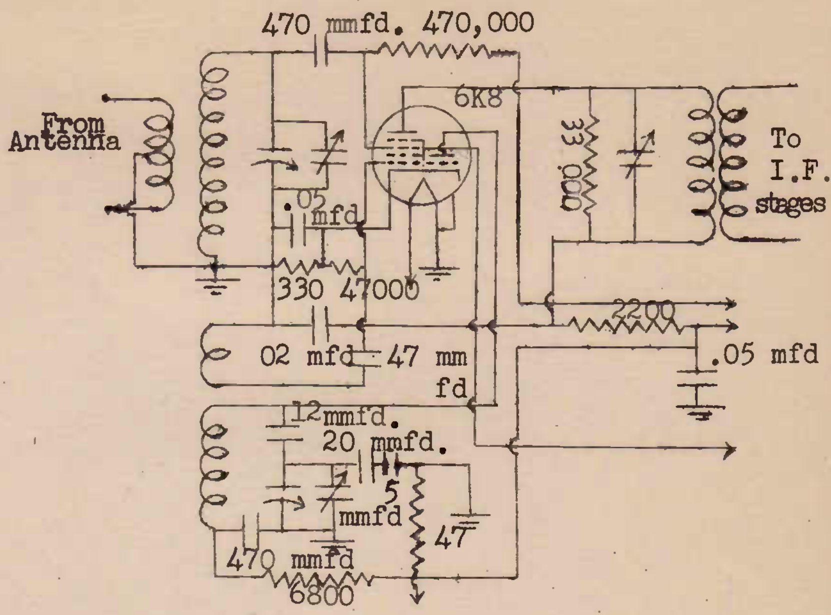
Formerly, when the 42 - 50 m.c. per sec. band was in universal use in America for F.M. it was common practice to tune over the band by the conventional ganged condenser method. With the advent of the higher 88 - 108 m.c. per sec. band this method is hardly practicable. At these frequencies the presence of small stray capacities render accurate "tracking" extremely difficult. The tendency now, therefore, is to use a separate tuned circuit for each channel together with a selector switch. The technique is similar to that described for television receivers. A fine-tuning control is provided in order to adjust each signal accurately to the centre of the I.F. channel.

CHOICE OF THE INTERMEDIATE FREQUENCY.

The choice of the I.F. for u.h.f. F.M. work is based on similar considerations to those which must be taken account of when fixing a suitable I.F. for ordinary A.M. reception.

It will be recalled that the use of the superheterodyne principle for reception may involve a number of special types of interference which are peculiar to this particular system. The main types of such interference are :-
(1) Image interference - This is interference resulting from the fact that the intermediate frequency (f_i) will be produced in the mixer by any incoming signal differing from-either above or below - the oscillator frequency (f_o) by an amount equal to f_i. For this type of interference between two stations to occur their frequencies would therefore have to differ one from the other by twice the intermediate

frequency (i.e. by $2f_i$). For example if two stations having frequencies f_1 and f_2 differing by $2f_i$ (f_2 greater than f_1, say), and the oscillator frequency (f_o) were set mid-way between these, then both signals may be heard. In this case we have $f_2 - f_o = f_i$ and $f_o - f_1 = f_i$; i.e. the I.F. (f_i), for which the receiver is designed, would be produced by either signal f_1 or f_2. If the receiver's design is such that the oscillator frequency (f_o) operates above the desired signal frequency, then f_1 would represent the desired signal, and f_2 would be an interfering undesired signal. The interference would represent the "image" of the signal frequency f_2. If, on the other hand the receiver were designed to operate with oscillator frequency (f_o) below the tuned signal, then in the case cited f_2 would be the desired signal and f_1 would produce the undesired image. In either case it will be noted that f_i must be one-half the difference between the two interfering signals i.e $f_i = 1/2\ (f_2 - f_1)$. Hence if the I.F. (f_i) is more than one half the difference between the highest and lowest frequencies in the particular band under consideration image interference cannot occur.



A TYPICAL CONVERTER STAGE. Fig. 2.

(2) Interference due to harmonics of the oscillator beating with undesired signal frequencies. For example an undesired signal frequency differing from twice the oscillator frequency (2nd harmonic) by an amount equal to the I.F. may give rise to interference. Putting this in symbols, any signal frequencies equal to $2f_o \pm f_i$, $3f_o \pm f_i$ etc. could cause trouble.

(3) Interference caused by two signal frequencies differing by an amount equal to f_i beating together in the mixer stage, and thus producing the intermediate frequency. If f_1 and f_2 denote two such signal frequencies then interference may occur if $f_2 - f_1 = f_i$.

In F.M. work, as in A.M., interference types (1) and (3) above may be reduced, or entirely eliminated, by increasing the frequency of the I.F. (f_i). It must be remembered that the receiver's r.f. tuned circuits are not adjusted to the undesired signal, and hence tend to discriminate against it before the mixer is reached. For image interference we have $f_i = \frac{1}{2}\ (f_2 - f_1)$ and for interference type (3) $f_i = f_2 - f_1$. Hence in either case increasing f_i will mean a greater frequency difference between f_2 and f_1, with the result that the undesired signal may be more effectively suppressed before frequency conversion. Of course, the additional selectivity before conversion obtained by the use of a tuned r.f. stage will, as in A.M. work, largely remove interference of all three types.

The frequency band assigned for F.M. transmission, as already stated, is 88 - 108 m.c. A comparatively high value, viz. 10.7 m.c. has been chosen for the intermediate frequency channel. This is more than one half of the total band width of 20 m.c., and hence as explained under (1) above image interference cannot occur.

The oscillator, unlike broadcast A.M. operation, is worked below the signal frequency. Hence the oscillator frequency will range from 88 - 10.7 = 77.3 m.c. to 108 - 10.7 = 97.3 mc. Interference from oscillator harmonics can hardly occur, since the lowest frequency harmonic (the second harmonic) would be 154.6 m.c., far above the frequency to which the r.f. circuits would be tuned, viz. 88 m.c. It will be noted that this type of interference can hardly occur whenever the total width of the transmission band is small compared with the carrier frequencies used. In F.M. work this band is 20 m.c. wide which is small compared with the lowest carrier frequency in the range, i.e. 88 m.c.

THE INTERMEDIATE FREQUENCY STAGES.

The I.F. stages of an F.M. receiver perform the same functions as those in A.M. receivers, viz. they should :

(1) Produce a considerable amount of amplification of the signal before detection in order to raise the former to a level sufficient for efficient operation of the detector stage.

(2) Discriminate sufficiently against all but the desired signal to avoid interference, while at the same time passing uniformly all the important side-bands of the modulated I.F. frequency.

In an F.M. receiver it is most important that the I.F. amplifiers yield a high over-all gain. If the signal level is not sufficiently high at the Limiter stage (immediately before the frequency detector) the advantages of noise suppression will be largely lost. As we shall see the Limiter does not operate until the signal strength reaches a certain minimum level at its input. Amplitude modulation, produced by "noise" voltages and other interference will pass through and produce audio frequency voltages in the final stages, thus resulting in noise in the output. Thus we have a situation which is just the opposite to that to which we have been accustomed. With A.M. the noise (not the signal-to-noise ratio) increases with receiver gain. With F.M., on the other hand, a high degree of gain before detection will result in practically noise-free reception under normal conditions.

For these reasons at least two stages of I.F. amplification are necessary. Many receivers use three stages. Although some voltage gain is obtained from the resonant dipole, and some from the r.f. stage, most of the amplification, before detection, must be produced by the I.F. stages. Working with an I.F. of 10.7 m.c. (as compared with 455 K.C. in broadcast receivers) the gain per stage tends to be low, If we were to use the same type of valves as commonly met with in A.M. broadcast sets (e.g. 6U7) the over-all gain in the I.F. section would be quite inadequate, even if using three stages. To off-set the increased r.f. losses associated with amplification at higher frequencies, valves having very high values of mutual conductance (at least 2 or 3 times normal) and low valves of inter-electrode capacities are used. From the point of view of gain the problems of the I.F. stages are similar to those discussed for the same stages in a television receiver. The r.f. pentode 6AC7 (1852), having a Gm of 9,200 μA. / volt (discussed in the television section) has proved very satisfactory for I.F. F.M. amplification. The latest tendency is to develop miniature type tubes having large values of Gm. One such tube is the

6BA6, which is used for both r.f. and I.F. amplification. Typical tubes, and their characteristics, for all stages of an F.M. receiver will be discussed in a later lesson.

COMPARISON OF I.F. BAND-PASS REQUIREMENTS FOR F.M. A.M. AND TELEVISION.

The band-width of a wide-band F.M. signal (deviation = 75 K.c per sec.) is taken as 150 K.c. per sec. This is very much wider than that for the ordinary A.M. signal which is, as transmitted, certainly no wider than 20 K.c. per sec. Actually the I.F. transformers of an average broadcast set pass a band of only about 10 K.c. per sec. or even less. Thus we see that the I.F. stages of an F.M. receiver must be designed to pass a band of frequencies 15 to 20 times as wide as is required for A.M. At the same time it should be realised that the band-width of an F.M. signal is not nearly as wide as that used in television. Here the picture I.F. amplifiers are required to pass a modulated signal having side-bands covering a range of anything up to 4 m.c. per sec. Now we have seen in the Television Lessons that it is possible to design I.F. stages, operating in the vicinity of 10 m.c. per sec. to pass this very wide band. The job, however, usually requires the design of very complicated circuits for inter-stage coupling, filter-circuit theory usually being resorted to. By comparison, therefore, it appears that it should not be very difficult to obtain a flat-topped I.F. curve, operating at 10.7 m.c per sec. to cover a band of only 150 K.c per sec. as required for F.M. The I.F. transformers have the same general form as those to which we are accustomed, i.e. they usually have both primary and secondary windings tuned. Two common methods of obtaining the necessary band-pass are in use : (1) over-coupling the primary and secondary, which tends to give the double-peak effect, and (2) use of damping resistors across the coils. Both methods are generally used concurrently. A typical I.F. curve is shown in Fig. 3. This gives the output voltage of the last I.F. stage for different frequencies above (shown as positive frequencies), and below, (shown as negative frequencies), the centre carrier frequency. Note the slight double-hump effect due to over-coupling. A narrow-band A.M. signal is shown, for comparison purposes, on the graph.

EFFECT OF INADEQUARE BAND-PASS.

In A.M. work the effect of too narrow a band-pass in the I.F. stages is to cut the higher side-frequencies resulting in a loss in the higher audio frequencies. The result is a loss of fidelity.

In an F.M. receiver, however, a somewhat different action occurs. When receiving an F.M. signal the full band-width of the channel is only used on the loudest sounds, for only then the frequency of the r.f. wave is deviated the full 75 K .c per sec on either side. Weaker sounds, irrespective of their audio frequency will result in smaller deviations, and sidebands which do not extend over the whole 150 K.c. per sec. band. Hence the effect of band-

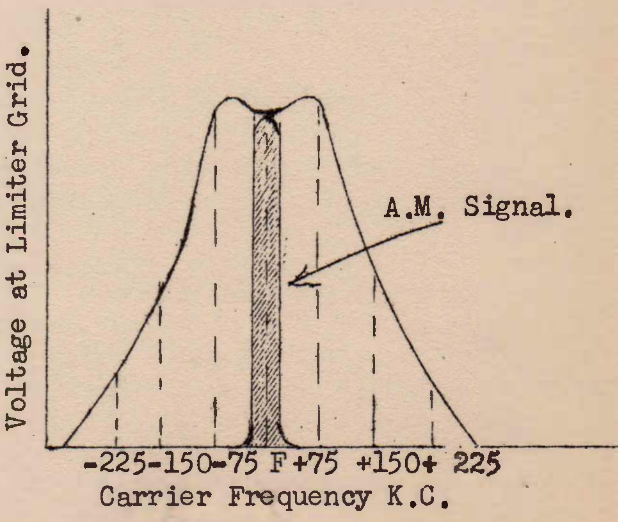


Figure 3.

cutting will be to "clip-off" the loud peaks of the sound signal, causing distortion. The effect would be somewhat similar to that occurring in the reception of an A.M. signal when using an overloaded valve.

PRACTICAL I. F. CIRCUITS.

Partial schematics of two commercial I.F. amplifiers are shown in Figs 4 & 5.

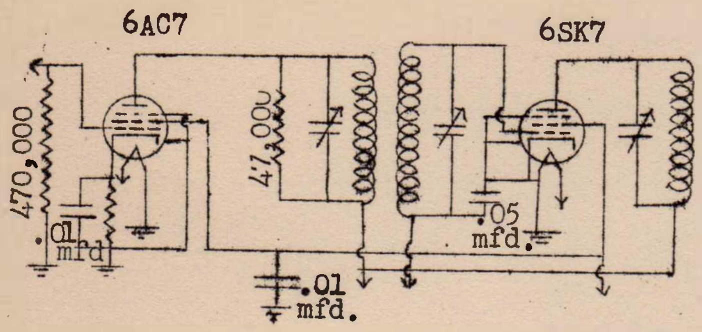


Figure 4.

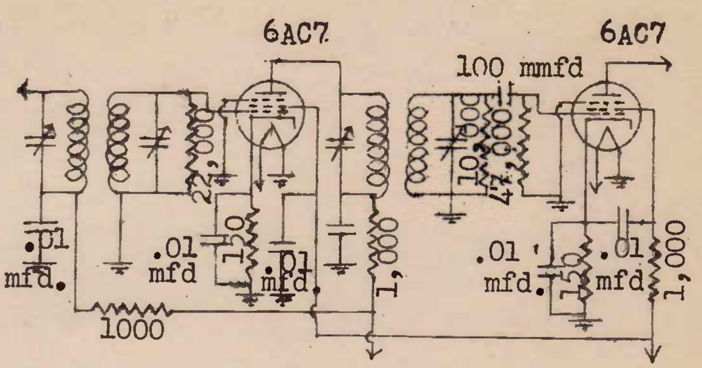


Figure 5.

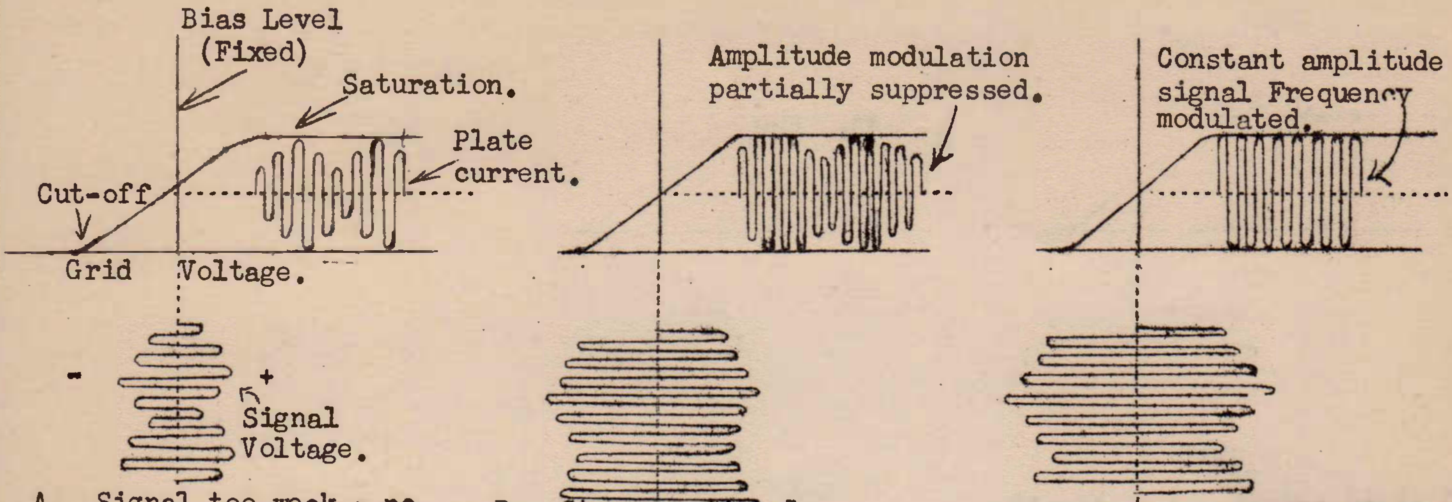
THE LIMITER STAGE.

So far we have been discussing circuits which have almost exact counterparts in A.M. receivers. The limiter is the first radical departure from conventional practice. Most of us have learned from experience that an overloaded amplifier is a prolific source of distortion in A.M. receivers. This is quite natural, since our object in the A.M. receiver is to provide an exact replica of all amplitude changes of the carrier, and anything which tends to suppress these changes will distort the signal.

This distortion does not affect the final result in F.M. work, provided it occurs before detection. Its only effect will be to cause harmonics of the I.F. signal. Since the lowest of these harmonic frequencies (i.e. the second harmonic) will be double the I.F., a tuned circuit (or low-pass filter) may be used in the plate circuit of the limiter to remove them.

The limiter is simply an amplifier which is normally operated in a completely overloaded condition. Now the output of an F.M. receiver is supposed to depend upon frequency deviations or changes only. Any changes in the amplitude of the r.f. (or I.F.) voltage reaching the discriminator detector will yield changes in the A.F. output. Such changes we have seen, are due to interfering "noise" or possibly an undesired carrier heterodyning with the desired signal. The limiter, since it operates in a very overloaded condition, has a constant output, provided that the amplitude changes due to interference are not too great.

The simplest type of limiter is a valve having a sharp cut-off (e.g. 6J7, 6AC7, 6SJ7) operated with low values of screen and plate voltage and a fixed bias. The plate characteristic of such an amplifier is shown in Fig. 6 . At "A" we have a very weak I.F. voltage at the limiter grid. This signal is amplitude modulated due to noise. Note that operation is entirely upon the straight part of the characteristic and the plate current output is a replica of the input. No limiting action occurs, and the undesired amplitude modulation remains. With such operation the full noise



A. Signal too weak - no <u>limiter action.</u>

B. Stronger Signal <u>Partial Limiter Action.</u>

C. Adequate signal. Limiter <u>action complete.</u>

Figure 6 - showing plate characteristic of limiter valve and limiter action on three signals of different strengths at limiter grid.

suppression characteristics of F.M. would not be realised. At "B" we have a somewhat stronger signal (due, for example, to more r.f. and I.F. amplification in the receiver). On the larger positive peaks of the r.f. voltage, plate current saturation is reached. Similarly on the larger negative r.f. peaks plate current cut-off occurs. The result is that portions of these larger peaks will be lopped off, resulting in <u>some</u> amplitude limitation. The smaller r.f. peaks, however, are not sufficiently large either to cause saturation or cut-off. The output from the limiter stage therefore contains some amplitude modulation, and reception will not be as quiet as it should be. At "C" the signal on the limiter grid is of sufficient amplitude to cause plate current saturation and cut-off for all cycles of the r.f. The result is an output current of constant amplitude. All amplitude modulation due to noise has been suppressed.

Note carefully that any frequency variations due to modulation in the input signal will appear unaltered in the limiter's output. These frequency variations represent, remember, the desired audio signal, which is "recovered" from the modulated wave by the discriminator.

The output from the limiter (Fig. 6 (c)) has the r.f. cycles flat-topped. This amounts to severe distortion of the r.f., but as remarked earlier the only effect is to generate harmonics of the r.f. (actually the I.F). These harmonics can be easily removed by a tuned circuit. Hence the signal passed to the discriminator will be a pure sine wave of constant amplitude and varying around the I.F. centre frequency with the frequency modulation.

The importance of having sufficient r.f. and I.F. amplification in order to bring the weakest signal to be received up to a level necessary to ensure complete limiter action, should now be obvious.

PRACTICAL LIMITER CIRCUITS.

Although the plate-current saturation method was used to explain limiter action, the more usual type of limiter is that depending on what is known as grid limiting. This is simply a sharp-cut-off tube operating with the grid-leak type of bias. Screen and plate voltages are usually lower than normal in order to reduce the negative grid voltage required for cut-off, and to avoid excessive plate current when no signal is being received.

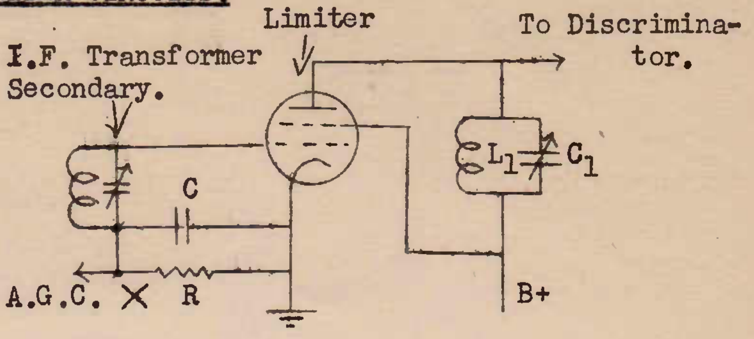


Figure 7.

A circuit diagram of a grid limiting stage is shown in Fig. 7. The grid leak and condenser are "R" and "C" respectively. L_1 C_1 is a circuit tuned to 10.7 M.c, (the I.F.). This has a high impedance to the I.F. and passes it on to the discriminator. To the higher frequency harmonics, produced by the limiter distorting the individual r.f. cycles, however, it acts as a short-circuit. In this way such harmonic frequencies are eliminated.

The grid action of this circuit is very similar to that of a grid-leak detector, with which the student is already familiar. Briefly, the grid bias potential is initially zero. On the arrival of the first positive peak of the I.F. signal the grid is momenterily driven positive, and grid current flows, charging the condenser "C" (left-hand plate negative). After several cycles "C" is changed to a value almost equal to the amplitude of the r.f. signal. This value then represents the negative bias developed, as shown in Fig. 8. The resistor "R" allows the charge on "C" to leak off only slowly - but sufficiently quickly to allow the average grid bias to change with any amplitude variations of the r.f. signal. The net effect, as will be observed from the diagram is that the positive peaks of the signal voltage are held practically at a constant level (a little positive in respect to the cathode). The changes in amplitude of the negative peaks are doubled as a result. But the plate and screen voltages are such that these negative peaks <u>all</u> fall below the cut-off voltage. The plate current will therefore be as shown in Fig. 8. All (or practically all) amplitude modulation has been suppressed. Frequency modulation will remain.

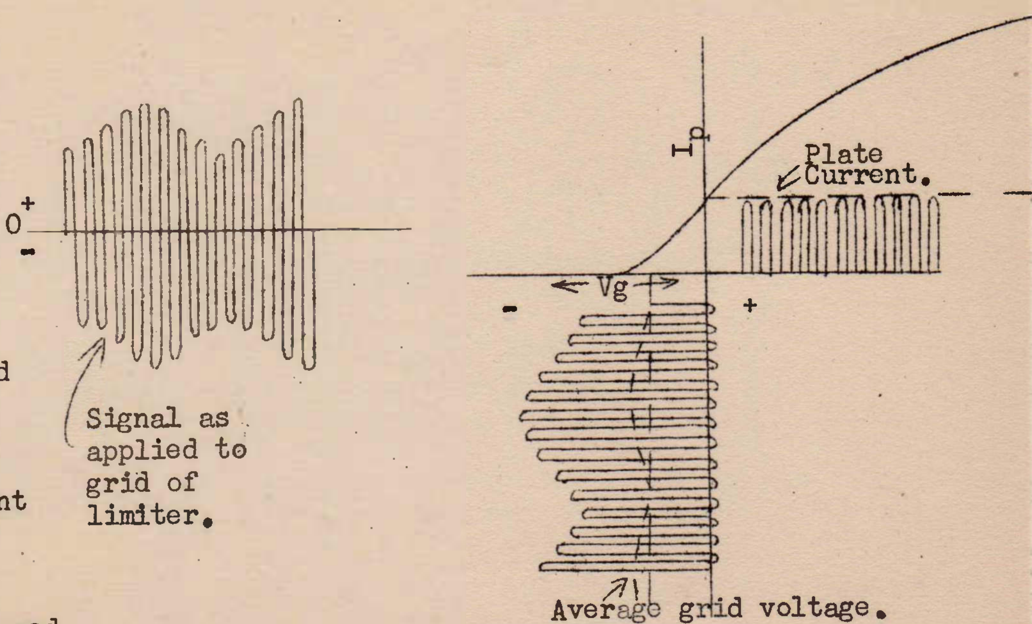


Figure 8.

For limiting action to be complete, as shown in Fig. 6C, it will be necessary, of course, to raise the signal strength to a certain minimum value before it arrives at the limiter grid.

EFFECT OF LIMITER ON GAIN.

On account of the low values of screen voltage required for proper limiting action, the limiter stage rarely produces any appreciable gain; in fact there is often a loss of signal strength involved. Some engineers strongly advocate the use of two limiters in cascade, as this improves the overall amplitude limiting action, especially on "transients" i.e. large amplitude pulses of very short duration. In this case a total gain of about 3 to 5 may be realised. Of course with the development of improved tubes for this particular job greater gains may eventually be possible.

AUTOMATIC GAIN CONTROL.

Automatic gain control, equivalent to A.V.C. in an A.M. receiver, is usually incorporated in an F.M. set. The conditions in the two types of receivers, however, are quite different. It must be remembered that the signal strength obtained from the I.F. section of an F.M. receiver and applied to the frequency discriminator is determined solely by the threshold level of the limiter's output - providing of course we consider only signals which operate the limiter normally. Any variation in the gain of the receiver before the limiter will not affect the output volume, provided that such gain is not reduced so far as to reduce the signal strength at the limiter grid below the threshold level.

What then is the reason for using automatic gain control ? The reason is to prevent overloading of the I.F. valves on very strong signals. Such overloading, of course, would not cause distortion in the same way as in an A.M. receiver, since the effect is simply one of amplitude limitation, which does not affect the frequency modulation. However if a strong signal carries the grids of the I.F. valves positive on the positive peaks, grid current would flow. This means that the input circuits of the valves would act like a comparatively low resistance. Such a resistance effect would appear as a small shunt resistance across the previous tuned circuit. This would cause additional damping of that circuit, resulting in a broadening of its frequency characteristic on strong signals.

The grid type limiter is particularly suitable for A.G.C. Referring back to Fig. 7 the grid circuit of the limiter really acts like a diode detector, "R" acting as the diode load. The average voltage (negative) at the point X will increase with signal amplitude. This voltage is applied back to the I.F. valves' grid as in conventional practice.

DETECTION OF F.M. SIGNALS.

We now consider the problem of converting frequency changes back to amplitude changes so that they may operate the speaker.

THE DISCRIMINATOR

An F.M. "detector" which has proved very satisfactory is that known as the Discriminator (for it is capable of discriminating between frequency variations).

A typical circuit is shown in Fig. 9. The input transformer (to which the signal is applied from the limiter) is the same as the other I.F. transformers except that its secondary has a centre top. A pair of diodes are used, these usually being contained in the same tube.

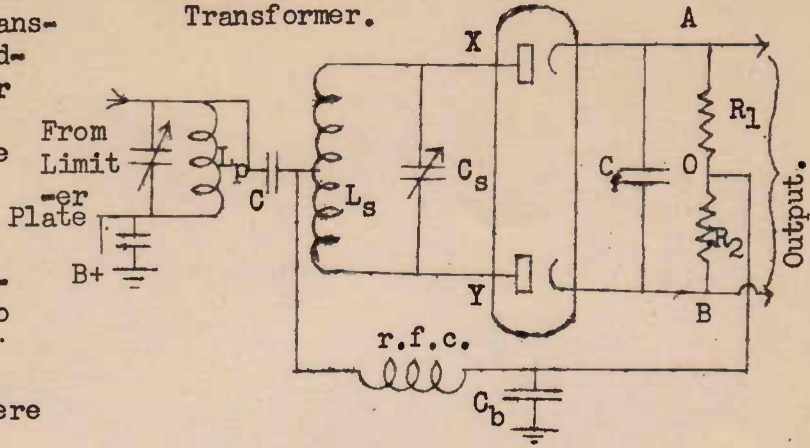
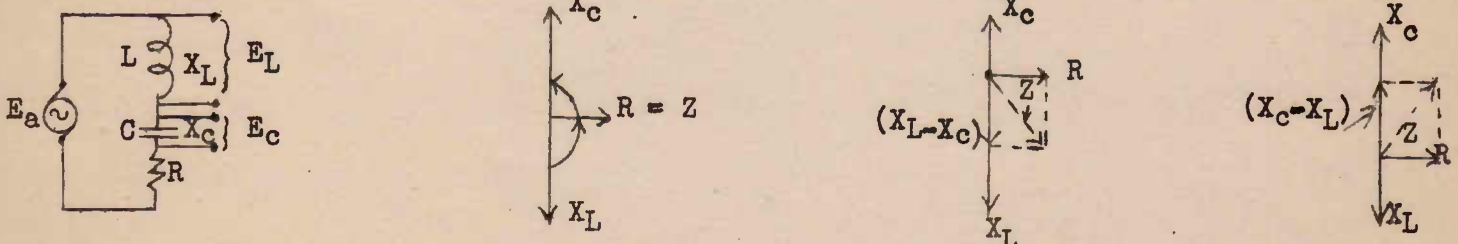


Figure 9.

The signal voltage is applied from the primary of the transformer to the secondary in two separate ways: in addition to the usual electro-magnetic coupling between the coils there is the coupling to the centre tap via the condenser "C". The reactance of the latter condenser is very small at 10.7 M.c, and hence there is practically no voltage drop across it. It thus appears that the r.f. voltage applied to each diode plate may be regarded as the net result of two separate voltages transferred from L_p to L_s (Fig. 9). In order to understand the operation of the discriminator we must consider the effect of each of these secondary voltages on each of the diode plates.

The tuned circuit L_s C_s is adjusted to resonance with the centre frequency of the carrier, viz. 10.7 M.c. At this point we must digress a little to explain the phase relationships and impedance effects which exist in a series tuned circuit at and near resonance. Consider Fig. 10A where we have an inductance, capacity and small resistance, together with a source of small A.C. voltage, in series. In the lesson on "Transmitters" it was explained how, in a series circuit, the reactances and resistances may be represented by vectors in order to obtain the total impedance. It was pointed out there that an inductive reactance vector is shown lagging the resistive vector by 90°, while a capacitive vector is shown leading the resistive vector by 90°. The lengths of the vectors are in all cases, of course, proportional to the reactances or resistances.



"A"

At Resonance.
"B"

Applied Frequency Above Resonant Freq.
"C"

Applied Freq. Below Resonant Freq. "D"

Figure 10.

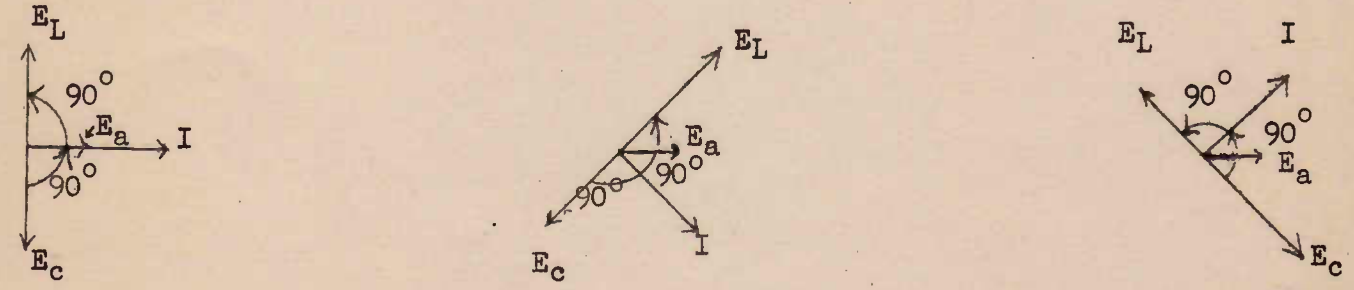
At B in Fig. 10 the vector diagram for the resonant condition is shown. At resonance $X_C = X_L$, and since these two vectors are 180° out-of-phase (exactly opposing) they will cancel. This leaves R as the only impedance in the circuit, i. e. Z = R, and the circuit is purely resistive. Current and applied voltage will be in phase. Also, since R is normally small compared with X_c or X_L, the "circulating" current flowing will be large.

Suppose now that the frequency of the generator in Fig. 10A is increased above the resonant frequency $X_L = 2\pi fL$ will be greater than before. $X_c = \frac{1}{2\pi fc}$ on the other hand, will be reduced in value. The new vector diagram is at C. (Fig. 10). X_L and X_c are still 180° out-of-phase, but they are no longer equal. Their vector sum is now $(X_L - X_c)$ in the direction of the larger, X_L. In other words the circuit now shows an inductive, as well as a resistive effect. The resultant Z lags on R by an angle less than 90°. This means that the current will lag the voltage by the same angle. Again suppose that the frequency of the generator is reduced below resonance. X_c will now be greater than X_L. The resultant of X_L, X_c and R, viz. Z, now leads R by an angle less than 90°. The circuit is capacitive, and I leads E. (See Fig.10D)

Now let us consider the phase relationships between the voltages across the three components of the circuit and the current at resonance, above resonance and below resonance. There is only one current, I, in the circuit of Fig. 10 A, but we may consider a number of voltages. We shall represent the applied voltage by E_a, the voltage drop across L by E_L, and that across C by E_c (see Figure 11 A).

Now consider the voltage drop across L. The current through L must lag the voltage across it by 90°, (since it possesses inductive reactance only). In other words the voltage drop across L must <u>lead</u> the current by 90°. Now the current through L is the total circuit current represented by I in Fig. 11 A. Therefore the voltage drop across L (E_L) will lead I by 90°, as shown at A. By a similar argument the voltage drop across C (E_c) will lag I by 90°. Note that both E_L and E_c are 90° out of phase with the applied voltage E_a. Care should be taken at this point not to confuse the vector diagrams for impedances (Fig. 10) and voltages and current (Fig.11).

Above resonance the current (I) lags E_a by some angle, as was shown in connection with Fig. 10 C. This phase relationship between E_a and I is now shown at Fig. 11 B. The



A. At Resonance. B. Frequency Above Resonance. C. Frequency Below Resonance.

Figure 11.

voltage across L must still <u>lead</u> I by 90°. Similarly the voltage across C must still <u>lag</u> I by 90°. These vectors are also shown at Fig. 11 B. Note now that E_L leads E_a by an angle less than 90°, and E_c lags E_a by an angle greater than 90°.

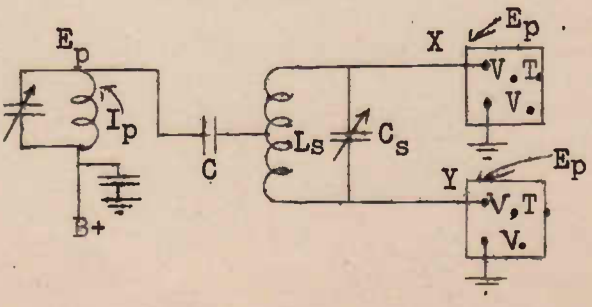
The case for the frequency, below resonance is shown at C, Fig. 11. Here I leads E_a by an angle less than 90° (circuit capacitive). E_L and E_c respectively lead and lag I by angles equal to 90°.

Note that both voltages, across L and C may be <u>much larger than the applied voltage</u> (E_a). This explains how a series tuned circuit can produce a voltage magnification or gain. Note also, the all-important point that the phase angles of E_L and E_c depend upon the <u>amount</u> by which the applied frequency differs from the resonant frequency, when the applied frequency is above the resonant frequency of the circuit, the phases of E_L and E_c are retarded; conversely when the applied frequency falls below the resonant frequency these vectors are advanced in phase, the size of the phase angles again depending upon the extent of the frequency deviation.

ACTION OF THE DISCRIMINATOR AT RESONANCE.

We shall now return to the circuit of Fig. 9. Let us first of all consider the primary voltage (E_p) applied through the condenser C to the centre tap of the secondary. Due to this coupling E_p will appear on each diode plate. This may be seen by referring to Fig. 12 where we have replaced the diodes by vacuum tube voltmeters. At the same time we have imagined that the primary of the transformer has been moved away from the secondary so that no <u>magnetic</u> coupling exists between then. Under these conditions the only transfer of primary voltage (E_p) will be via condenser C. The reason why the full <u>value</u> of E_p appears at X and Y, (Fig. 12) is that there is no flow of A.C. current through L_s, because vacuum tube voltmeters act as open circuits. As a result there will be <u>no</u> A.C. voltage drop across each half of L_s. In the actual circuit (Fig. 9) the resistors R_1 and R_2 are very large compared with the reactance of each half of L_s and the r.f. current between the centre tap of L_s and earth (via condenser C_b) will be negligible. Hence <u>practically</u> the full value of E_p will be applied to each diode plate. Note also, that this transfer of E_p to each diode occurs <u>without</u> change in phase, since negligible current flows.

The important point here is that E_p, which is applied through C to the centre tap is measured with respect to earth, and therefore has <u>no</u> tendency to cause a circulating current to flow around the tuned circuit L_s C_s. In addition to the primary voltage transfer via condenser C, there is, of course, a transfer on account of the induced voltage (E_i) in the secondary. This induced voltage (E_i) will normally be only a



<u>Figure 12.</u>

small fraction of the total primary voltage (E_p), since the coupling between primary and secondary is loose. Although small, however, E_i will at, or near, resonance cause quite a large current to flow around the tuned circuit L_s C_s, and this current will in turn develop a voltage drop (r.f.) across the coil which may be many times as large as E_i. Hence on each diode plate we may imagine that the total r.f. voltage is the vector sum of 2 voltages - one due to condenser C, the other due to the normal transformer action.

DISCRIMINATOR ACTION WHEN SIGNAL IS AT CENTRE FREQUENCY.

First consider the case when the incoming wave is modulated, i.e. the I.F. frequency is at its centre value to which the secondary circuit of the transformer is tuned. We shall start from the current flowing in the primary coil of the transformer (I_p). The voltage across this coil (E_p) will lead I_p by 90°. This phase relationship is shown in Fig. 13 in both sine-wave and vector form. Now I_p in the transformer primary will induce a comparatively small voltage (E_i) in the secondary, such that the induced voltage E_i lags the primary current (I_p) causing it. (Note: in a previous lesson we explained how an induced voltage lags the current causing it. At that stage we were considering the voltage induced in a coil by a current flowing in the same coil. Here we are considering a voltage induced in a secondary coil by a current flowing in the primary. The result will be the same, however, since the same magnetic field produces both induced e.m.f's). The induced voltage E_i in the secondary is shown lagging I_p in Fig. 13. This induced voltage E_i in L_s (Fig. 9) may be considered as a small generator placed in series with L_s and C_s as shown in Fig. 14. Since a resonant condition exists a comparatively large current (I_s) will be set up, circulating around the tuned circuit, which, at resonance acts like a pure resistance. Hence I_s will be in phase with E_i. (Refer back to Fig. 11, if necessary). I_s is also shown in sine-wave and vector form in Fig. 13. Now this current, flowing through L_s will cause a voltage drop (r.f.), E_s across L_s, the voltage across the coil leading the current by 90° (this was explained in connection with Fig. 11). E_s leading I_s by 90° and therefore lagging E_p by 90° is also included in Fig. 13. The student should be careful to distinguish between the small voltage induced from the primary (E_i) into the secondary, and the much larger voltage drop (E_s) developed across the latter by the resonant current (I_s). (See Fig. 14).

Now the voltage E_s across the secondary is applied to the diode plates, together with E_p, which was transferred, without change in magnitude or phase via the condenser C of Fig. 9. Each diode plate, however, only receives one half of E_s, because of the centre-tapping of the coil. The phase of E_s shown in Fig. 13 was that which exists if we were measuring the voltage at the upper end of the secondary in respect to the

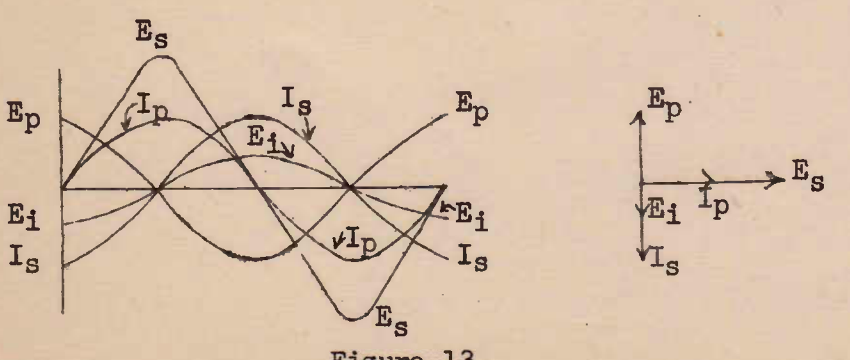


Figure 13

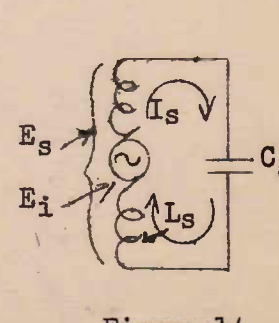


Figure 14.

primary. This is so because the primary voltage (E_p) as represented in the diagram was assumed to be measured from its upper end, in respect to its lower. Now if we viewed the voltage at the upper end of the secondary with respect to its centre-tap (call it E_{s1}), this voltage will be only half of E_s, but will be in phase with E_s; i.e $E_{s1} = \frac{1}{2} E_s$. This (E_{s1}) is the voltage applied to the plate of the upper diode, together with the voltage E_p. Considering now the lower diode, in addition to E_p we have the voltage developed across the lower half of the secondary (Fig. 9) applied to it. Call this latter voltage E_{s2}. E_{s2} will also be one half of the total E_s, and it will be 180° out of phase with E_{s1} or E_s. The reason for this is that we are now measuring the voltage from the lower end of the secondary with respect to the centre tap, whereas E_{s1} was measured from the upper end. (Remember that when the voltage at one end of a coil is going, say, positive, with respect to the centre tap, that at the other end of it is going negative, (i.e. the voltages at the two ends are 180° out of phase).

Figure 15 shows the two voltages on the two diode plates; E_p and E_{s1} in the case of the upper diode, and E_p and E_{s2} in the case of the lower diode. These are added vectorially as shown in Fig. 15. Note that the resultant voltages on the two diodes are equal in amplitude.

These voltages on the diode plates, remember, are alternating r.f. voltages. Each diode will rectify the voltage applied to it in the usual way. The rectified currents of the two diodes will flow in opposite directions through the respective load resistors R_1 and R_2 of Fig. 9. These rectified currents will be equal, since the r.f voltages on the two diode plates are equal and the resistors R_1 and R_2 are equal. Therefore the voltages developed across R_1 and R_2 will be equal and opposite, and the total voltage measured between A and B (Fig. 9) will be zero. This is the discriminator's output when the carrier frequency is at it centre value.

DISCRIMINATOR ACTION WHEN SIGNAL IS ABOVE CENTRE FREQUENCY.

Consider now what happens where, due to modulation, the carrier (and therefore the I.F.) frequency rises above its centre value. I_p, E_p, and E_i will have the same phase relationships as before, and as shown in Fig. 13. The secondary current, however will no longer be in phase with the induced voltage E_i causing it, because the series tuned circuit L_s, C_s of Fig. 9 now is no longer at resonance. Since the frequency is above resonance this circuit now presents an inductive reactance to the current, as was explained in connection with Fig. 10 earlier. As a result the secondary current (I_s) will lag the voltage E_i by some angle (see also Fig. 11). The angle of lag will depend upon how much off resonance is the frequency, i.e. upon the frequency deviation due to modulation.

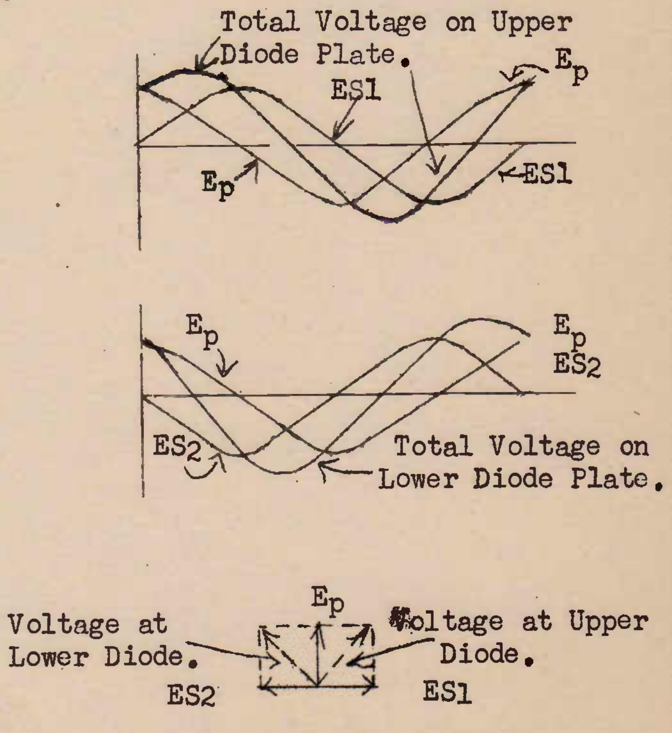


Figure 15

The vector diagram of Fig. 16 shows the new conditions. Here I_s is lagging E_i by about 45°. The voltage across the secondary (E_s) will still lead the current through it (I_s) by 90°, as shown. This diagram should be compared with that of Fig. 13. The voltage across the upper-half of the secondary (E_{s1}) is still in phase with the total voltage (E_s) across it, and the voltage across the lower half E_{s2} (shown dotted in Fig. 16) is 180° out of phase with E_s as before. The separate voltages at the upper diode (E_p and E_{s1}) and at the lower diode (E_p and E_{s2}) together with their resultants are shown on the combined vector diagram of Fig. 17. Note now that the resultant r.f. voltage at the lower diode plate is greater than that at the upper diode plate. Consequently, the rectified D.C. current through resistor R_2 will be greater than that through R_1 (Fig. 9). This means that the voltage drop across R_2 will be greater than that across R_1, and therefore the total voltage across the output ($R_1 + R_2$), which is the difference between these, will no longer be zero. Point A in Fig. 9 will be more negative than point B. Since point A usually connects to the grid of the first audio tube, we may say that the output is negative in this case.

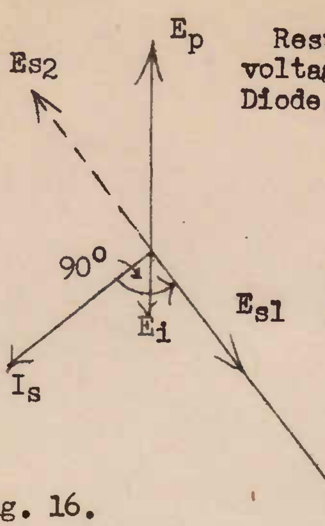


Fig. 16.

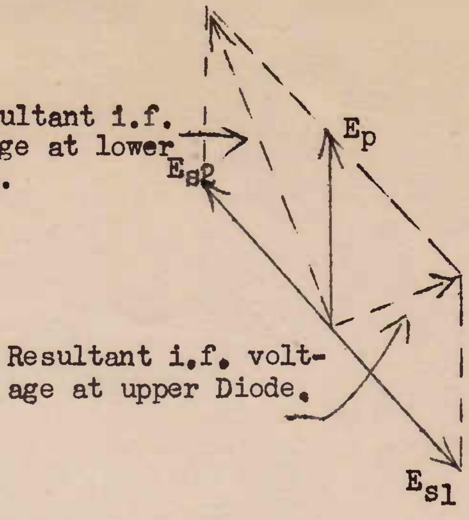


Fig. 17.

It should be noted, at this stage, that the value of the output voltage will depend upon the amount of frequency deviation of the signal. A bigger deviation from the resonant frequency than that considered will result in a greater lag in I_s compared with E_i in Fig. 16. This will increase further the resultant r.f. voltage on the second diode plate, and reduce that on the first diode plate. The net output (rectified) voltage will thus be larger.

DISCRIMINATOR ACTION WHEN SIGNAL IS BELOW CENTRE FREQUENCY.

When, due to modulation the I.F. frequency falls below the resonant point, the discriminator's tuned circuit will become capacitive. (Refer back to Fig. 10D). As a result the secondary current (I_s) will lead the induced voltage causing it, with a consequent readjustment to the phase of the vectors E_s, E_{s1}, and E_{s2}, as shown in Fig. 18. The resultant r.f. voltages on the diode plates are now as represented in Fig. 19. The upper diode will now deliver the larger rectified current, i.e. the current through R_1 will be larger than that through R_2, and point A will become positive with respect to B (Fig. 9).

Thus we see that as the frequency swings above and below the centre value, due to modulation, the discriminator develops an alternating voltage across its load. The frequency of this output voltage will be identical with that of the rate of frequency swing, i.e it will be the audio frequency.

A typical discriminator characteristic, showing how the output voltage will vary with frequency deviations, above and below the centre frequency, is shown in Fig. 20.

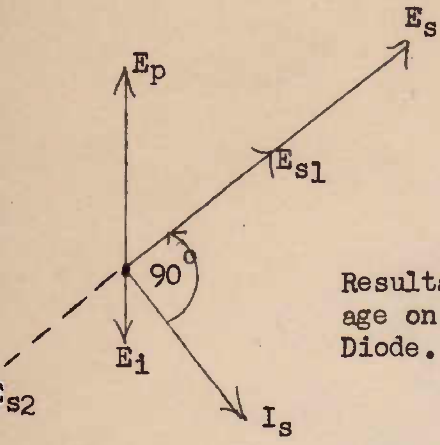


Figure. 18.

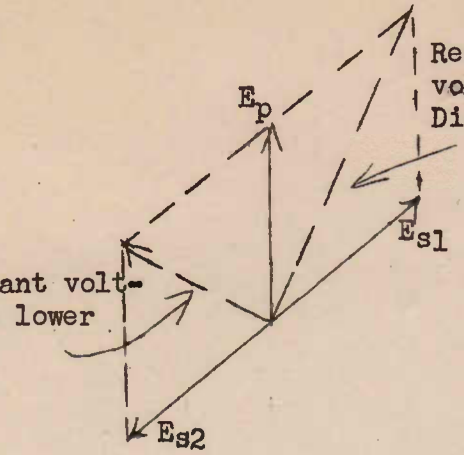


Figure 19.

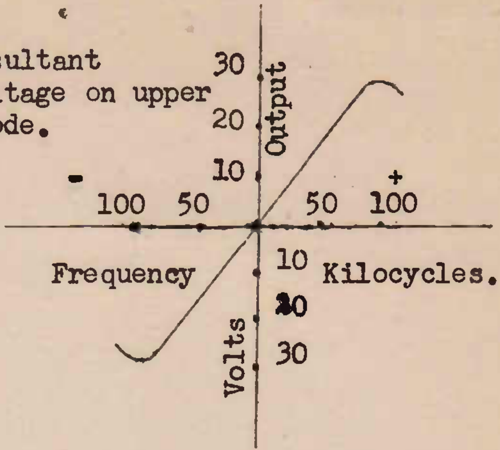


Figure 20.

HOW THE DISCRIMINATOR WILL RESPOND TO AMPLITUDE VARIATIONS.

The output voltage of the discriminator is really the difference between the rectified voltage outputs of the diodes - these latter voltages being developed across the resistors R_1 and R_2 of Fig. 9. When the carrier (I.F.) is at the centre frequency of the discriminator tuned circuit the r.f. voltages on the diode plates are equal, and consequently the rectified (D.C.) voltages across R_1 and R_2 are equal. Under these conditions the total output developed across $R_1 + R_2$ must be zero, irrespective of the carrier amplitude. Hence variations in r.f. amplitude (due to noise) occurring when the carrier is at its centre frequency cannot cause variations in discriminator output. But under actual conditions of reception the carrier frequency is at the centre frequency for only a very small fraction of the total time. Amplitude modulation occurring where the carrier is deviated from its centre value will result in changes in the discriminator output. For this reason we have stated that it is necessary to precede the discriminator stage by one or more stages of amplitude limiting, otherwise the receiver will display very little, if any, superiority over the conventional type from the point of view of noise suppression.

To see how variations in amplitude of the I.F. carrier affect the output consider the following example. Suppose that the undeviated carrier results in a d.c. voltage of 10V across each diode load. The total output will be zero since these voltages are equal and opposite. Then if the carrier deviates in such a way that the r.f. voltage applied to the first diode increases, and that applied to the second diode decreases, the rectified voltage across the first diode resistor may increase to 15V while that across the other resistor decreases to 5V. The output will now be 15V - 5V = 10V.

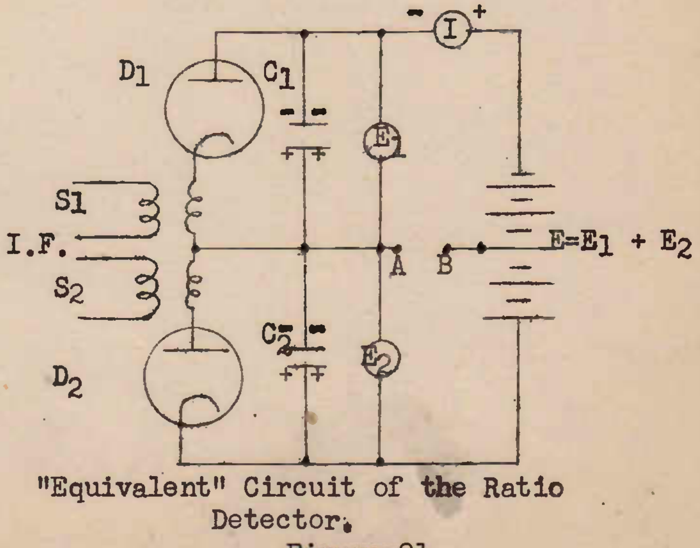
Now take another case. Suppose the carrier becomes stronger, so that under zero-deviation conditions the voltage across each diode load resistor is 20V. The same frequency deviation as in the first case will increase the first diode's output to 30V and decrease that of the second diode to 10V. The net output will now be 30V - 10V = 20V. Thus an increase of carrier amplitude will double the discriminator output for the same frequency deviation. In other words the discriminator is sensitive to amplitude changes as well as to frequency changes. If an F.M. detector could be made unresponsive to amplitude changes the full benefits of F.M. could be obtained without the necessity for limiting and the large amount of r.f. and i.f. gain required for normal limiter action.

THE RATIO DETECTOR.

This is a practical detector having the desired characteristics mentioned above. It is based on the idea of having the detector's output voltage proportional only to the ratio of the two r.f. voltages applied to the separate diodes, and not to the difference of these voltages as in the conventional discriminator. The separate r.f. voltages applied to the diodes are developed from the F.M. carrier as was explained in connection with Figs. 15, 16, 17, 18 and 19 earlier in the lesson. A little thought will show that if the carrier amplitude is changed all the voltages represented by the vectors of these diagrams will change in the same proportion. Hence the ratio S1/S2 (say) of the r.f. voltages on the diodes will remain constant with changes in carrier amplitude. Changes in carrier frequency (due to F.M), however, will alter the ratio S1/S2. In the examples quoted above this ratio increased from 1/1 with no frequency deviation to 3/1 with frequency deviation in one direction. Note that the ratio was the same in the two examples - 15/5 in the first case, and 30/10 in the second - although the differing amplitudes gave rise to an output signal twice as large in the second case as in the first

The principles underlying the operation of the Ratio Detector may best be explained by reference to the simple "equivalent" circuit of Fig. 21. The battery of total voltage E, is connected directly across the diodes (which are in series with each other) as shown. This battery of constant e.m.f. (E) and negligible internal resistance will thus maintain the total D.C. voltage across the two diodes at the constant value E. Note further that in the absence of an r.f. signal the diodes will not conduct, since the polarity of the battery is such that the diode plates have a negative bias (in respect to their cathodes). Thus when the battery is connected the equal condensers C_1 and C_2 will charge up, one half of E appearing across D_1, and the other half across D_2. In other words, the voltages E_1 and E_2, as measured by D.C. voltmeters, will be such that $E_1 = E_2 = \frac{1}{2}E$. The output is taken between A and B, where B is the centre tap of the battery. Then since $E_1 = E_2$, the P.D between A and B will be zero.

Now suppose an r.f. signal comes in. Actually the separate r.f. voltages for the two diodes are obtained by the same type of phase-changing circuit as was described for the discriminator. In Fig. 21, however, for simplicity, these separate r.f. voltages (S_1 and S_2) are shown applied to the diodes by means of separate transformers. If the carrier is at its centre frequency S_1 equals S_2, and if these are of sufficient amplitude to overcome the negative bias on the diodes the latter will conduct equally.



"Equivalent" Circuit of the Ratio Detector.
Figure 21.

Now the diodes are so connected that the rectified D.C. current of each diode flows through the other diode, and will be measured by the ammeter I. The output voltage, measured between A and B, however, will remain at zero. This point may be better realised by referring to Fig. 22 where each diode may be represented (as far as D.C. rectified current is concerned) by an equivalent D.C. voltage source (V_1 or V_2) in series with a resistor (R_1 or R_2) representing the internal impedance of the tube. The P.D. between A and B must be zero, providing $V_1 = V_2$ and $R_1 = R_2$.

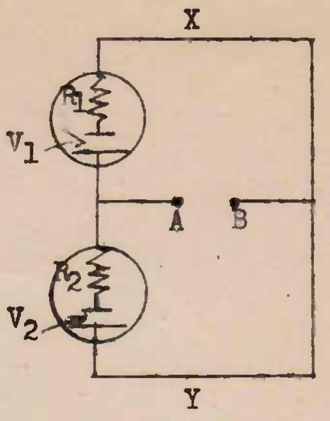


Figure 22.

If now the r.f. signals S_1 and S_2 are both increased, but remain equal, the rectified current measured by I (Fig. 21) will increase, but the potential at A remains unchanged, and the P.D. between A and B remains zero. Refer again to Fig. 22. If V_1 and V_2 both increase (but $V_1 = V_2$ still) the potential at A will not alter.

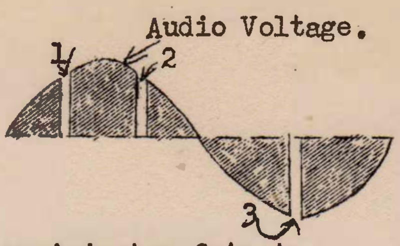
Suppose now that, due to frequency deviation of the I.F. the r.f. voltage (S_1) applied to diode [illegible] increases and that (S_2) applied to diode 2 decreases - say S1/S2 becomes equal to 2/1. Diode 1 will tend to conduct more vigorously and the condenser C, (really an r.f. by-pass condenser) will charge more fully. That is E_1 (Fig. 21) will increase. But since $E_1 + E_2$ must remain constant (equal to the fixed battery voltage E), E_1 can only increase if E_2 decreases. The reduction in r.f. voltage applied to D_2 will, of course, in this case, also tend to reduce the D.C. voltage (E_2) across C_2. The result will be that the ratio E1/E2 increases to 2/1, i.e. S1/S2 = 2/1.

The voltage at A will now be more positive than it was before, since E_1 has increased, and therefore there will be an output voltage between points A and B.

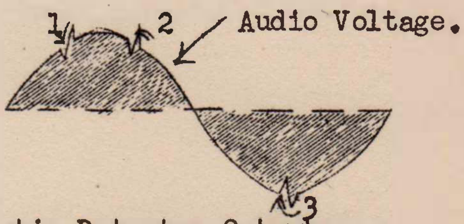
Let us now consider an <u>amplitude</u> change of the applied signal. If both S_1 and S_2 increase in the same ratio (due to an amplitude increase of the I.F. signal) both diodes will conduct more heavily, and there will be a tendency for the charges on the condensers C_1 and C_2 to increase. But since the total voltage $E_1 + E_2$ across these condensers must remain constant at the battery voltage, both E_1 and E_2 cannot increase. The result will be that providing the <u>ratio</u> S1/S2 remains unaltered (= 2/1) the voltages E_1 and E_2 will <u>not</u> change, and the ratio E1/E2 will remain equal to 2/1. Thus amplitude changes will have no effect on the output.

To see how really efficient is the ratio detector in suppressing amplitude changes, let us take an extreme case. Suppose at the instant when the signal deviation is such that S1/S2 = E1/E2 = 2/1 the r.f. wave is suddenly and momentarily reduced to zero (due for example to 100% amplitude modulation caused by impulse interference). When this occurs the diodes will suddenly become non-conducting due to the negative bias provided by the battery, and the absence of r.f. voltage. The voltage at A will remain at the value it had immediately prior to the cutting off of the wave. The reason for this is that the potential at A cannot now change, because this point is entirely isolated from the rest of the circuit by the non-conducting dielectric of C_1, C_2 and the <u>cut-off</u> diodes (see Fig. 21). Hence while the r.f. signal is zero electric charge cannot leave or approach the point A. This means that although the r.f. wave drops to zero the output remains unchanged. Fig. 23 shows oscillograph pictures of the audio outputs of A, a discriminator and B, a ratio detector when the signal is momentarily cut-off at points 1, 2 and 3. The effect, in the case of the Ratio Detector, is even less on the ear than the visual representation.

We have thus seen that the audio output taken from point A (Fig. 21) depends upon the variation in the ratio E1/E2 and this ratio depends only upon the ratio of S1/S2 and not on the absolute values of S_1 and S2. In the extreme case, for maximum deviation in one direction, E_1 would become equal to E and E_2 would be zero. For maximum deviation in the other direction E_2 would become equal to E, while E_1 would reduce to zero. Thus the maximum in amplitude of the audio voltage output, (measured in respect to the centre tap of the battery) would be 1/2 E, no matter how great the frequency deviation.



Discriminator Output.



Ratio Detector Output.

FIGURE 23 showing effects of momentary 100% Amplitude Modulation on Audio Outputs of Discriminator and Ratio Detector.

Now the circuit of Fig. 21 is not a very practicable one. To provide sufficient output audio voltage the value of E would have to be fairly large (since it determines the maximum output available). This would mean, however, that weaker signals could not be received at all, because the r.f. diode voltages must overcome the negative bias provided by this battery before they can conduct.

What we require is a source of voltage E which changes automatically with the average carrier level of the signal received, but one which does not vary with audio frequency fluctuations. This is achieved in the practical circuit of Fig. 24. Here the battery is replaced by a resistor R bypassed by a condenser CB. R carries the D.C. rectified current of the diodes, which develops a voltage across it with polarity as shown, and having a value depending upon the strength of the signal received. The voltage across R remains constant for all variations occurring at <u>audio</u> frequency, as a result of the smoothing or filtering action of C_B , which is a large value electrolytic condenser. The output is taken from the point A, measured in respect to the cathode of the lower diode. R_2 is a volume control potentiometer of such large resistance that it does not upset the normal operation of the circuit as previously described. In this circuit the audio voltage will not have an average value of zero, but will vary about a negative level equal to $\frac{1}{2}$ the voltage across R. This of course is immaterial

The output is thus really the output of the lower diode. If the volume control were connected across the upper diode the net result would be very little different because the audio frequency <u>changes</u> in voltage across the two diodes are equal, although opposite in polarity. The steady voltage across R, which readjusts itself with changes in <u>average</u> signal level is also used, as shown, for A.V.C.

The ratio detector is, as the student will agree, a most ingenious circuit, and will probably render the limiter-discriminator combination obsolete. Despite its obvious advantages, however, it suffers from several disadvantages as compared with the discriminator. The relative merits and de-merits of the two detector units will be compared in detail in the discussion on typical receiver construction incorporated in the lesson which follows.

HOW INTERFERENCE R.F. (NOISE) VOLTAGES AFFECT THE F.M. DETECTOR.

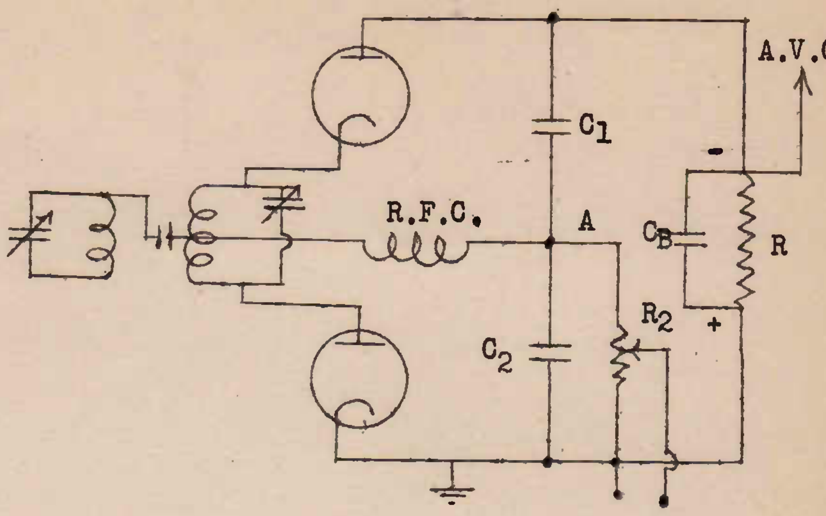


Figure 24.

The explanation of the effect of interfering signals in F.M. detectors, presented in the remainder of this lesson, cannot, unfortunately, be presented in simple words but requires a somewhat mathematical treatment illustrated by vector diagrams. If you are able to understand clearly the application of vectors, you should not find much difficulty in understanding the following pages, especially if you study them over several times. If you make several attempts and feel that you cannot fully understand the remainder of this lesson, do not worry as it is not of extreme importance. It simply provides proof of the fact that interference is far less severe with F.M. than with A.M.

In any case commence studying the following pages with particular care and thoroughness and you will probably find that you understand them quite well. If not, them simply continue with the next lesson.

We have earlier in these lessons explained how noise or interference in a radio receiver is due to a whole series of r.f. voltages which "beat" with the carrier and modulate it to produce an audio voltage after detection. It was pointed out how such an interfering voltage caused both amplitude and a certain amount of phase, and consequently frequency modulation. We now take up this subject again to show just how effective the F.M. system's immunity from noise can be.

Consider an incoming carrier of frequency f_c and voltage amplitude V_c, together with an interference voltage (r.f.) of frequency f_i and amplitude V_i. These two voltages will "beat" (or heterodyne) together, causing a modulation of the carrier at a frequency which equals their difference ($f_i - f_c$) (suppose f_i is greater than f_c, i.e. interference frequency lies above carrier frequency). The depth of amplitude modulation produced will depend upon the ratio $\frac{\text{Amplitude of Interference Voltage}}{\text{Amplitude of carrier voltage}} = \frac{V_i}{V_c}$.

For example if $V_i = \frac{1}{2} V_c$, the <u>percentage</u> modulation will be $V_i/V_c \times 100\% = \frac{1}{2} \times 100\% = 50\%$
In this case the audio noise voltage produced after detection in an A.M. receiver will be one half the amplitude of the audio signal representing the loudest sound which can be heard. Of course, as already explained, the noise voltage will only give rise to an <u>audible</u> sound if the interfering r.f. voltage has a frequency which differs from that of the carrier by an amount which does not exceed the A.F. limit, viz. 15,000 cycles per sec. In other words, for audible interference ($f_i - f_c$) must not exceed 15,000 cycles per sec.

A simple vector diagram will show the relative effects of such an interference voltage as regards amplitude and frequency modulation. Referring first to Fig. 25, the carrier and interference voltages may be represented by vector lines, each of constant length, and rotating at speeds (constant) depending upon their frequencies. At A the two r.f. voltages are in phase. The two will not remain in phase because their

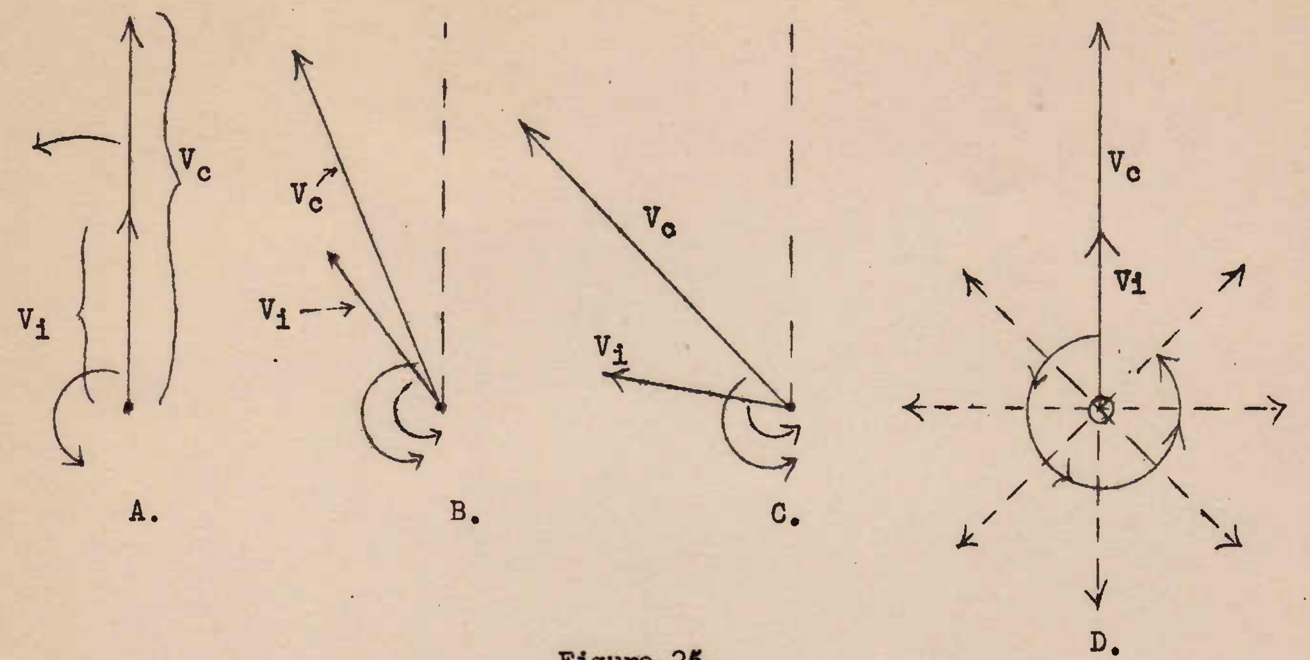


Figure 25.

frequencies are different. The vector representing V_c will be rotating (counter-clockwise) at a rate of $360 \times f_c$ degrees per second (since 1 cycle = 360°). Vector V_i will have a rate of rotation equal to $360 \times f_i$ degrees per second.

If the interfering voltage (V_i) lies in frequency above the carrier it will be rotating at the faster rate. Hence, a small fraction of a second later, the vectors will be as at B (Fig. 25), and later still as at C. Vector V_i is drawing away from vector V_c, at a rate equal to the difference of their separate rates of rotation, i.e. at a rate = $360\ f_i - 360\ f_c = 360\ (f_i - f_c)$ degrees per sec. It is this relative rate of rotation between the two in which we are interested. Hence, as shown at D (Fig. 25) we could imagine that vector V_c remains fixed (pointing **vertically**) and that vector V_i was rotating counter clockwise around the point 0 at a rate equal to the difference between their rates of rotation, viz. $360\ (f_i - f_c)^\circ$ per sec. To visualise this it could be imagined that the page, as a whole was rotated around 0 at a speed of $360\ f_c$ degrees per sec. Then V_i would actually be rotating at 360times $(f_i - f_c) + 360\ f_c = 360\ f_i$ degrees per sec).

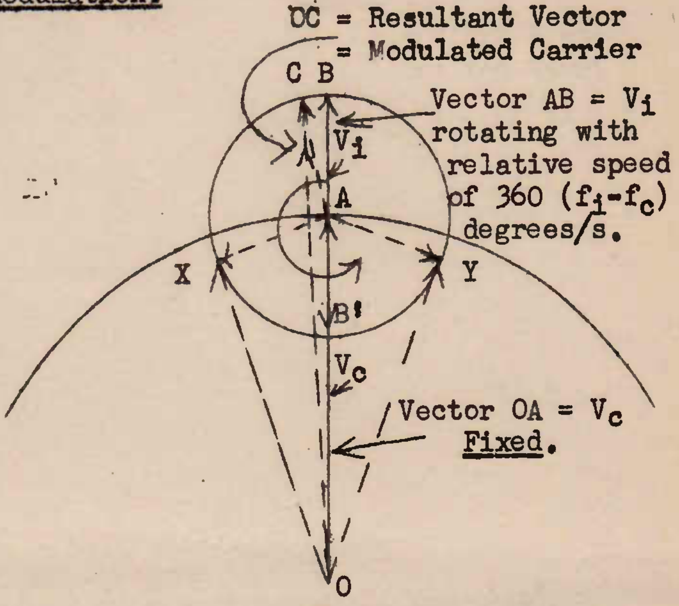
In fig. 26 we have transferred the centre of rotation of V_i to the point A (the end of the vector V_c, which is still imagined to be fixed in direction). As at Fig. 25D, the vector V_i in Fig. 26 is imagined to be rotating at a rate of $360\ (f_i - f_c)$ degrees per sec. We have transferred V_i to this new position because it is easier to "compound" the two vectors by the "triangle of vectors", when drawn "end-to-end" in this manner. Referring to this diagram (Fig. 26) as V_i rotates the resultant of V_i and V_c (viz. the vector representing the modulated carrier) will continually change in direction and magnitude (i.e. amplitude). Where V_i is in the position AB the resultant will be OB (a maximum). At this instant the phase of the modulated carrier (OB) is the same as the unmodulated carrier (OA = V_c). A little later when V_i is at

AC, the resultant (completing the triangle of vectors OAC) will be OC. Later still when V_i is in position AX the resultant is OX. As time goes on and V_i reaches the position AB' the resultant is OB'. At this instant the modulated carrier's amplitude has reached a minimum value. Further rotation of V_i will change the resultant modulated carrier to position OY, and eventually back again to OB.

Note that as the vectors get into and out of phase the carrier is amplitude modulated, as shown by the continual change in the length of the resultant vector. The carrier's amplitude is changed in the ratio of V_i/V_c, and the percentage modulation is $\frac{V_i}{V_c} \times 100\%$. This is the noise amplitude modulation.

In addition to the amplitude modulation there is a phase (and therefore "equivalent" frequency) modulation. The phase of V_c is first advanced (from OB to OX) through an angle AOX, and then retarded to OB', and back to OY. The resultant vector "oscillates" between the two limits OX and OY. Its rates of rotation are momentarily zero at OX and OY, and a maximum when passing the position OB. The movement of this resultant vector may be likened to that of an oscillating pendulum.

We have already seen earlier that if the phase of a carrier is increasing, its frequency must be momentarily higher than the frequency of the unmodulated carrier. Conversely if the phase of the modulated carrier is decreasing it must have a frequency below that of the unmodulated carrier. Hence in Fig. 26, when the resultant carrier vector is moving from OY towards OX (phase advancing) the modulated carrier frequency must be above the unmodulated frequency. Similarly when this vector is moving from OX towards OY (phase retarding) the modulated frequency lies below the numodulated frequency.



Phase Modulation of Carrier by Interence R.F. Voltage of Constant Amplitude and Frequency. Phase Oscillates between Limits OX and OY.

Phase Deviation = Angle AOX
= Angle AOY.

Figure 26.

In positions OX and OY the phase is momentarily unchanging, and hence at these moments the carrier's frequency is neither above nor below its nnmodulated frequency i.e. it is at its centre value, and the frequency deviation is zero.

The carrier frequency will reach its maximum value (i.e. maximum positive frequency deviation) when the phase is advancing at its greatest rate, i.e. when the oscillating vector is moving through the position OA in a counter-clockwise (right to left) direction. By a similar argument the frequency deviation will have a maximum negative value when the vector is moving through OA in the clockwise direction.

Figure 26 thus illustrates an important point concerning phase and frequency modulation: when the phase deviation is at a peak (OX or OY) the frequency deviation is zero; conversely when the phase deviation is zero (position OA) the frequency deviation is at a peak (above or below the central frequency depending upon whether the resultant vector is moving to left or to right).

Figure 26 will also tell us the amount of frequency modulation of the carrier (V_c) produced by the interfering voltage V_i. As we have just seen the peak frequency deviation will occur when the resultant vector is in the position OA. At this instant the interference vector V_i and the carrier vector V_c are in the same straight line. V_i is in the position AB, say, and is rotating counter-clockwise, at a rate 360 ($f_i - f_c$) degrees per sec. Its rotation is causing a counter clockwise rotation of the carrier vector, but the latter rate of rotation is slower than 360 ($f_i - f_c$). The reason for this is that the rotating line AB is shorter than the fixed line OA, and AB rotates through more than 90° in the same time that OA rotates through only a few degrees to OX. If V_i (AB) is small compared with V_c (OA) it is not very hard to see that the rate of rotation of the resultant will be only the fraction $AB/OA = V_i/V_c$ of the rate of rotation of AB (V_i). Thus if AB = 1/10 OA, then the resultant is turning at a rate equal to 1/10 of that of AB. Since the rate of rotation of $V_i = 360\ (f_i - f_c)$ we have:

$$\text{Rate of Phase Change of Resultant} = 360\ (f_i - f_c) \times \frac{V_i}{V_c} \text{ degrees per sec.}$$

$$= 360\ (f_i - f_c) \times \frac{V_i}{V_c} \div 360 \text{ cycles per sec.}$$

$$\text{i.e. Frequency } \underline{\text{change}} \text{ or Frequency deviation} = (f_i - f_c) \times \frac{V_i}{V_c} \text{ cycles per sec.}$$

We thus have the important resultant that the frequency deviation (peak) produced by the interaction of an interfering r.f. voltage (V_i) upon the carrier (V_c) depends not only upon the ratio of the amplitudes of the two voltages, but also upon the difference in their frequencies.

This difference in frequency ($f_i - f_c$), it should be remembered, is the rate at which the two r.f. voltages move into and out of phase, and represents the modulation frequency. Consider a few examples.

Example 1. If $(f_i - f_c) = 15{,}000$ c. per sec. and $\frac{V_i}{V_c} = \frac{1}{5}$

Frequency deviation = $15{,}000 \times \frac{1}{5} = 3{,}000$ cycles per sec.

Example 2. If $(f_i - f_c) = 7{,}500$ cycles per sec. and $\frac{V_i}{V_c} = \frac{1}{5}$

Frequency deviation = $7{,}500 \times \frac{1}{5} = 1{,}500$ cycles per sec.

Thus when the modulation frequency is at the limit of audibility (a high pitched noise) the amount of frequency modulation is twice as great as when the modulation frequency, and the pitch of the sound, is halved.

We saw earlier that the amount of audible interference produced in an A.M. receiver depended only upon the ratio of interfering voltage amplitude to carrier amplitude (i.e. upon V_i/V_c) and was the same for all noise frequencies. In the case of F.M., on the other hand, the amount of noise produced depends upon the frequency difference between the interfering voltage frequency and carrier frequency. Those interfering voltages lying close to the carrier frequency will produce very little audible noise, i.e. low audio frequency noise will be negligible. The most noise will result from these voltages which lie relatively far away from (above or below) the carrier frequency. In other words, in the case of F.M., unlike that of A.M. noise is not uniformly distributed over the audio spectrum.

Consider now a narrow-band F.M. system in which the maximum deviation, i.e. that corresponding to 100% modulation (maximum sound) is 15,000 cycles per sec. Consider further an interference voltage lying 15,000 cycles per sec. away from the carrier frequency, and therefore producing an audible sound of this frequency. The frequency deviation produced will be

$$\text{Deviation} = (f_i - f_c) \times V_i/V_c \text{ cycles per sec.}$$

$$= 15{,}000 \times V_i/V_c \text{ cycles per sec.}$$

Since, in this case, a deviation of 15,000 cycles per sec. produces the maximum sound (i.e. corresponds to 100% modulation) the noise modulation will be

$$\frac{15{,}000 \times V_i/V_c}{15{,}000} = \frac{V_i}{V_c}.$$

This is the <u>same amount</u> of noise modulation as would be produced in an A.M. receiver - see line AB - Figure 27.

Consider now a case where $f_i - f_c = 1{,}500$ cycles per sec, the noise-to signal voltage amplitude ratio (V_i/V_c) being the same as before. The frequency deviation produced is $1{,}500\ V_i/V_c$ cycles per sec. i.e. 1/10 of the former value. The noise modulation (and therefore the level of the interference in the A.F. stages) will also be 1/10 of the value quoted above i.e. only $1/10 \times V_i/V_c$ - see line C.D. Figure 27.

These examples should show, as illustrated by the graph OB in Figure 27, that noise in an F.M. receiver increases with audio frequency, from zero at zero frequency to a maximum at the limit of audibility, viz. 15,000 cycles per sec. At this frequency, <u>in the narrow-band system</u> the noise interference becomes as bad as in the A.M. system. The important point, however, is that in the latter system the noise remains at the AB level (Fig. 27) for the whole range of audio frequencies, as shown by the horizontal line BE. Hence, even considering an F.M. system of the same band-width as the ideal A.M. system, an improvement in noise is obtained, tests showing that on a power basis the improvement is 3 to 1.

By using a wide-band F.M. system a much greater improvement is obtained, as already discussed in an earlier lesson. If, for example, the deviation is 75,000 cycles per sec. the <u>maximum</u> noise modulation which results (where $f_i - f_c$) equals 15,000 cycles per sec) is : $\frac{15{,}000}{75{,}000} \times \frac{V_i}{V_c} = \frac{1}{5} \times \frac{V_i}{V_c}$.

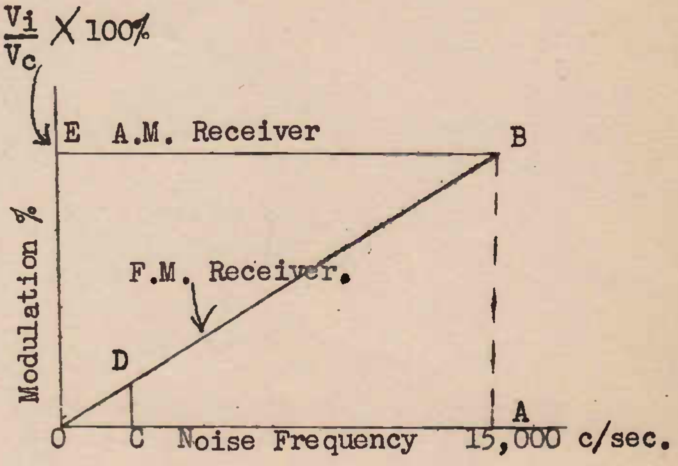


Figure 27.

This improvement, on a power basis, due to increasing the band-width by 5 times is 25 to 1, or 75 to 1 compared with the A.M. system. Actually the improvement is much greater than this, due partly to an ingenious method whereby the higher audio frequencies (which are most affected by noise interference) are pre-emphasised in the transmitter, and then subjected to a corresponding de-emphasis in the receiver, thus, incidentally also reducing the noise at those frequencies where it is most pronounced. This point will be taken up again in a later lesson.

THE CAPTURE EFFECT.

This effect, whereby one signal, providing it is more than about twice the strength of a second signal, will take virtually full control of a receiver, has been already mentioned. It has been stated that in practice the net effect of the phenomenon is that it is almost impossible to experience interference as between two stations.

A weaker, interfering, carrier normally causes interference by beating with, and modulating, the stronger carrier. We can now easily understand the action in an F.M. receiver by using the diagram of Fig. 25 where vector V_i represented a weaker r.f. signal modulating (in amplitude and frequency) a stronger r.f. signal (f_c). The interference modulation was seen to be :

$$\frac{(f_i - f_c)}{D} \times \frac{V_i}{V_c} \quad \text{where } D = \text{the peak deviation.}$$

In this formula we may now take V_c and f_c to represent the amplitude and frequency, respectively, of the stronger carrier. V_i and f_i will represent the amplitude and frequency of the weaker interfering carrier. The formula shows that if the two carriers have the same frequency, i.e. ($f_i - f_c$) equals zero, <u>absolutely no interference modulation</u> of the stronger signal can occur. If the two carriers are close together (($f_i - f_c$) small) the interference will be negligible. Hence it is impossible to experience the type of interference due to two carriers heterodyning as occurs with A.M. systems. The worst possible interference occurs when the signal frequencies differ by 15,000 cycles per sec. In this case the interference modulation for a case where $V_c = 2 \times V_i$, i.e. $\frac{V_i}{V_c} = \frac{1}{2}$ is

$$\frac{15,000}{75,000} \times \frac{1}{2} = \frac{1}{5} \times \frac{1}{2} = \frac{1}{10}$$

This is a voltage ratio. On a power basis the ratio of $\frac{\text{Interfering Signal}}{\text{Desired Signal}}$ equals $\left(\frac{1}{10}\right)^2 = \frac{1}{100}$.

Actually this worst possible condition only occurs for a very small fraction of the total time, even if the two carrier's centre frequencies differ by 15,000 cycles per sec. The reason for this is that when the carriers are modulated their frequencies are continually changing, so that, at any given moment, the frequency difference will probably be either <u>less than</u> 15,000 cycles per sec. (when the interference modulation is less pronounced) or <u>above</u> 15,000 cycles per sec. (when the interference is above the range of audibility).

It thus appears that the so-called Capture Effect results from the same action in the F.M. receiver as that which results in the relative immunity from noise due to "static" thermal agitation and "shot"effect. In considering the action of r.f. noise voltages we assumed that the carrier was unmodulated by speech or noise. The situation, however, is practically unchanged when F.M. is superimposed on the signal. When this occurs the carrier frequency simply moves up and down between its deviation limits over a band 150 K.c wide. Since noise r.f. voltages occur at every frequency the result will be that only those voltages which differ from the instantaneous carrier frequency by 15,000 cycles per sec. or less will be effective in causing interference.

LESSON 16 - EXAMINATION QUESTIONS.

(1) Why is high sensitivity in the R.F. and I.F. stages usually a more important consideration in an F.M. receiver than in an A.M. receiver?

(2) Explain why the problem of oscillator stability is rather a difficult one to solve in F.M. receiver design. Mention methods used to secure adequate stability.

(3) What would be the oscillator range of frequencies for a band of signals from 88 to 108 m.c. per sec., if the I.F. is 10.7 m.c. per sec ?

(4) Why cannot Image Interference occur when operating on a band 88 - 108 m.c. per sec. with I.F. of 10. 7 m.c. per sec. ?

(5) What would be the effect of an inadequate I.F. band-pass in the I.F. stages of an F.M. receiver?

(6) What are the necessary operating conditions for a valve used as a Limiter (grid limiting) ?

(7) Why is very little, if any, amplification obtained from a limiter ?

(8) What is the reason for Automatic Volume (or gain) control in an F.M. receiver ?

(9) How do the output voltages of a discriminator and an ordinary A.M. diode detector differ when the signals, in each case, are unmodulated ?

(10) What is the chief difference in the principle of operation of a Ratio Detector compared with a discriminator?

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LESSON 17.

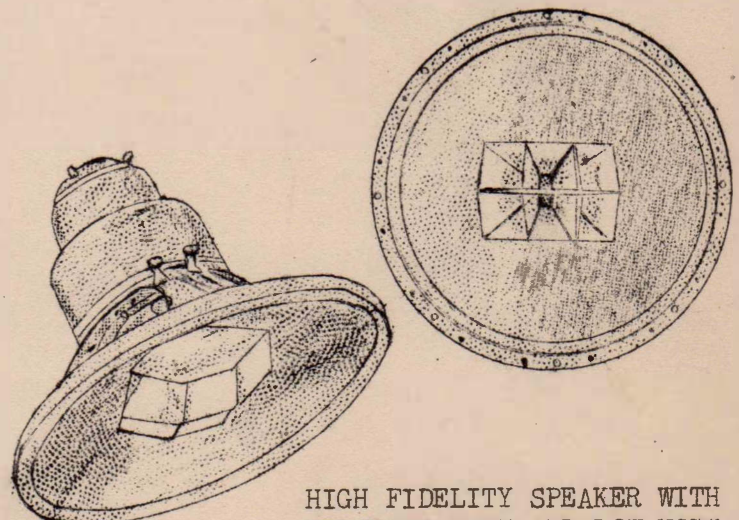
AUDIO SYSTEMS AND TYPICAL RECEIVERS.

Section A - Audio Frequency Systems.

The audio signal derived from the demodulation (detection) of an F.M. wave - as explained in the previous lesson - is exactly the same type of signal as that obtained from an A.M. wave. If, however, we were to use in an F.M. set an audio system as customarily designed for a conventional A.M. receiver we would fail to realise one of the main advantages - that of high fidelity - which is characteristic of this new method of broadcasting.

The usual low-fidelity audio amplifiers and speaker to be found in the great majority of receivers seriously attenuates the very low frequencies and the high frequencies above about 5,000 cycles per sec. There would be but comparatively little advantage, however, in extending this frequency range of the audio section when using A.M., because the system, in its present form, is incapable of transmitting the higher frequencies without giving rise to undesirable interference and noise.

The "wide-band" F.M. system, on the other hand, is fully capable of transmitting the entire audio spectrum - extending up to 15,000 cycles per sec. and more. It is most desirable, therefore, that the audio amplifiers and speaker of an F.M. receiver should be capable of handling, without discrimination, all frequencies passed on from the detector stage. To obtain this high fidelity special consideration must be given to the voltage amplifiers, to the power amplifier, to the output transformer, and to speaker construction and speaker mounting. It will be the purpose of Section A of this lesson to describe and explain the special characteristics of these several sections of an audio system suitable for a good F.M. receiver.



HIGH FIDELITY SPEAKER WITH
SEPARATE HIGH AND LOW NOTE
CHANNELS.

Figure 1

DE-EMPHASIS OF HIGH AUDIO FREQUENCIES AFTER DETECTION.

In the grid circuit of the first audio voltage amplifier in an F.M. receiver there is usually to be found a special resistance capacity or inductance-resistance filter network. The necessity for this filter is due to an ingenious method of taking advantage of the particular manner in which interference (noise) voltages affect the audio output from an F.M. detector. As previously pointed out, "noise" in an F.M. receiver, unlike that in an A.M. receiver, is not uniformly spread over the audio frequency spectrum, but is more pronounced at the higher of these frequencies. If we were to measure the intensity of the noise in the output from an F.M. detector at all frequencies from zero up to the limit of audibility (say 15,000 cycles per sec.) the intensity would increase with frequency as shown by the straight line "A" in Figure 2. Here we are assuming, of course, that all amplitude modulation due to noise has been been fully suppressed by limiters or by the use of a "ratio detector". For comparison purposes the graph of noise - versus - frequency for an A.M. receiver has also been shown in Fig. 2 (line "B"). In the latter case the line is horizontal, indicating that the effect of noise is uniformly distributed over the whole of the A.F. range.

This peculiarity of the noise characteristic of an F.M. system is taken advantage of, in practice, to still further reduce the effect of interference. In the modulator of the transmitter it is customary for the higher audio frequencies of the signal to be pre-emphasised or accentuated over and above the lower frequencies. In the receiver, after detection, the higher audio frequencies in the signal are de-emphasised or de-accentuated as compared with the lower frequencies. The effect of such de-emphasis is to produce a proper balance again among the various components of the A.F. signal, while at the same time reducing the strength of the noise voltages at these higher frequencies where they are more pronounced.

A simple A.F. de-accentuator net-work is shown in Figure 3. The audio output from the F.M. detector is applied across an R.C. circuit and the signal applied to the 1st A.F. amplifier is taken from across the condenser C. At low frequencies the reactance of C is much larger than R and practically the full detector output is applied to the A.F. amplifier. As the signal increases with frequency the reactance of C decreases. Since the circuit consisting of R and C acts as an A.C. voltage divider the percentage of the total signal which is passed on to the amplifier becomes smaller and smaller as the frequency increases. The values of R and C must, of course, be properly proportioned so that the de-emphasis obtained matches the amount of pre-emphasis utilised at the transmitter.

In the case of the ratio detector the high A.F. de-emphasis may be conveniently achieved by choosing suitable values of the condensers across the diodes and the condenser applying the signal to the centre-tap of the transformer secondary. The total effective value of these capacities appears across the output impedance of the circuit, which in practice is comparatively low. Hence, at the higher audio frequencies a certain amount of by-passing action may be brought about.

AUDIO VOLTAGE AMPLIFIERS:

A good A.F. voltage amplifier in an F.M. receiver should amplify uniformly all sound frequencies from 30 cycles per sec. to 15,000 cycles per sec. This is not a wide range when compared with the requirements of a television video amplifier, but is somewhat wider than that which most audio

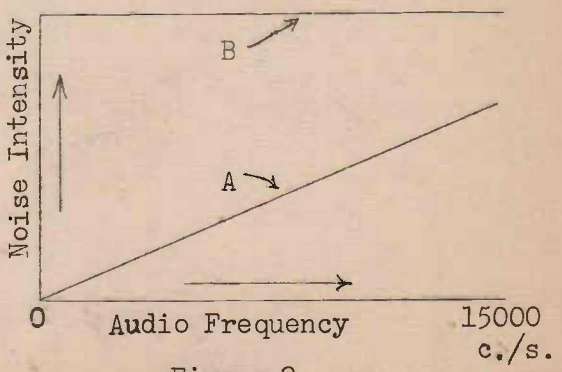


Figure 2

amplifiers in A.M. receivers are capable of handling.

We have already discussed in detail in the television lessons the causes of loss of gain in resistance capacity coupled amplifiers at the very low and at the very high frequencies. These points should now be recalled.

The main differences between a typical A.F. voltage amplifier in an F.M. receiver compared with the corresponding stage in an A.M. receiver are :-

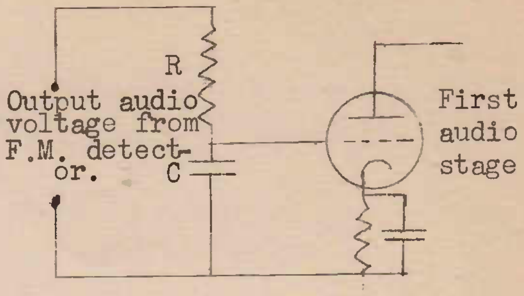


Figure 3.

(1) A somewhat lower value of load resistor, particularly when using a pentode, to extend the high-frequency range.

(2) A valve having in general a larger value of mutual conductance, to offset the loss of gain at <u>all</u> frequencies due to the smaller load resistor.

(3) All valves are almost invariably of the "single-ended" type, i.e. they have no grid caps. Instead the grid connection in each case is brought out to one of the base pins. This reduces the length of the plate-to-grid lead between valves, thus reducing the stray capacity to ground, and improving the high-frequency response.

To realise just how inadequate would be a typical pentode R.C amplifier refer to Fig. 4. Here we show a plate resistor of .5 meg. followed by a grid resistor (for the next stage) also of .5 megohm), giving an effective plate load of .25 meg. The stray capacities (shown by C_s), having a typical value of 70 µ.µ.f., consist of course of the output capacity of the stage, together with the input capacity of the next stage, and stray wiring capacity. Note that the gain begins to fall off rapidly at about 3,000 or 4,000 cycles per sec. while at approx. 16,000 cycles per sec. it is down to 50%.

A useful fact to remember when judging the higher frequency response of an R.C. amplifier is that the gain is down to 0.707 of its normal value at that frequency at which the reactance of the stray-capacities is equal to the effective load resistance (or, in the case of triodes, to the effective value of the load resistance in parallel with the valves internal plate resistance). Thus, in the case illustrated, at 9,000 cycles per sec. the reactance of C_s = 70 u.u.f. works out at approximately 0.25 megohms.

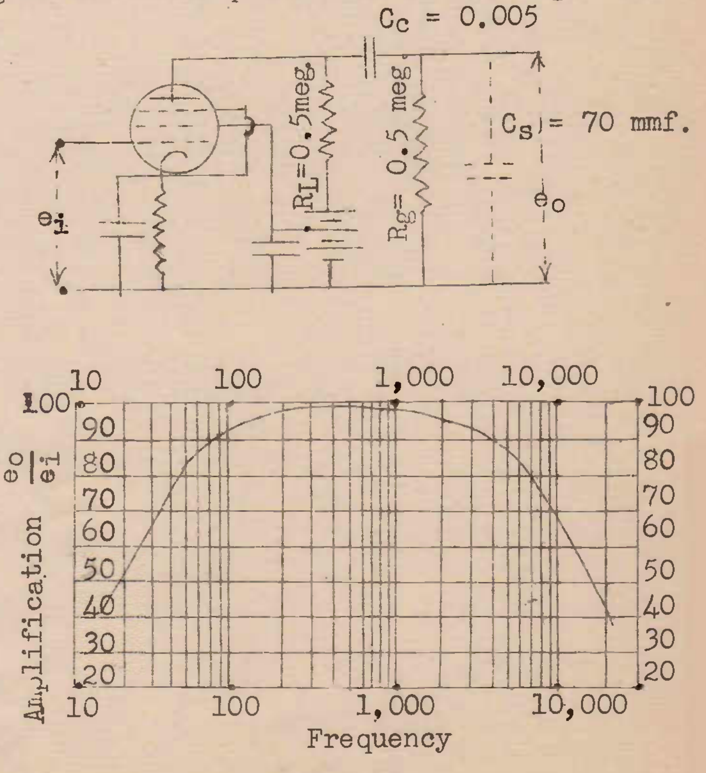


Figure 4

A value equal to the effective load. From the graph of Figure 4 it will be seen that the gain at 9,000 c. per sec. is about 0.7 of its normal value.

Suppose now we were to reduce the load resistor to 0.1 meg. The effective value of the plate load would now be that of 0.1 meg. in parallel with 0.5 meg. (the grid resistor). This is $\frac{.1 \times .5}{.1 + .5}$ meg.=.083 meg. about one third of its former value. The frequency could now be increased to three times 9,000 cycles per sec. i.e. 27,000 cycles per sec. before the reactance of C_s became equal to the effective value of the load resistance, and therefore before the gain fell off to 0.707% of normal value. Thus it is seen that when using a .1 meg. load in parallel with a .5 meg. following grid resistor, the higher audio frequencies up to, say, 15,000 cycles per sec. could be adequately accomodated without any appreciable loss of gain occurring. The position would be even better if we were to use single-ended pentodes, of low internal capacities (as is the usual practice). In this case the stray capacities would be less than the 70 $\mu.\mu.$f. assumed above.

With reference to the low-frequency response, it is desirable to extend the latter down to about 50 cycles per sec. otherwise the reproduction will sound high-pitched and"tinny". Any extension of the high-frequency range of an audio amplifier, without a compensating extension of the low-frequency range, produces a very noticeable lack of tonal balance in the reproduced sound. It might be remarked, in this connection, that one purpose of tone control in an ordinary A.M. receiver is to attenuate the higher frequencies (even though these might extend up to only 3,000 - 5,000 cycles per sec.) to offset the absence of the very low frequencies. For high-fidelity reproduction both the very high and the very low frequencies must be adequately handled, not only in order that all essential components of the original sound are reproduced, but also in order to preserve a natural balance between the high and low tones.

The low-frequency response of an amplifier depends upon the time-constant product $C \times R$ where C = capacity of the grid coupling condenser, and R = effective value of the grid resistor (R_g) in series with the preceding valve's plate resistance and load resistor (in parallel). In the case of a preceding triode, which has a low plate resistance, R may be taken simply as the grid resistor (R_g). Even with pentodes, if the preceding plate load resistor is comparatively small (as in high-fidelity work) R, for rough purposes, may be taken as the value of the grid leak (R_g).

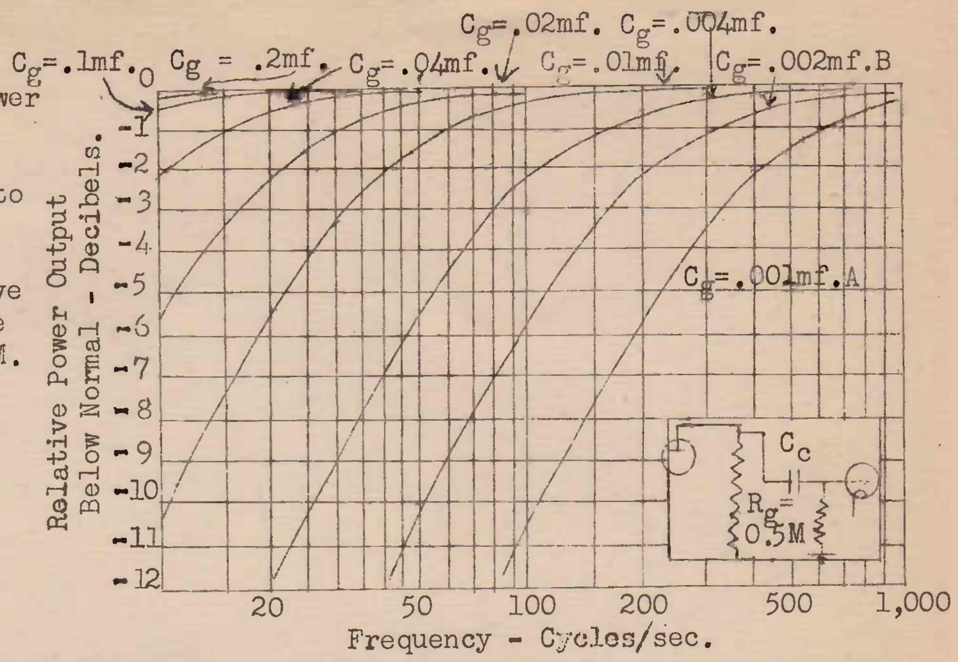
Figure 5 shows the effect of various values of grid coupling condenser (C_c) when the grid resistor is 0.5 meg. It will be seen that for negligible low frequency attenuation C_c must be .02 m.f., or higher when the resistance is 0.5 megohm. These curves may be used for any value of resistance providing the capacity is multiplied by the correct factor. For example if the resistance were 1 megohm instead of .5 megohm curve A would hold for a grid condenser of capacity $.001 \times \frac{1}{2} = .0005$ m.f. The reason for this is that the time-constants $.001 \times .5$ secs. and $.0005 \times 1$ sec. are equal.

THE POWER AMPLIFIER.

Any common type of power output valve e.g. a 6V6, is suitable for an F.M. receiver. The main considerations to be satisfied in respect of the output stage are:-

(1) There should be abundant power output (watts) available.

(2) Distortion should be kept to a minimum.



Showing reduction in gain due to effect of grid-coupling condenser. Note. Each division (1 Decibel) on the vertical scale represents a change in sound intensity which is just noticeable by the human ear.

Figure 5.

With reference to point (1) above it should be remembered that the peaks of audio power from an F.M. signal are considerably higher than those from an A.M. signal even though the average level of the sound is the same in the two cases. This is because the F.M. signal provides a much wider "dynamic range" than does the A.M. signal. The audio signal in the latter case is considerably "compressed" before modulation at the transmitter. The maximum power output rating of the power valve or valves of an F.M. receiver, therefore, should be many times the average power at which it is desired to operate the set, otherwise the volume peaks will be cut off and distorted. For ordinary domestic purposes where the receiver is operated in a small room, and a high level of average output is not required, a single pentode or beam power tetrode, such as the 6V6, is considered adequate. In the case of the more ambitious receivers, however, from which it is desired to obtain the full benefits of the wide dynamic range of the high fidelity signal, several of such valves either in parallel or in push-pull - preferably the latter - should be used. Whether a single valve or two valves are used it cannot be too strongly stressed that the stage should be correctly designed and adjusted to give the maximum undistorted power of which the valves are capable. Such points as correct plate load and correct grid bias (as published in the data sheets) should be given close attention.

With reference to the question of distortion mentioned under (2) above little need be said here. The same considerations apply as in the A.M. receiver. Negative or inverse feed-back is especially recommended in all cases in order to reduce distortion generated within the valve.

THE OUTPUT (SPEAKER) TRANSFORMER.

A high-quality speaker transformer is essential for high fidelity output. Correct design of the other sections of an audio amplifier for full audio frequency range is useless if the speaker transformer is inadequate.

It should be recalled that the impedance "reflected" into the primary of a correctly designed transformer depends only upon the load imposed upon the secondary, and the "turns ratio". If the secondary load is a pure-resistance, then the primary impedance should also appear as a pure resistance. The value of this primary resistive impedance, in such a casè is given by

$$Z_p = Z_s \times \left(\frac{T1}{T2}\right)^2$$

where Z_p = "Reflected primary impedance

Z_s = Load imposed on the secondary.

T_1 and T_2 = No. of turns on primary and secondary respectively.

See Figure 6.

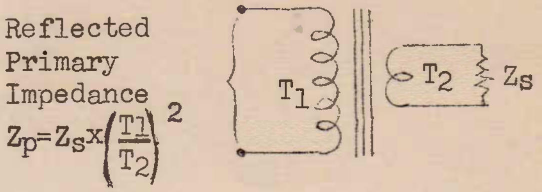


Figure 6.

The important point to note is that the load imposed on the output valve (and therefore the power output obtained) should not vary with frequency. If, however, we look at a typical amplification frequency curve for a power amplifier with output transformer (Figure 7) we note that although the output remains substantially constant over a considerable range of the middle frequencies, it does fall off sharply at the very low and the very high frequencies. What causes this loss of output at these extremes of frequency ?

LOSS OF OUTPUT AT LOW FREQUENCIES DUE TO SPEAKER TRANSFORMER.

Although the primary of an output transformor consists almost entirely of inductance the reactive effect of the latter is entirely masked at all but the very low frequencies. The reason for this is that the resistive impedance $\left(Z_s \times \left(\frac{T1}{T2}\right)^2\right.$, reflected into the primary by the electro-magnetic coupling effect, really appears in parallel with the primary inductance as shown in Figure 8. Now at all except the very low frequencies the reactance Lp is very much larger than $R_s \times \left(\frac{T1}{T2}\right)^2$. Hence, for all except the very low frequencies the load imposed on the valve (R_L Figure 8) is practically equal to the reflected impedance only - and the latter is independent of frequency.

At the very low frequencies, however, the reactance ($2\pi f L_p$) of the primary inductance might fall to such a value as to cause an appreciable shunting of the reflected impedance (Z_p). The effective load (R_L) in the plate circuit of the power valve then becomes reduced in value, and the output falls off.

Summarising we may say that undue falling off in the gain from a power amplifier at the lower frequencies may be due to insufficient primary inductance in the output transformer. To maintain a constant output down to say 50 cycles per sec. the output transformers primary must have a larger inductance than to be found in a typical unit as used for A.M. work. This normally involves a larger iron core and a larger number of

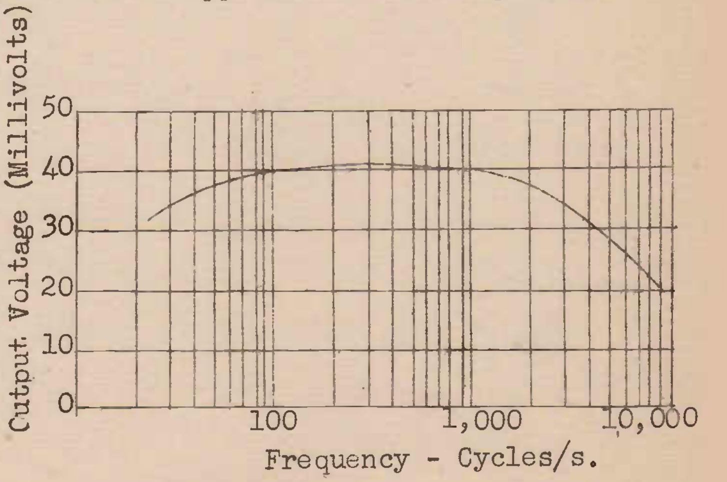


Figure 7.

primary turns, together with a corresponding increase in the secondary turns in order to maintain the turns ratio $\frac{T_1}{T_2}$, constant.

Figure 9 shows the improvement in low frequency response in a typical circuit when the primary inductance is increased from 3.7 henries to 11.1 henries. Note that the primary inductance has no effect on the output at the middle and high frequencies.

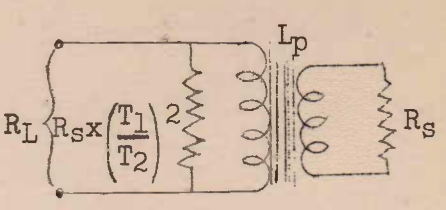


Figure 8.

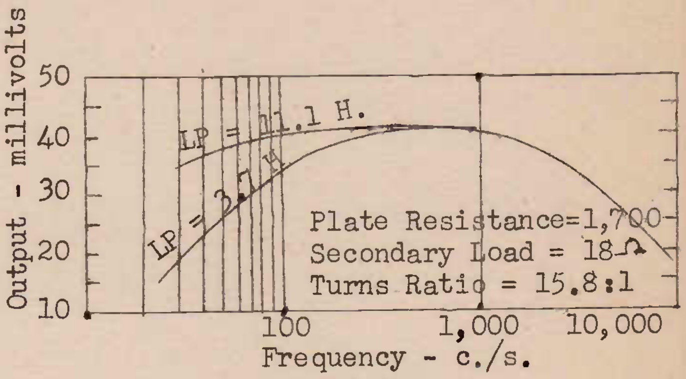


Figure 9.

LOSS OF OUTPUT AT HIGH FREQUENCIES DUE TO SPEAKER TRANSFORMER.

The falling off in output at the high frequencies is usually described as being due to the "leakage inductance" of the transformer. In the ideal transformer all of the magnetic flux (lines of force) of the primary should "cut" or pass through all of the turns of the secondary. Similarly all of the secondary flux should cut all the primary turns. In a practical transformer, however, a certain small percentage of the magnetic flux of each coil fails to cut the other coil. (See figure 10). A mathematical analysis shows that the effect of this leakage flux is the same as if an extra small inductance were placed outside the transformer, but in series with the primary into which is reflected the impedance $R_s \times \left(\frac{T_1}{T_2}\right)^2$. See figure 11.

Now at low and medium frequencies the reactance ($2\pi f L_L$) of this "leakage inductance" is negligibly small compared with the reflected impedance $R_s \times \left(\frac{T_1}{T_2}\right)^2$. At the higher frequencies, however, the reactance of L_L becomes appreciable and results in a loss of output.

Another serious effect of leakage inductance occurs when the latter resonates with stray capacities in the circuit. These stray capacities consist of capacity between the transformer windings themselves together with wiring and valve capacities external to the transformer. Since both leakage inductance and stray capacities normally have low values the resonant frequency is usually high, but it may fall within the audio frequency range for which the transformer is designed. If this occurs a small band of these higher-frequencies will be accentuated unduly, i. e the frequency - response curve will depart from the desired linearity and will show a sharp peak in the higher frequency range. In a well

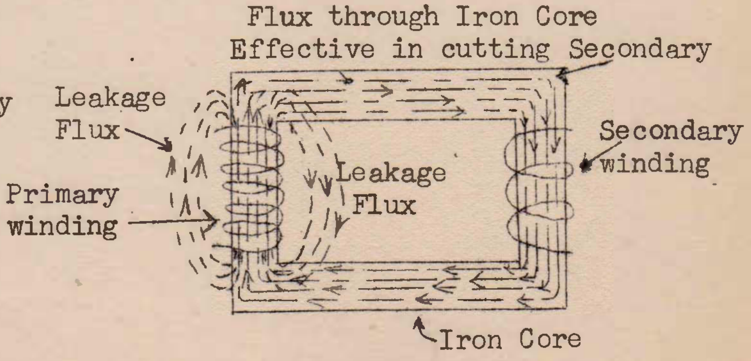


Figure 10.
Showing leakage of Primary Magnetic Flux.

designed transformer the resonant peak of the combined leakage inductance and stray-capacities should fall somewhat <u>above</u> the higher frequency limit for which the transformer is designed. If this condition obtains the resonant peaking effect may be utilised to offset, to some extent, the reduction in gain at the higher frequencies within the designed range, which reduction is due to the presence of the leakage inductance above.

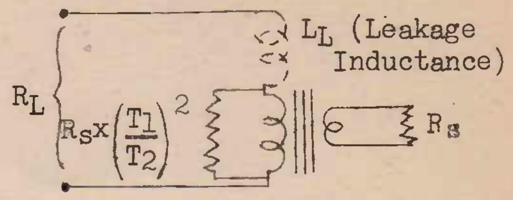


Figure 11.

Leakage inductance is reduced by:

(1) Winding the coils on a central iron-leg of the iron core, the windings being divided into a number of sections with primary and secondary interlaced.

(2) Using iron of high magnetic "permeability".

(3) Having a core of large cross-sectional area.

Winding capacities are reduced (to raise the resonant peak referred to above) by dividing each section of the transformer windings into sub-sections spaced apart by small distances.

It will now be realised that an ordinary output (speaker) transformer considered satisfactory for a low fidelity A.M. receiver would be quite inadequate to handle the frequency range 30 - 15,000 cycles per sec. desirable in F.M. work. Increasing the normal primary inductance to avoid loss of gain right down to 30 cycles, and reduction of the leakage inductance to maintain the response up to 15,000 cycles involves higher costs in manufacture. Nevertheless it would be unreasonable to counteract the results of proper design for high fidelity in other parts of the receiver by the use of a low quality output transformer.

HIGH QUALITY SOUND REPRODUCTION - LOUD SPEAKERS.

Having retained the full range of audio frequencies right up to the output of the speaker transformer it still remains to convert this electrical signal into sound wave power without discriminating against, or favouring, any band of frequencies within the range.

The position is this : we have in the secondary of the speaker transformer electrical power distributed over a wide range of frequencies. The job is to convert this electrical power into acoustical or sound power with the same degree of efficiency for all frequencies within the range. Now the design requirements for an electro-acoustic device (e.g. loud-speaker) to operate efficiently at high frequencies are quite different from the requirements for high efficiency at low frequencies. For this reason it is a very difficult technical problem to construct a <u>single</u> electro-acoustical device to operate uniformly over the frequency range of say 30 - 15000cycles per sec.

THE PRODUCTION AND NATURE OF A SOUND WAVE.

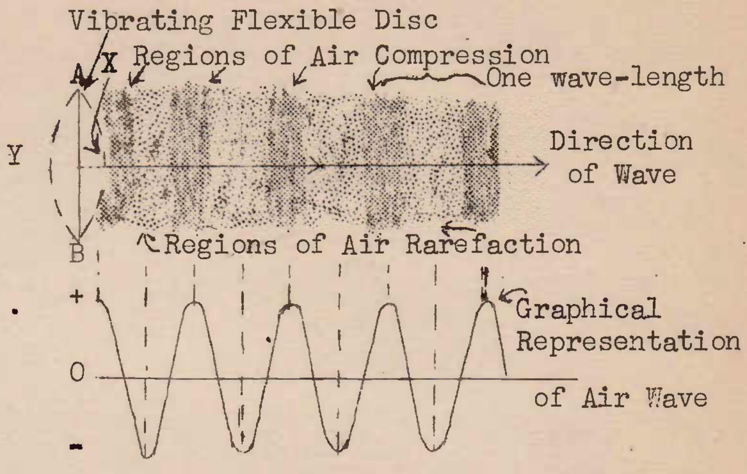


Figure 12.

In order to understand the material which follows in these pages concerning high-fidelity sound reproduction, it will first be necessary to grasp a few simple fundamentals relating to the manner in which an air sound wave may be produced, and the nature of such a wave.

Referring to Figure 12 - suppose AB is a flexible metal disc, caused to vibrate bodily at audio frequency by, say, some electrical means, Suppose further that at the present moment the disc is moving in the direction y to x. The air on the right-hand side of the disc, since it possesses a certain amount of weight, and therefore inertia, will not have time to flow away from the moving disc. The result will be that the air particles will be compressed together to some extent, i.e. a region of high air pressure is built up. Then, as the disc moves back in the direction x to y a partial vacuum will be created behind it, since the air particles have insufficient time to flow into the space. In other words a region of rarefaction will result. In the meantime the region of compression will have moved onwards to the right at the velocity of sound. Thus as the rapid vibration of the disc continues a "compression wave" moves continuously to the right. Of course a similar wave (not shown) will also move out to the left of the disc. It should be understood that the air, as a whole, does not flow bodily in the direction of the wave. Actually each individual air particle simply performs a vibratory or oscillatory motion about its normal average position. It is the positions of the air compressions and rarefactions which continually change or move. The diagrammatic representation of Fig.12 may be imagined as a sort of "snap-shot" of the state of affairs at any one instant of time.

The air wave may be represented by the usual sine-curve by depicting regions of compression as positive half-cycles, and regions of rarefaction as negative half cycles, as shown in Figure 12.

The frequency of the wave (i.e. the "pitch" of the sound) will depend upon the number of air compressions passing any point per second. The intensity of the wave (i.e. the loudness of the sound) will be determined by the intensity of the pressure in the regions of compression, and this will depend, among other things, upon the amplitude of vibration of the disc. The speed at which the wave moves through air is approximately 1120 ft. per sec., irrespective of the frequency and intensity. The wave length is the distance between any two adjacent points of maximum air pressure. (See Figure 12). The wave length (in fact) of sound wave may be calculated from the formula : Wave length = $\frac{1120}{\text{Frequency}}$ feet. Speed = 1120 ft./sec. is correct for 17° C temp. and normal barometric pressure.

Thus the wave length of a sound wave of frequency 224 cycles per sec. is $\frac{1120}{224}$ = 5 ft.

HOW THE SOUND INTENSITY VARIES WITH THE FREQUENCY OF VIBRATION AND THE DIAPHRAGM AREA.

Suppose a rigid diaphragm (Figure 13A) is caused to vibrate by the application of some constant force to it. (In the case of a loudspeaker the force is one developed by the flow of the alternating audio-frequency current in the voice-coil which is situated in a magnetic field). If the frequency is continually increased it is found that the intensity of the wave set up varies as shown in Figure 13B.

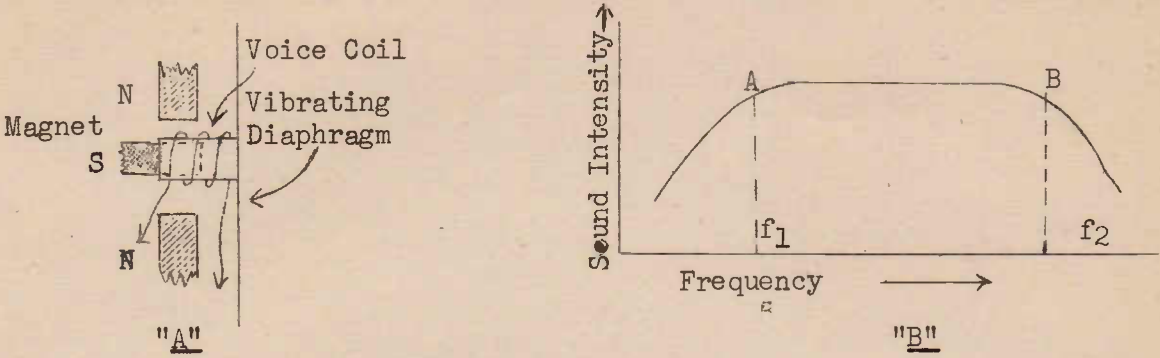


Figure 13.

At low frequencies the vibrating diaphragm does not get a chance to "bite" on the air very effectively. At those frequencies the air tends to slide around the edges as the surface moves backwards and forwards. As a result the air pressures developed, as explained in connection with Figure 12, are not very high, and the sound wave's intensity is small. As the frequency increases the "bite" on the air becomes more and more effective and this tends to result in a more intense wave. On the other hand the amplitude of vibration of the diaphragm decreases as the frequency increases. The cause of this reduction in the amplitude of vibration is due to the mass of the diaphragm. As the frequency increases it becomes ever more difficult to move this mass back and forth at the desired rate. Since the force available to cause the vibration was assumed constant, the result will be that the amount of vibration produced will fall off with increase in frequency. The result of this reduction in amplitude of vibration would be, of course, (other things being equal) to reduce the intensity of the sound wave.

It thus appears that, with increase in frequency, there are two opposing tendencies as far as the strength of the wave is concerned. The improved "bite" on the air tends to produce a more intense wave. On the other hand the falling off in amplitude of vibration tends to result in a weaker wave.

At very low frequencies (below f_2 Figure 13B) the former tendency more than offsets the latter, and the wave intensity increases to a maximum at A, corresponding to frequency f_1.

Over a certain range of frequencies f_1 to f_2 (Figure 13B) the ever increasing "bite" on the air, and the ever decreasing amplitude of vibration just about off-set each other, with the result that the wave intensity remains substantially constant.

It is found that when the frequency is such that the diameter of the diaphragm equals one half a wave length, the "squash" of the air to the sides of the vibrating surface becomes negligible. In other words the "bite" on the air becomes practically 100% at this frequency, and therefore does not improve further as the frequency goes up. The frequency at which this occurs is represented by f_2 in Figure 13B. As the frequency increases further above f_2 the amplitude of vibration, due to the effect of diaphragm mass, will of course continue to decrease. The result will be that as the frequency of vibration increases above f_2, the wave intensity will rapidly fall-off.

Summarising, the frequency-sound intensity characteristic of a rigid vibrating diaphragm , operated by a constant force (due, say to an audio current of constant amplitude in the "voice coil"), we have the following points :-

(1) The sound intensity remains constant over a certain frequency range.

(2) The lower-frequency limit (f_1 Figure 13B) of this constant range is determined by the area of the diaphragm. The limit may be lowered by using a larger diagram, for the latter will present a larger vibrating area to the air, and will thus secure a better "bite" at the lower frequencies.

(3) The upper frequency limit of the constant range (f_2, Figure 13B) also depends upon the size of the diaphragm. This frequency limit, however, can only be raised by reducing the diaphragm size. It was pointed out that the frequency f_2 corresponds to a wave length twice the diameter of the diaphragm (i.e. diameter = $\frac{1}{2}$ wave length).

For example, in the case of an 8" diaphragm (e.g. an 8" cone speaker), the frequency (p) at which the acoustic power begins to fall off will be that corresponding to a wave length of $2 \times 8" = 16" = 1\text{-}1/3$ ft. This frequency is $1120 \div 1\text{-}1/3 = 3360 \div 4 = 840$ cycles per sec. If a diaphragm of diameter only 4" were used the corresponding frequency would be double this, i.e. 1680 cycles per sec.

The fundamental difficulty encountered in wide-range (high-fidelity) sound reproduction should now be obvious. The efficient reproduction of the very low frequencies requires a diaphragm (or cone) of large area, but this is detrimental to the high frequencies. If the latter are to be reproduced without loss, a small diaphragm is desirable, but this cuts out the very low frequencies. Let us see how this problem may be solved.

PERFORMANCE AND LIMITATIONS OF A TYPICAL SPEAKER.

It will first of all be necessary to recall the action of a typical cone speaker and see how far its performance satisfies the requirements of high fidelity reproduction.

It is assumed that the mechanical-electrical principles of operation of the dynamic type of speaker are already familiar to the student. The following points, however, will be stressed. The alternating current, at audio frequencies in the voice coil cause it to move in a left and right direction across the page (Figure 14), and this oscillatory motion, at sound frequency, is transferred to the cone, which acts as the vibratory diaphragm. Now if a rigid cone were used the sound output would be constant over only a very limited frequency range as explained in connection with Figures 12 and 13. The problem is this : if a large cone is used the lower frequencies will be well catered for, but the higher frequencies will not be adequately reproduced. On the other hand a small cone will favour the higher frequencies at the expense of the low. The problem is partly overcome by using a cone of "corrugated " construction. Stiff rigid sections in the cone surface are separated by corrugations possessing a certain amount of elasticity or "give", as shown in Figure 14.

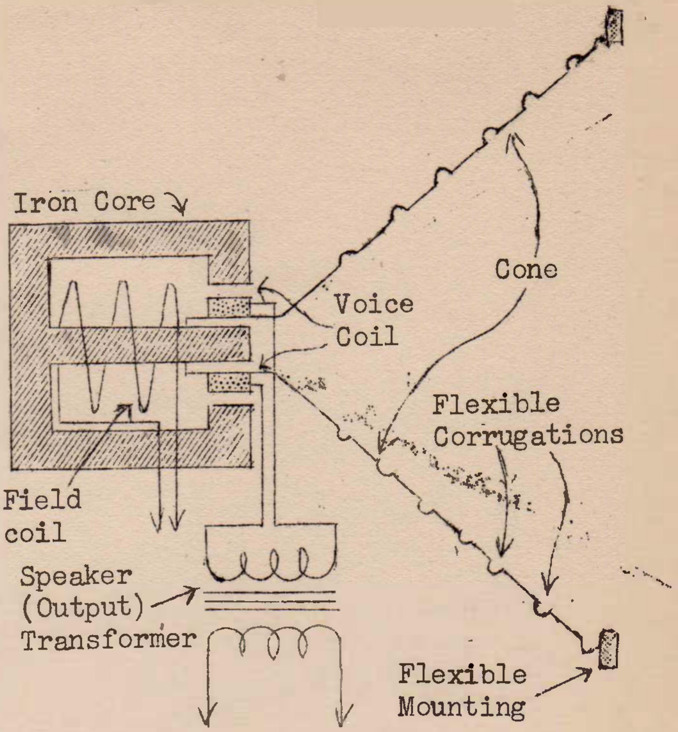


Figure 14.

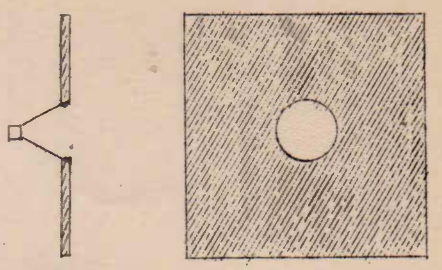
Considering an 8" speaker at low frequencies up to about 800 - 1000 cycles per sec. the stifness of the corrugations is such that the cone vibrates as a whole, and the effective area utilised in producing sound waves equals the whole cone area. Up to this frequency corresponding to f_2 in Figure 13, as we have already seen for an 8" cone, the acoustical power output remains practically constant, but above it there would be a marked falling off in the output. Somewhere about this 800 - 1,000 cycles frequency mark, however, the cone corrugations begin to "give" with the result that the amplitude of vibration of the outer sections of the cone is less than that of the inner sections. As the frequency increases the "give" of the corrugations becomes more and more pronounced, until at about 3,000 or 4,000 cycles per sec. only the inner portion of the cone is moving. The net effect of this action is that the effective area of the cone in use decreases with increase in frequency (in the range 1,000 to 3,000-4,000 cycles per sec.). The resulting decrease in mass of the vibrating section allows of a greater amplitude of vibration than would otherwise occur. Such increase in vibration amplitude tends to off-set the tendency for the acoustical power to decrease.

It is thus seen that in the case of a typical 8" speaker the corrugated structure of the cone extends the high frequency limit, at which a fall in output commences, from about 1,000 cycles per sec. to about 3,000 or 4,000 cycles per sec. Above the latter frequency the mass of the voice coil itself is the limiting factor. To extend the range still higher a lighter voice coil must be used, and this in practice means that the whole speaker construction must be smaller. But a small cone would be detrimental to the low frequencies. The problem of raising the upper-frequency limit to a value which is adequate for high-fidelity reproduction such as is required in an F.M. receiver will be taken up a little later in the lesson.

Consider now the low-frequency response of the typical speaker. Even though we have the comparatively large diaphragm area of, say, an 8" cone, the response would begin to fall off below several hundred cycles. This is not good enough even for ordinary medium-fidelity work. What happens at these low frequencies is that the cone, as it vibrates, simply pumps air from one side of it to the other, thus preventing the building up of high pressures necessary for a strong sound wave.

BAFFLES

To prevent this flow of air from front to back (and vice versa) of the vibrating cone it is necessary to surround the cone with a "baffle". A "baffle" may be defined simply as a piece of more or less sound absorbent material which increases the acoustical or air path between front and rear of the cone. In the ordinary use of the term the baffle is flat, surrounding the speaker cone as shown in Figure 15.


A. Side View B. Front View

Square Speaker Baffle.

Figure 15.

The lower the frequency it is required to handle the larger the baffle should be. A rough rule to give the diameter of a circular baffle is as follows :- Baffle diameter = one-half wave length of lowest frequency for which little or no loss of power is required. For example if frequencies down to 150 cycles per sec. are required baffle diameter should be $\frac{1}{2} \times \frac{1120}{150} = 3.7$ ft. (approx). If a square baffle were used the length of its side should be equal to, or perhaps slightly less than, this figure.

If a baffle of regular shape, say a square or circle, is used, it is found that a frequency about double the lowest frequency for which the baffle is designed there is a sharp dip in the response. This is due to the wave radiated from the back of the cone tending to cancel the normal radiation from the front at this particular frequency. Referring back to Figure 12, and the discussion relating to that diagram, it will be seen that at an instant of time when the diaphragm is moving forward an air compression is being set up in front while at the same moment an air rarefaction, or partial vacuum is created behind. This means, that at, any given moment the air waves radiated forward and backwards are 180° out of phase.

In the case of a listener situated on the axis, and in front of the cone, as at O in Figure 16, it must not be imagined that all the sound he hears comes from the front of the cone alone. It must be remembered that sound waves (particularly low frequency sound waves with which we are dealing at the moment) are capable of bending around corners. Hence some of the sound heard at O will have originated at the back surface of the cone. In the absence of a baffle, the sound waves arriving at O from front and back surfaces will be practically 180° out of phase and partial cancellation will result. This type of cancellation of two waves is called "destructive interference". Actually the purpose of a baffle is to alter the 180° phase relationship between the two waves, and so prevent this destructive interference. When a baffle is used, the wave from the back of the cone has to travel an extra distance equal to AB + BC (Figure 16) in getting to the point O, compared with the distance travelled by the front-surface wave. This distance is called the "path-difference" of the two waves. The effect of this extra path difference is to delay the wave from the rear surface by a time equal to that taken for it to travel the distance AB + BC. This alters the 180° phase relationship between the two waves, and so prevents (or at least reduces) the destructive interference. When, however, the path difference equals one wavelength(corresponding to a phase change of 360°) the two waves which start out from their respective surfaces 180° out of phase are once again 180° out of phase when the one from the back of the cone reaches the point C

(Figure 16). Hence for that particular frequency for which the path difference AB + BC equals one wavelength the situation is much the same as if no baffle were present, and serious destructive interference between the two waves results. The net effect is a sudden dip in the response curve at this frequency.

It will be observed (Figure 16) that the path difference is measured from a point A on the edge of the cone outwards to the edge of the baffle, then down the front of the latter to the edge of the cone again. In the case of a square baffle the path difference may be taken as the length of the side of the square minus the cone diameter. Thus in the case of a 36" square baffle and an 8" cone the path difference is 36" - 8" = 28" = 2-1/3 feet. This distance equals one-wavelength of a sound wave when the frequency is

$$\frac{1120}{2\frac{1}{3}} = \frac{1120}{7} \times 3 = \frac{3360}{7} = 480 \text{ cycles per sec.}$$

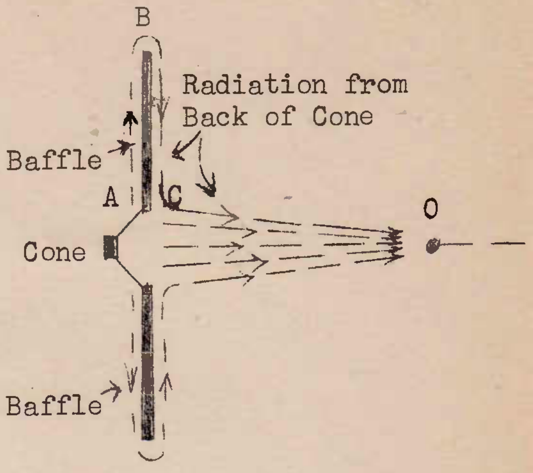


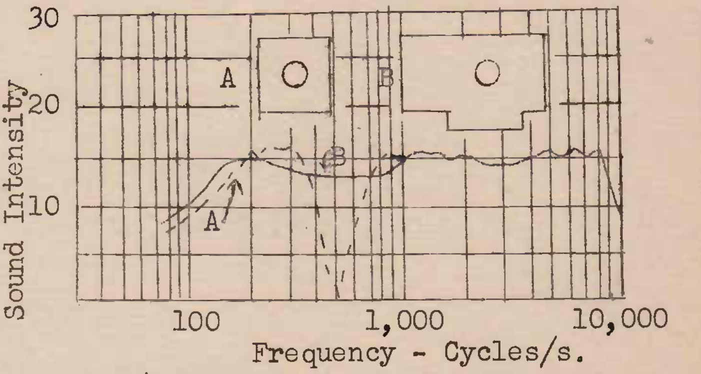
Figure 16.

Somewhere around this frequency a serious dip in the sound intensity measured in front of the speaker would result.

The effect described above may be greatly reduced by the use of an irregularly shaped baffle, where the path differences, measured from back to front of the cone, vary considerably. For such a baffle the destructive interference of the two waves is spread over a wide frequency range. Instead of a pronounced dip in the vicinity of one particular frequency, we then obtain only a negligible reduction in intensity spread over this frequency range, as shown in Figure 17.

RADIO CABINETS.

The receiver cabinet is not merely a container to house the chassis, but also serves the purpose of a baffle, separating the two surfaces of the speaker cone by an appreciable air path. For good low frequency response the shortest air path from the back of the cone, out the back of the cabinet, to the front surface of the cone should be as long as possible. Since there are a number of paths of different lengths by which the sound waves emitted from the back of the cone can pass to the front of the receiver, the cabinet acts like an irregular baffle, and the effects of destructive interference of the sound waves are not serious being spread over a wide frequency range as in curve B of Figure 17.



Showing effect of destructive Interference of Waves from front and rear surfaces of cone in case of, A, Square Baffle, and B, Irregular Baffle.

Figure 17.

RESONANCE IN RADIO CABINETS.

The enclosed (or semi-enclosed) volume of "air" within a radio cabinet has a natural or resonant frequency of vibration of its own. This resonant frequency in the case of the average floor-model cabinet is usually about 140-150 cycles per sec. When the speaker is emitting a frequency coinciding with this resonant frequency of the cabinet, the resonant effect causes a peak in the output. Such a peak it must be remembered, is equally as bad as a "dip" in the output if high fidelity is desired.

Cabinet resonance effects may be minimised by proper design and location of the parts to break up the large air mass into a number of smaller masses.

MECHANICAL RESONANCE IN SPEAKERS.

Another effect which may detract from the linearity of the frequency-sound intensity curve of the acoustical system is that due to a mechanical resonance effect of the voice-coil assembly. The voice-coil is suspended by the "spider" which gives an elastic support, allowing the coil to vibrate under the influence of the forces electro-magnetically generated within it. There is one particular frequency (about 100-150 cycles per sec. in the case of the ordinary 8" speaker) at which the voice-coil tends to oscillate of its own accord. When the sound frequency coincides with ths, the amplitude of oscillation becomes very great, causing a peaking effect in the response curve.

Actually, in the case of the ordinary low-fidelity receiver this speaker resonance is usually taken advantage of to boost the bass notes. It occurs at a frequency somewhat lower than that at which the low frequency response begins to deteriorate, and therefore gives a "boost" at frequencies where such is desirable. However, when really high-fidelity results are required this method of increasing the bass response is not a very good one. For such purposes it is therefore desirable to use a speaker in which the voice-coil's mechanical resonant frequency is below the lowest frequency which is to be reproduced.

HIGH FIDELITY REQUIREMENTS.

So far we have investigated the problems encountered in obtaining an acoustical output which is uniform over a considerable frequency range. It has emerged that for the low frequencies a large cone area, together with a proportionately large voice-coil unit is required, whereas best results are obtained in the high frequencies range when using a small cone and voice coil. It has been explained how, using a single speaker, the low frequencies are improved by using a large "baffle" area (in the form of a cabinet), and how the high frequency range is extended to some extent as a result of the corrugated construction of the cone.

We have seen that the ordinary radio receivers acoustical system is capable of producing a sound output which is reasonably uniform over a range from, perhaps 100 cycles per sec. up to approximately 3000-4000 cycles per sec., despite certain "peaks" and "dips" resulting from such phenomena as "destructive interference" of air waves travelling by different paths, mechanical resonance of voice-coil, and cabinet resonance. Such a performance, while adequate for the low fidelity signal carried by an A.M. carrier is really not good enough if the full advantages of the high-fidelity F.M. signal are to be enjoyed.

We shall now describe methods whereby, firstly, the high frequency range, and then the low frequency range, may be improved.

A WIDE-RANGE MOVING COIL SPEAKER.

In the case of the conventional speaker it was pointed out that the upper frequency limit (3000 -4000 cycles per sec. for an 8" cone) was set by the mass effect of the moving coil itself. For higher frequencies the effective mass of the latter must be reduced.

Figure 18 shows diagromatically the construction of the moving coil of a speaker which provides this requirement.

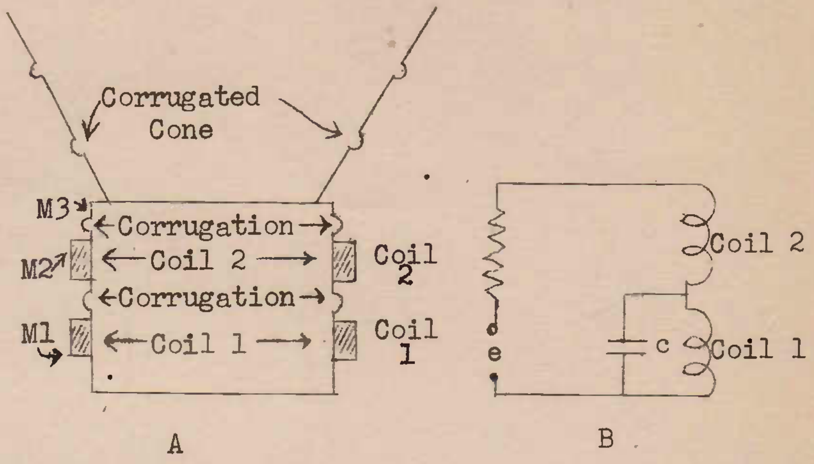


Figure 18.

The voice-coil is divided into two sections, connected in series as shown at B. The voice coil cylinder is divided into three separate masses (shown as M1, M2, M3 at A) by two elastic corrugations.

Below 1,000 cycles per sec. the unit moves as a whole, and both coils are effective, acting as a single coil as in an ordinary speaker. In the range 1,000 - 4000 cycles per sec. the action is gradually transferred to coil 2 alone. In this range the corrugation between the two coils begins to "give", and, at the same time, coil 1 becomes partially by-passed, as far as the A.F. current is concerned by condenser C (Figure 18B).

In the range 4,000 - 6,000 cycles per sec. coil 2 above is effective, the first corrugation allowing it to move, while coil 1 remains almost at rest. At the same time, in this range the by-passing action of the condenser is practically 100% complete.

Above 6,000 cycles per sec. the corrugation between coil 2 and the remainder of the cylinder (M3) becomes partially effective, thus reducing the effective mass upon which the coil has to act.

The net effect of this action is that the mass of the vibrating voice unit is progressively reduced, thus off-setting the reduction in amplitude of oscillation which would result if the mass remained constant. This type of speaker is capable of a uniform response over practically the entire audio range.

DUAL SPEAKERS.

Perhaps the best method of securing wide-range reproduction is by using dual speakers - one for the low notes (bass) and one for the higher frequencies (treble). The low frequency speaker is usually of large diameter (12" and more), has a rigid cone (i.e. no corrugations), and is fitted with a large voice coil necessary to drive the heavy cone adequately for low frequency operation. The treble speaker is smaller and of particularly light construction (especially as regards the voice-coil). The two —

speakers are mounted close together in order to produce correct phasing of the sound waves.

The bass speaker usually handles frequencies up to only 400 cycles per sec. Above this the treble speaker alone is effective. Since the latter is not called upon to handle anything below 400 cycles per sec. it may be designed to reproduce very high frequencies indeed.

The acoustical power from the output stage is divided for the two speakers by means of a special filter circuit having a "cross-over" point at 400 cycles per sec. A typical circuit is shown in Figure 19 together with the frequency characteristic for the two filter sections. Below 400 cycles per sec. the reactance of C_2 is high and that of L_2 is low, with the result that practically no output appears across L_2. This prevents damage to the more delicate H.F. unit by the L.F. currents. At these frequencies the reactance of L_1 is low and that of C_1 is high. Since L_1 and C_1 in series form a voltage divider, practically all the output appears acorss C_1, and is thus applied to the large speaker.

Above 400 cycles the reactances of C_1 and C_2 become comparatively low, and those of L_1 and L_2 comparatively high. The net result is that at these frequencies practically the full output appears across the treble speaker, and a negligibly small amount across the bass.

The curves of Figure 19B show that such a circuit has a very sharp "cross-over" point, and that the impedance of the whole unit remains remarkably constant for all frequencies.

Figure 1 of this lesson showed a single unit which incorporates dual, but separate speakers, In this unit the H.F. speaker is really a horn type, the small horn passing through the centre of the voice-coil which operates the L.F. cone. The H.F. horn is of "cellular" construction to flare out the sound waves which have a tendency to be concentrated in a beam at the very high frequencies.

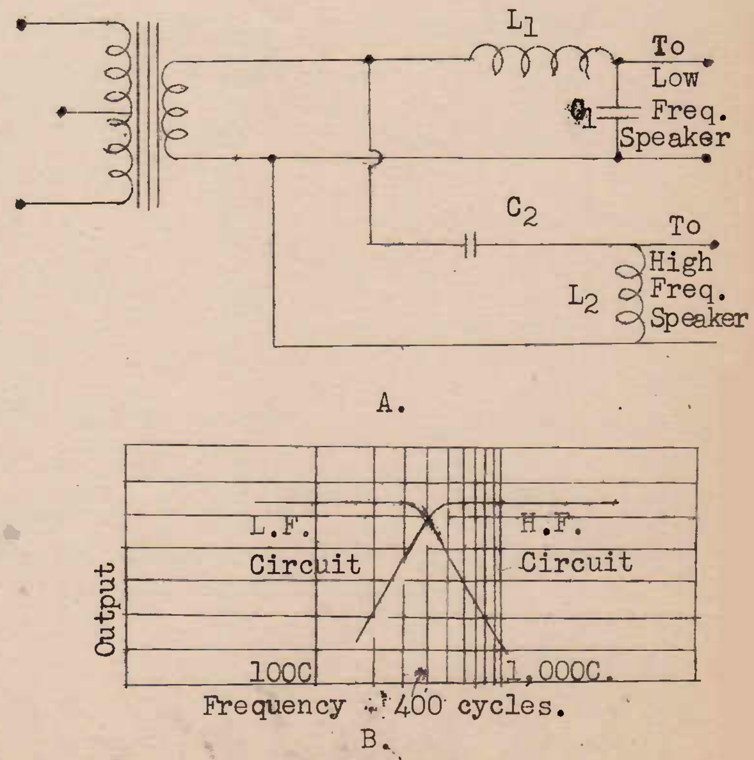


Figure 19.

IMPROVING THE BASS RESPONSE - THE ACOUSTICAL LABYRINTH.

At very low frequencies even with a large speaker, it has been pointed out that the response drops off due to the cone simply "pumping air" from one side to the other. Or, what amounts to the same thing, it may be imagined that the two waves radiated from the two surfaces partially cancel each other.

The speaker cabinet, acting as a baffle will, if large enough, prevent this effect. But from the data given under the heading of "Baffles" it will be realised that an extremely large cabinet would be required to handle adequately frequencies down to say 40 or 50 cycles per sec.

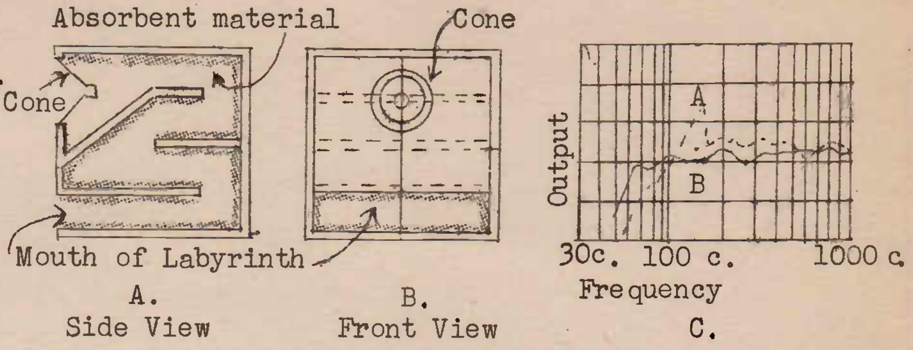


Figure 20 - The Acoustical Labyrinth.

This improvement in the bass response may be realised by use of an "Acoustical Labyrinth". The dictionary definition of a "labyrinth" is a "winding or tortuous passage or path". This is exactly what the acoustical labyrinth is - as far as the sound wave radiated from the rear surface of the speaker cone is concerned.

The construction of the labyrinth will be understood after reference to Figure 20 where, at A, a cross sectional view , and at B a front view, are shown.

As seen here, we have a folded passage-way, lined with sound absorbent material, leading from the back of the speaker, and opening out at the front of the cabinet. The length of the passage is usually equal to 1/4 wave-length of a sound wave having a frequency equal to the speakers mechanical resonant frequency, say 75 cycles per sec. for a large good quality speaker. It is found that an open-ended passage-way of air like this, produces a form of anti-resonant effect at a frequency for which its length equals 1/4 wavelength. This anti-resonance is taken advantage of to off-set the mechanical resonance at about 75 cycles per sec.

At double this frequency, viz. 150 cycles per sec. the air column in the labyrinth tends to resonate, but no apparent peak in the output results because this is about the "cut-off" frequency of the system. For higher frequencies than 150 cycles the speaker is unable to vibrate the large volume of air in the labyrinth, and the rear surface wave from the cone is entirely absorbed. Above this cut-off frequency, in other words only direct radiation from the front of the cone occurs.

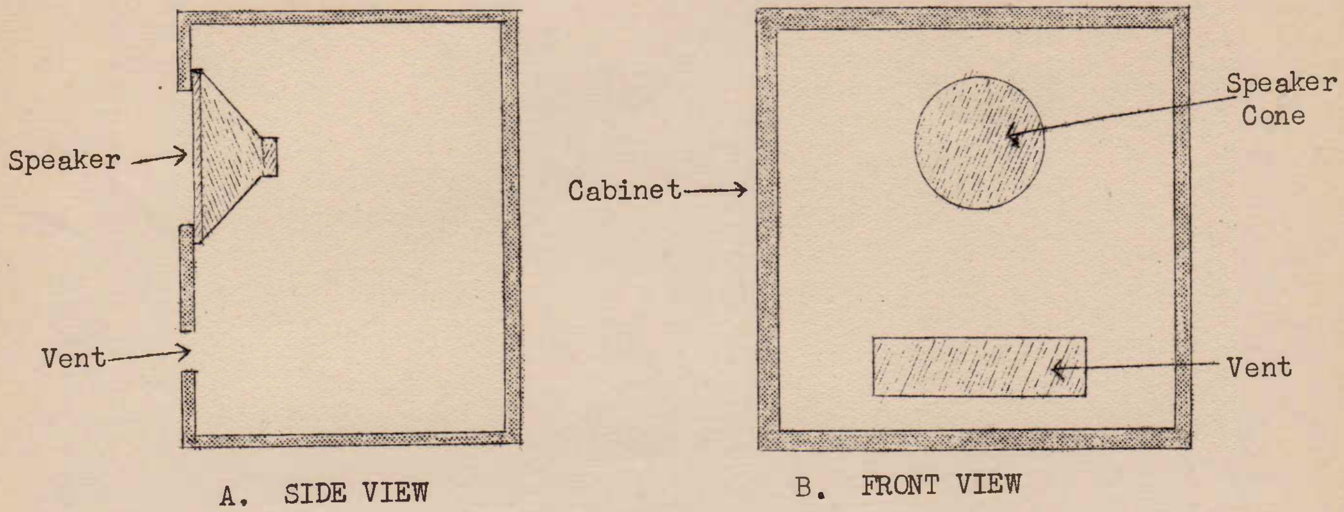
Another merit of the acoustical labyrinth is that is prevents cabinet resonance, by removing the large volume of air normally enclosed. Fig. 20C shows the effect of a labyrinth on the low frequency response. Curve A is for a normal cabinet without a labyrinth. Note the sharp peak due to cabinet resonance. Curve B shows the improvement obtained by incorporating a labyrinth. Note that the peak due to cabinet resonance no longer occurs. The curves also show improvement in the very low frequency response.

If a dual speaker system is used, the H.F. speaker may be mounted above the L.F. unit, a shelf may separate the two, and the labyrinth built into the bottom only.

THE VENTED "BAFFLE" OR VENTED ENCLOSURE.

The acoustic labyrinth, as a device for improving the response curve in the low frequency range, and extending this curve downwards to the very low (bass) frequencies, is rather a costly arrangement. A cheaper method of securing these advantages it to make use of a special type of baffle system known variously as Vented, Tuned or Reflex

Enclosure or Baffle.



A. SIDE VIEW B. FRONT VIEW

The Vented Enclosure. Fig. 21.

We have seen that the chief defects of the low frequency response in the case of a speaker mounted in an ordinary cabinet are :-

(1) Insufficient "baffle" area, resulting in loss of the very low frequencies due to rear surface and front surface waves cancelling.

(2) Cabinet Resonance

(3) Speaker (Mechanical) Resonance. The latter two both result in undesired peaks in the lower frequency range.

The purpose of the Vented Enclosure is to control the radiation from the rear of the speaker, so as to off-set the two resonant effects mentioned above, and to extend the low frequency response of the system.

The Vented Enclosure, illustrated in Figure 21, consists simply of a cabinet (which houses the speaker) and which is completely enclosed except for a "vent" or opening in the front and preferably close to the speaker itself. The box, or cabinet is either constructed out of sound absorbent material, or lined with a suitable material, such as felt. The vent may be of any convenient shape (it is usually circular or rectangular), but its area is made equal to the <u>effective</u> radiating surface of the speaker cone.

When air is enclosed in a confined space having a single orifice or opening, the air in the orifice can be made to resonate at a particular frequency, which is governed by the <u>volume</u> of air enclosed, and the area of the orifice. A common example of this effect may be observed when a stream of air is blown across the mouth of a bottle. Another example, of course, is the conventional radio cabinet.

The volume of air in the enclosed cabinet is adjusted so that the resonant frequency of the vented enclosure is equal to the bass resonant frequency of the speaker itself.

The result is that the peak in the output due to the latter is off-set by the resonance of the enclosed air. The reason for this cancellation effect is due to the vented enclosure behaving, at resonance, in a manner analogous to a parallel resonant electrical circuit, where the impedance rises to a peak at resonance.

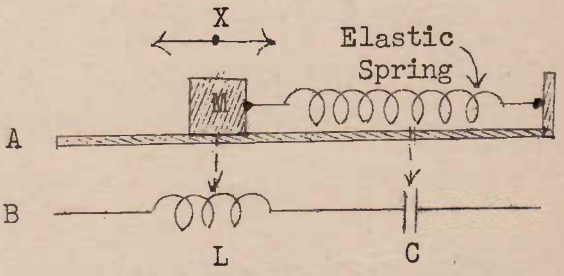
The best way to understand the action of such a system as this is to compare mechanical and acoustical resonance effects with those which occur in electrical circuits containing inductance, cpacity and resistance.

Consider Figure 22 where we represent a weight of mass M attached to an elastic steel spring which is anchored at P. For the moment we will imagine that M rests upon a perfectly smooth surface (i.e no resistance to motion). If the mass is pulled outwards (stretching the spring) and then released it will oscillate about its mean position (X) as shown, the spring being alternately stretched and compressed. If there were absolutely no resistance oscillation would continue indefinitely. In practice the oscillation would die out due to resistance effects. The frequency of oscillation depends upon two things - (1) The mass of the weight, and (2) the"stiffness" of the spring. Here it would be better to speak of the "compliance" of the elastic spring, the latter quality being the reciprocal or opposite of the stiffness, so that a spring of great stiffness would have only small compliance and vice versa. In this mechanical system an increase in mass of the weight would result in a lower resonant frequency of oscillation, and vice versa. This is due to the property of inertia and momentum of a mass, whereby there is a tendency to oppose any change (increase or decrease) in its velocity.

Hence "Mass" may be likened to inductance (L) of an electrical circuit as shown at B in Figure 22. Consider now the effect of the compliance of the spring upon the frequency of oscillation. If the compliance is increased (i.e. "stiffness" decreased) the resonant frequency would be lowered, and vice versa. Thus the compliance of an elastic system may be compared with the capacity (C) of an electrical circuit.

Carrying this idea further, suppose now that there is resistance to motion between the mass of Figure 22A and the surface upon which it rests. This resistance (if comparatively small) will not affect the resonant frequency, but will increase the total impedance to oscillatory motion of the system. Thus mechanical resistance may be compared with electrical resistance (R).

Consider now the conventional speaker. The moving coil and cone possesses mass which we will represent by L_s. This L_s must also take into account the air loading of the cone, for a certain mass of air (depending upon the cone area) must be moved as the cone vibrates. The compliance, represented by C_s, is due to the elastic support of the "spider" and also to a certain amount of "give" or elasticity in the cone itself. The speaker system also possesses mechanical resistance (R_s) due to imperfect elasticity, and also, due to acoustical radiation losses (just as we may take into account the loss of energy of an antenna system due to radiation by supposing the circuit to contain an extra radiation resistance).



Showing a mechanical oscillatory system (A), and its electrical equivalent (B).

Figure 22.

The electrical equivalent of the speaker is shown in Figure 23. At that frequency when the "reactance" of the mass equals the "reactance" of the "compliance" a resonant condition is set up, just as in the analogous electrical circuit. This is the bass resonance which occurs at about 70 - 120 cycles per sec. in the case of the conventional speaker.

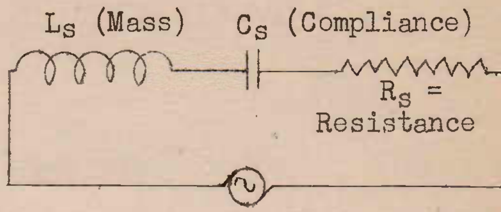
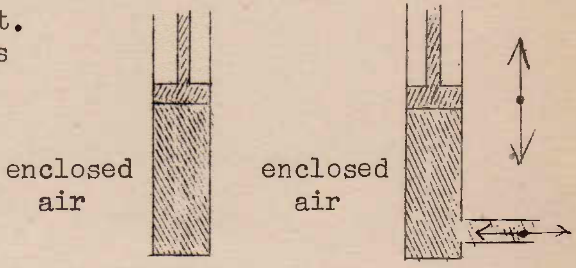


Figure 23.

Now consider a simple acoustical or air system as in Figure 24. At A we have a cylinder with a closely fitted piston totally enclosing a volume of air. Air is compressable, i.e. elastic. If the piston is pushed down, the air is compressed by an amount depending upon the force applied and the volume of enclosed air. This volume of air therefore possesses "stiffness" and, hence, "compliance", corresponding to capacity of an electrical circuit. If the air is totally enclosed it does not possess any appreciable mass reactance, corresponding to inductive reactance. Hence an enclosed air mass cannot have a resonant frequency of oscillation, just as a circuit possessing capacity only has no particular resonant frequency.



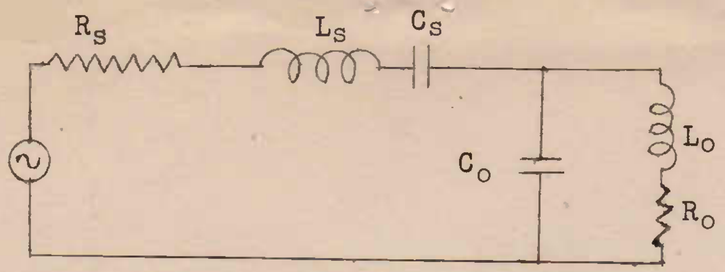
A. B.

Figure 24.

At B (Figure 24) the partially enclosed volume of air has a vent or opening via the pipe as shown. If the piston is rapidly moved up and down, the air will be alternately compressed and rarefied, and an oscillatory flow of air will take place through the pipe. Within the pipe the rate of flow of air will be rapid, and the "reactance" of its mass will exert an appreciable effect. The mass of the air within the pipe, or vent will thus act like inductance in an electrical circuit.

Returning now to the problem of speaker response, suppose we enclosed the back of the speaker in a totally enclosed box. The wave radiated from the back of the cone would be completely contained, and could not have any effect on the front surface radiation. In this respect the enclosed box would act like an infinite baffle, and it might be expected that very good low frequency response would be obtained. Although some improvement may thus be obtained, under certain conditions, another effect off-sets the improved baffle action. The compliance of the enclosed air volume is in series with the speaker compliance, and therefore increases the effective stiffness of the moving coil and cone. At low frequencies the "reactance" of this compliance becomes large, and reduces the amplitude of the cone movement. As a result the acoustic output will fall off rapidly as the frequency decreases.

In the case of the vented enclosure the corresponding electrical circuit is shown in Figure 25. The symbols represent effects due to the properties of the system shown under the diagram. Note that L_o is due to the mass of air only in the immediate vicinity of the vent. The air in this region will be moving rapidly in and out of the opening. In actual fact at low frequencies the air at the vent will be vibrating in exactly the same manner as that in the immediate vicinity of the cone itself. Hence at these frequencies, the vent cross-section acts just like a vibrating diaphragm.



R_s = Cone Support Resistance + Radiation Resistance

L_s = Moving Coil + Cone Mass + Mass of Air in vicinity of cone.

C_s = Cone and "Spider" Compliance.

R_o = Acoustic Losses in Enclosure.

L_o = Mass of Air in and near Vent.

C_o = Compliance of Enclosed Air Volume.

EQUIVALENT ELECTRICAL CIRCUIT OF SPEAKER IN VENTED ENCLOSURE.

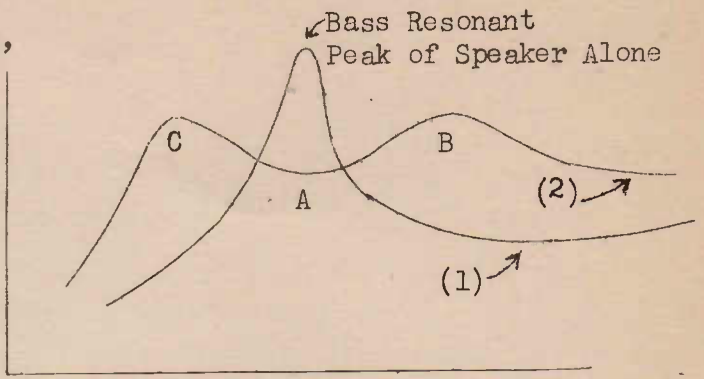
Figure 25.

It will be observed that in the diagram (Fig. 25) L_s and C_s (of Speaker) form a series resonant circuit, while L_o and C_o (due to the vented enclosure) form a parallel resonant circuit, in series with the speaker. The enclosed volume is so proportioned in respect to the vent area (and therefore to the latters air mass) that L_o and C_o resonate at the same frequency as L_s and C_s, the latter being the bass resonant frequency of the speaker itself. In this circuit L_o C_o presents a high dynamic impedance at resonance. This impedance, being in series with L_s and C_s reduces the current through the latter, which current would otherwise be large due to the series resonance of these components.

From the physical view-point, what happens is this. When the vented enclosure resonates, there is a large movement (oscillatory) of air in the vent, but the resonant effect is such that it imposes a large opposing impedance on the back of the speaker. The result is that the speaker cone is held practically stationary, at this frequency which normally would result in large cone movements. Actually at the bass resonant frequency of the speaker, practically all the sound output comes from the vent opening. The effect of the parallel resonance effect of the vented enclosure in cancelling the speakers bass resonance is shown at A in Figure 26.

At frequencies above the common resonant frequency of the speaker and vented enclosure the tuned circuit L_o C_o of Figure 25 becomes capacitive, (being a parallel circuit) while the series circuit L_s C_s becomes inductive. At some particular frequency the capacitive reactance due to the vented enclosure resonates with the inductive reactance of the speaker, and a subsidiary peak, shown at B (Figure 26) results. Below the resonant frequency of either circuit alone, L_o C_o becomes inductive while L_s C_s becomes capacitive. At some particular frequency these inductive and capacitive reactances are equal and a series resonant effect resulting in the peak in output shown at C (Figure 26) results.

Summarising, Figures 25 and 26 show how the vented enclosure acting in conjunction with the speakers mechanical resonance improves the low frequency response, by yielding two separate resonant peaks of comparatively small amplitude, and spread over a considerable frequency range. The effect is exactly comparable with the wide band-pass obtained in I.F. amplifiers when using a pair of over-coupled tuned circuits to yield the "double-hump" effect. Not only does the vented enclosure level off the response curve over the bass frequency range, but extends this range downwards to a considerable extent, as a comparision of the two curves of Fig. 26 will show.



Curve (1) - Speaker in ordinary baffle.
Curve (2) - Speaker in vented enclosure.

Figure 26.

The vented enclosure may be utilised to house the receiver apparatus. A separate cabinet is not a necessity. Of course the presence of this electrical equipment within the enclosure would reduce the effective volume of enclosed air, and this must be taken into account in adjusting the resonant frequency. A typical enclosure using a 12" speaker whose resonant frequency when loaded in an "infinite" baffle is 60 cycles per sec. would about 12" deep, 20" wide and 49" high. The vent would be a single circular hole approximately 9" in diameter, or a rectangular aperture about 16" x 4".

SECTION B. - RECEIVER TYPES AND CONSTRUCTION.

If an F.M. receiver is to fulfil its special purpose, viz. higher quality sound reproduction with freedom from interference, it requires, as we have seen, more circuit components, also more careful design and construction than to be found in the average A.M. receiver. The great desirability, if not the absolute necessity, for high quality audio systems, involving large reserves of power output, large speakers and cabinets (for adequate baffle action) practically rules out the small mantel set and the dry battery portable type.

Then again we have to consider the fact that F.M. is not (for many years at least) entirely supplanting A.M. This means that many people will demand a receiver capable of receiving signals from all station - F.M. and A.M., and this adds to the complication.

HOW MANY VALVES ?

Owing to the higher frequency of operation (R.F. and I.F.), and the necessity for the flat-top on the I.F. selectivity curve, the gain per stage is very much less than with an ordinary A.M. broadcast receiver. A good F.M. 8-valve receiver may actually be less sensitive than a 5-valve A.M. receiver on the medium wave band. This reduced gain per stage would be even lower, only that high gain valves are used in the R.F. and I.F. stages, with transconductance two or three times normal.

Using these special valves, designed for F.M. work, it would appear that the minimum number of valves required (for F.M. reception only) is eight, comprising R.F. amplifier (6BA6), Converter (6BA6) 1st I.F. Amplifier (6BA6), 2nd I.F. Amplifier (6BA6), Ratio Detector (6HG-GT), A.F. Amplifier (6SQ7-GT or equivalent, e.g. 6SF7-GT), Power Amplifier (6V6-GT) and Rectifier (5Y3-GT). The valve type numbers in brackets are suggested types only. A smaller and cheaper set could possibly omit either the r.f. Amplifier or one I.F. stage. Such a receiver, however, would only be satisfactory in areas of high signal intensity, e.g. in the inner metropolitan area.

It is stressed that the arrangement given above would represent only a quite unambitious receiver. For a larger receiver designed for those demanding the maximum in high fidelity reproduction, at least an additional two valves would be required - a phase splitter and an extra power output valve for push-pull. Then again the larger receiver possibly would incorporate a discriminator detector together with a limiter stage or stages. This would mean an additional valve if one stage of limiting were used, or two additional valves if two limiters (or alternatively an extra I.F. amplifier) were incorporated. Such a receiver would therefore required up to 11 or 12 (or even more) valves.

DISCRIMINATOR OR RATIO DETECTOR ?

The Ratio Detector was described in an earlier lesson, and several of its more obvious advantages pointed out there. Let us now compare the two detection systems in greater detail.

Advantages of the Ratio Detector over the Limiter - Discriminators are :-

(1) No necessity for "limiters" which contribute practically nothing to the receiver's gain.

(2) Less I.F. and R.F. gain required, as there is no "threshold" level to be reached at the detector stage input. The reduced high frequency gain in turn minimises difficulties relating to instability due to regeneration in these high-frequency stages, and also minimises the tendency for "noise" voltages to phase - modulate the signal.

(3) The Ratio Detector affords the same degree of immunity from interference on the very weak signals as on the strong, whereas the Limiter Discriminator detector may fail to provide any noise suppression whatever on the very weak signals.

(4) The Ratio Detector probably suppresses impulse interference (where the carriers may be momentarily entirely "blotted out") more effectively than does the Limiter Discriminator.

On the other hand the Ratio Detector appears to suffer several disadvantages as compared with the Limiter-Discriminator -

(1) It introduces slightly more distortion.

(2) It is more difficult to align for linear conversion.

Summarising, it appears that, certainly in all receivers where it is desired to limit the number of valves used, the Ratio Detector is to be preferred. Probably, however, in the case of the higher priced quality receivers, where the number of valves incorporated is not an important consideration, the Limiter - Discriminator will be retained.

COMBINING A.M. AND F.M.

The greatest difficulty is that of providing a receiver, at reasonable cost, which is capable of handling both F.M. and A.M. signals.

Possible combinations are :-

(1) F.M. and medium wave broadcast A.M. only.

(2) F.M./A.M. - dual wave.

(3) F.M./A.M. - all-wave or multi-band.

(4) F.M./A.M. - short-wave band only.

(5) F.M./A.M. - multi short-wave bands only.

If completely separate channels are provided for the A.M. and F.M. signals in those combined receivers, it is obvious that a very large number of valves and other components would be required. This, of course, would result in a very expensive receiver.

There is no difficulty in using a common audio section for the two types of signals, but for best results it is considered that separate R.F. and I.F. channels are required. The higher priced receivers in America are of this type, using up to 24 valves in all.

To provide a combined F.M. and A.M. receiver of reasonable cost, however, it is necessary to use the same valves for both signal types. Although this involves several difficulties it is quite a practical scheme.

COMBINING F.M. AND A.M. HIGH FREQUENCY CHANNELS.

With this arrangement, separate r.f. coils and I.F. transformers must of course, be used for the F.M, the A.M. medium band, and the A.M. short-wave band(s) (if any). The switching must, therefore, cover the aerial coils, r.f. transformers, oscillator coils, also possibly I.F. transformers, and small shunt or series condensers in each section of the gang condenser.

Difficulties to be overcome are a result of the high mutual conductance valves necessary for F.M. These are actually beneficial on the A.M. short-wave bands, although over-loading of the converter is likely to occur on strong signals. This effect, however, is easily overcome by reducing the gain of the R.F. transformer.

If ordinary transformers were used on the medium-wave A.M. band the gains of the stages would be so high as to be impracticable. Valves would be overloaded, and difficulties experienced due to regeneration causing self-oscillation (i.e. instability). To avoid these troubles a number of expedients are used such as reduction of gain by using high-loss transformers, heavy shunting by resistors across the coils, tapping down of the transformers, or a combination of two or more of these.

When a common I.F. channel is used for both A.M and F.M., a common arrangement to simplify the over-all switching mechanism is as follows :-

In each stage the two I.F. transformers' primaries and secondaries are connected in series, the F.M. coil boing closer to the plate or grid of the valves as shown in Figure 27. When receiving F.M. the 10.7 mc. transformer's primary has a high dynamic impedance at its resonant frequency and keeps the signal out of the 450 K.C. A.M. transformer. On switching to A.M. the F.M. transformer's primary acts like a short circuit at 455 K.C. and allows the 455 K.C. signal to pass on to its proper transformer, In order to avoid any possibility of interference from high-frequency signals which may reach the I.F. stages, the switching arrangement sometimes provides a short-circuit across the F.M. transformers when receiving A.M.

CONSTRUCTIONAL DETAILS - LAYOUT OF RECEIVER.

The chassis layout of the different stages and components of an F.M. receiver follows the same general technique as for A.M. receivers. Shielding in the R.F. and I.F. stages, however, must be even more efficient than that to be found in a modern A.M. type.

All coil units and I.F. transformers, including the discriminator transformer (which consists of a primary in the plate circuit of the limiter, and, a centre-tapped secondary connecting to the two detector diodes) are enclosed in metal cans, as in usual practice.

All leads carrying high-frequency currents should be as short as possible to reduce stray wiring capacities. As already mentioned all valves are of the single ended-type, i.e. no grid-cap is used. This allows of short leads from the plate circuit of one stage to the grid of the following valve.

The usual precautions to keep 50 cycles per sec. power supply voltages out of the circuits should be taken. This envolves such points as adequate magnetic shielding of the power transformer, reasonable isolation of the rectifier valve and circuits, and twisting together the heater leads. It may be mentioned here that any 50 cycle fluctuation applied to the converter valve may give rise to a 50 cycle frequency modulation of the I.F., which will appear as a 50 cycle (not 100 cycle) hum in the speaker output. This is due to the varying voltages applied to this valve affecting the input capacity due to the "Miller-effect". Such capacity, of course, helps to determine the oscillator frequency. If this frequency is thus caused to vary at 50 cycles per sec. so will the resulting intermediate frequency.

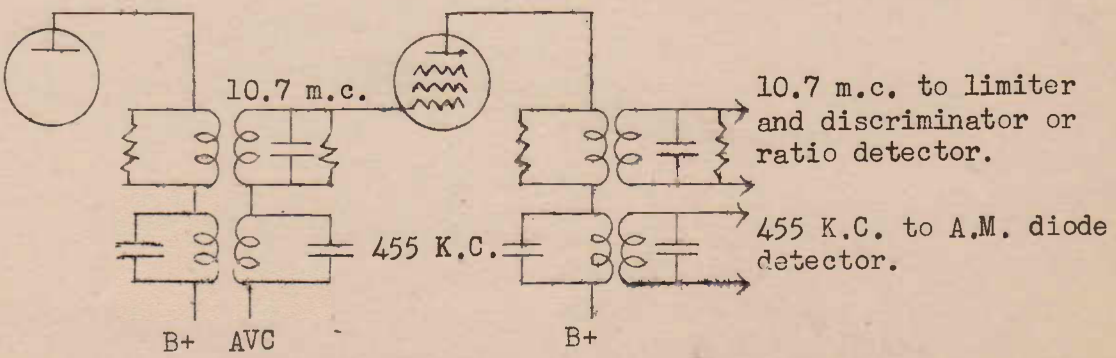


Figure 27.

EXAMINATION QUESTIONS - LESSON NO. 17.

1. Explain briefly the purpose of high audio frequency de-emphasis in an F.M. receiver ? Where, in the receiver, is this de-emphasis effected ?

2. Why is adequate power handling capacity a very important consideration in an F.M. receiver ?

3. With reference to a power output transformer what is meant by "Leakage Inductance ?" What is the effect on the output of an undue amount of leakage inductance ?

4. What are the requirements of a loud-speaker for high efficiency at
   (a) very high frequencies ?
   (b) very low frequencies ?

5. What is the purpose of the "corrugations" in the cone of the usual type of speaker?

6. What places the final limit on the high-frequency response of the usual type of speaker ?

7. What is the purpose of a "baffle ?" What should be the minimum dimensions of a baffle designed for full response down to 150 cycles per sec. ?

8. Why is an irregular baffle to be preferred to one of regular shape ?

9. Name two types of non-electrical resonance effects which may mar the output of a speaker system ?

10. What factors determine the required volume of a vented enclosure ?

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T.FM & F. LESSON 18.
INSTALLATION, ALIGNMENT AND SERVICING OF F.M. RECEIVERS.

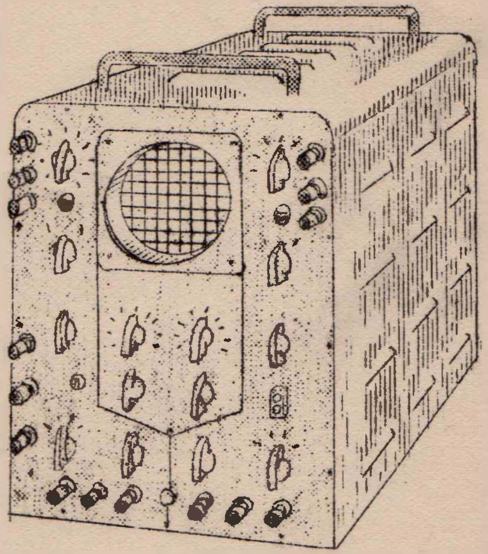
EQUIPMENT REQUIRED FOR TESTING AND SERVICING F.M. RECEIVERS:

The two outstanding virtues of F.M. are :

1. A substantial improvement in signal to noise ratio.
2. Its ability to produce a wide-range acoustic output with very low distortion.

In order to take full advantage of these potentialities of F.M. the design requirements of an F.M. receiver are more stringent than those of the A.M. type, and the adjustment and setting up (alignment etc.) should be even more carefully carried out. In the case of the ordinary low-fidelity A.M. receiver even quite large errors in alignment and other adjustments may not result in a perceptible falling off in the quality of the output. This is because the frequency range of the acoustic output is so limited in the system, and because distortion, at the best is not particularly low, and consequently the ear does not appreciate further deterioration in quality until the adjustments to the circuits are well off their correct values. In a good F.M. receiver, on the other hand, almost perfect reproduction is possible when the set is properly set-up, and equipped with a good quality loud-speaker. As a result any distortion, noise and departure from linearity in the acoustic output curve introduced by even quite small errors in voltage and tuned circuit settings become, by comparison, quite noticeable to a critical ear. It behoves the serviceman, therefore, to acquire the knowledge and skill necessary to carry out scientific and accurate methods of aligning and otherwise adjusting F.M. receivers.

Despite what has been said above, however, it should not be thought that there is anything particularly difficult in servicing an F.M. receiver, nor is any large amount of new and unusual equipment necessary.


A CATHODE RAY OSCILLOSCOPE.
FIGURE 1.

The following is a list of equipment which is adequate to carry out all routine tests, fault-finding and alignment of an F.M. receiver.

(1) A multimeter incorporating the usual voltage and current ranges and an ohm-meter (for continuity tests).

(2) A screw-driver of low-loss insulating material.

(3) A V.H.F. Signal Generator (unmodulated) covering the frequency range 88-108 m.c. per sec.

(4) An R.F. Signal Generator (unmodulated) covering the I.F. band usually 10.7 m.c. per sec.

Items 3 and 4 will probably be the one instrument.

In addition to the above the following equipment is desirable :

(1) A centre-zero scale micro-ammeter reading to about 50 or 100 microamps on either side of zero. This is useful for certain tests on the discriminator.

(2) A 0-100 microamp-meter as an output meter for alignment adjustments. If this is not available the 0-1 milliamp range of a multimeter can be used.

For servicing commercial receivers which, it is assumed, are correctly designed in the first place, the above equipment is entirely adequate. Other more costly equipment which although not essential is desirable, particularly if alterations to circuit design are to be made, is described later in this lesson. This includes :

(1) A Frequency-modulated Signal Generator covering the I.F. of the receiver (10.7 m.c.) and producing a frequency deviation of ± 75 Kc per sec.

(2) A Cathode-Ray Oscilloscope.

(3) A valve voltmeter.

(4) An audio oscillator covering the range 30-15,000 cycles per sec.

ROUTINE TESTS AND FAULT-FINDING:

Most faults in any type of receiver are due to broken down resistors and condensers, and broken or short-circuited leads. Such faults involve open and short circuits. The technique of locating such faults in an F.M. receiver is exactly the same as for an A.M. receiver. The only instrument required is a continuity tester or ohm-meter.

Concerning voltage checks it is important to remember that any departure from the correct values may have, relatively, a more serious effect in an F.M. receiver than in the case of an A.M. receiver. Particular care should be taken to adjust accurately the plate, screen and bias voltages of the power output tube(s). Wrong values here introduce distortion which mars the normal high-fidelity of the output. Again, low voltages on any of the R.F. or I.F. valves may reduce the pre-detection gain to such a point that the limiter does not operate to saturation, with the result that the noise level is higher than it should be. Thirdly, very important voltages to check are those on the plate and screen of the limiter(s). These should be much lower than customarily used on an ordinary amplifying valve. Typical values lie between 25 and 40V, depending upon the valve used and the receiver design. The correct value should be ascertained from the data supplied by the manufacturer of the particular receiver under test. A limiter plate and screen-voltage which is too high may mean that the stage is not working at saturation (as it should), and amplitude variations of the signal will be passed. The result will be a high noise-level in the output. On the other hand a voltage which is too low will result in inadequate speaker output (low volume). In this connection it should be remembered that the limiter fixes the level of the I.F. signal which is applied to the discriminator for detection.

RECEIVER ALIGNMENT:

The essential receiver tests to be carried out are as follow :

(1) Alignment of the Discriminator.

(2) Adjustment of the Limiter.

(3) Alignment of the I.F. stages.

(4) Alignment of the R.F. stages including oscillator and R.F. circuit trimmer adjustments for correct "tracking".

(5) Customary A.F. section tests.

These tests will be explained in the order given above.

ALIGNMENT OF THE DISCRIMINATOR:

This test should be the first to be carried out (after, of course, testing all circuit voltages). The equipment necessary is :

(1) The F.M. unmodulated signal generator capable of delivering a calibrated output of 0.1 volts at the intermediate frequency.

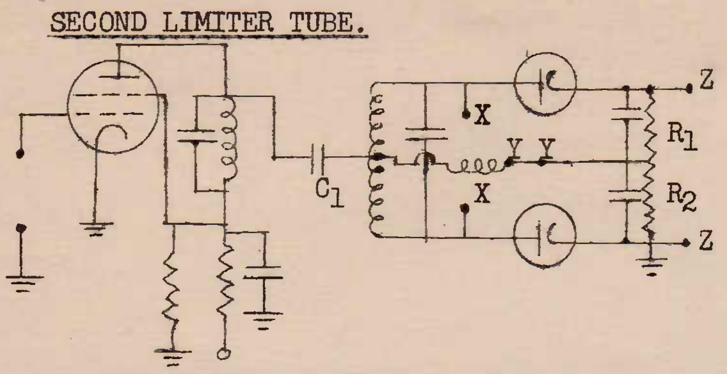
(2) The centre-scale micro-ammeter, or if not available a 0 - 1 milliammeter.

(3) The 0-100 micro-ammeter (or alternatively the 0-1 milliammeter may be used).

(4) An alignment screw driver.

A typical discriminator circuit, together with the preceding limiter is shown in Figure 2. The Signal generator output is adjusted to the I.F. of the receiver (usually 10.7 m.c) and applied to the grid of the stage preceding the discriminator.

The primary of the discriminator transformer is aligned first. To do this the 0-100 micro-ammeter is inserted between the points marked Y Y in Figure 2, and a piece of wire is connected between the points marked XX. It is a good idea to carry a short length of insulated wire with a spring clip at each end for this purpose. The latter short-circuits the secondary of the transformer, and so eliminates any effects the closely-coupled secondary may have on the primary tuning. It should be remembered at this point that the r.f. voltage applied to each diode plate of the discriminator is the vector sum of the two r.f. voltages - one which is applied through a condenser (via the centre tap) from the primary transformer circuit, and the other which is developed across each half of the secondary due to the normal circulating current in this circuit. The latter is eliminated in this adjustment by means of the short-circuit XX.



TYPICAL DISCRIMINATOR SYSTEM SHOWING COUPLING TO FINAL LIMITER STAGE AND TEST POINTS. VALUES FOR THE KEYED COMPONENTS ARE C_1 - 50 mmf.; R_1, R_2 - 0.1 megohm.

FIGURE 2.

The primary coil of the transformer is now adjusted until the micro-ammeter at YY shows a maximum reading. Note that this meter is reading the total rectified currents of the two diodes. A maximum reading here indicates, therefore, that maximum voltage is being applied from the primary. The primary will therefore be peaked at the correct I.F.

Next to align is the secondary of the discriminator transformer. The short-circuit is removed from XX, and the meter removed from YY. The centre-scale micro-ammeter is converted into a high-impedance voltmeter by connecting a one megohm resistor in series with it. This meter is connected across the discriminator output, between the points ZZ of Figure 2. For a signal equal to the centre-frequency of the I.F. the secondary circuit of the transformer should be at resonance, so that the r.f. voltages developed across each half of the coil, and applied to the diodes, should be equal, resulting in zero output between ZZ. If the meter shows a deflection on either side of zero this therefore indicates that the secondary is not correctly adjusted. Adjustment is therefore made until a zero reading on the output meter is obtained.

It is of importance to remember that both terminals of the transformer secondary condenser are well above ground potential, and, therefore, a well insulated screw driver is needed for this adjustment. The adjustment is, besides, rather critical since it balances the discriminator.

An alternative method of aligning the discriminator, which avoids the use of the meter in the position YY and the short circuiting of the secondary between XX (Figure 2) is as follows :

The signal generator output is connected to the limiter-grid and the output meter connected between ZZ, as before. In the case of this method the secondary is adjusted first. Adjustment is made for a zero reading on the output meter. The frequency of the signal generator is now re-adjusted to a value say 75 K.c. per sec. above the centre frequency and the reading on the high-resistance output meter noted. Signal generator frequency is next reduced to a frequency 75 K.c. per sec. below the centre frequency. The output meter will now deflect in the opposite direction. Unequal deflections would indicate that the primary adjustment is incorrect. Hence the primary is adjusted until equal and opposite meter deflections are obtained from the ± 75 K.c. off centre frequencies. Since adjustment to the primary may de-tune the secondary (due to the tight coupling between them) it will now be necessary to re-adjust the latter circuit to give zero meter reading for a 10.7 m.c. signal, as explained above. It may be found that the whole procedure has to be repeated several times before both circuits are correctly aligned.

If a centre-scale micro-ammeter is not available for the output meter any meter having a sensitivity of not less than 1,000 ohms / volt (i.e. 1 m.a. for full-scale deflection) and an internal resistance of not less than 1 megohm may be used. The 0-1,000 volts range on a good quality multimeter would satisfy these requirements.

In the case of the first method of alignment described, and the case of the secondary peaking in the second method, a zero adjustment of voltage was required. A slight backward deflection of the needle off the scale will do no harm while the adjustments are being made. In the case of the primary alignment by the second method it would be necessary to reverse the leads of the meter between the points ZZ (Figure 2) when the signal generator frequency was shifted from 75 K.c above the centre frequency to a value 75 K.c below the latter.

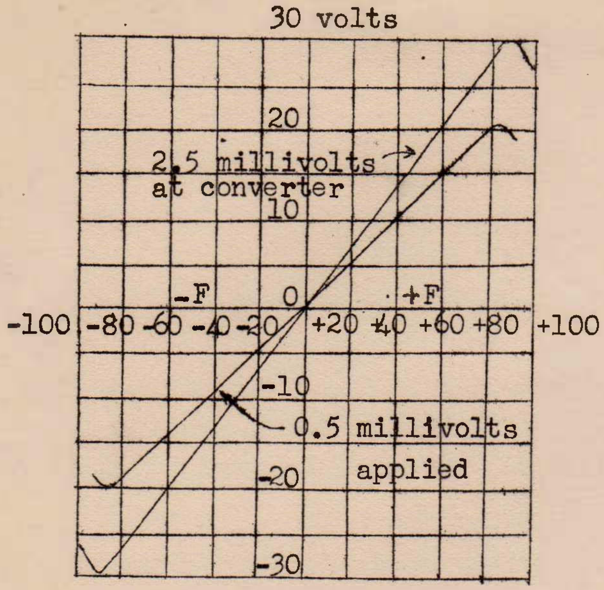
In connection with the second method described above it may be desirable to defer the discriminator alignment until <u>after</u> the alignment of the I.F. transformers. If this is done the signal generator may then be connected to the <u>converter</u> input, so that the signal will be amplified by the I.F. stages. These deflections obtained in the output meter for the 75 K.c off centre-frequency adjustments of the signal generator will then be larger, allowing of more accurate adjustment of the discriminator primary winding. If the output meter available is not of sufficient sensitivity and/or if the r.f. output of the signal generator is small this procedure may be absolutely essential if an accurate adjustment is to be obtained.

The above tests on the discriminator should be completely adequate for a commercially designed receiver where it may be assumed that the discriminator band-pass and linearity are satisfactory when alignment is correct. If there is any doubt about the stage's performance, however, due for example to having replaced any circuit components, a complete output curve may be obtained as follows. <u>After</u> having aligned the I.F. stages (see below) the signal generator is connected to the converter grid and the output meter connected between points ZZ (Figure 2) as before. The signal generator frequency is moved away from the centre frequency in steps of 5 or 10 K.c. per sec. depending upon the accurancy required in the curve, and the accuracy with which the generator frequency may be set. The D.C. voltage across the diode load, as shown on the output meter, is noted for each frequency setting. Readings are recorded for frequencies both above and below the centre-frequency. A curve is plotted similar to those shown in Figure 3. Here two curves are given one for a signal of 2.5. millivolts and the other for 0.5 millivolts at the converter grid. The curve obtained should be linear for a total frequency range appreciably wider than twice the maximum (i.e 150 K.c. per sec.). This margin is required to allow for the fact that the I.F. may not be exactly at its correct centre frequency 10.7 m.c.) when actually receiving a station. A discriminator characteristic which is barely wide enough will mean that if the receiver's tuning is only very slightly incorrect distortion will result due to the frequency excursions on loud sounds carrying the signal frequency off the linear portion of one end of the characteristic. It should be remembered, in this connection, that a band-pass which is too narrow anywhere in the I.F. stages results in amplitude distortion due to cutting off the loud sounds, rather than in a reduction of the high audio frequency response, as is the case with A.M.

<u>ALIGNING THE I.F. STAGES:</u>

The procedure for aligning the I.F. stages is, in general, very similar to that followed in an ordinary A.M. receiver. The main difference lies in the use of an unmodulated R.F. signal, also in the method of measuring the tuned circuit response, and in the special precautions taken to ensure that the I.F. transformers are adjusted symmetrically with respect to the centre frequency.

As an output indicating device the 0-100 micro-ammeter is used, being connected in series with the grid return of the limiter. If two limiter stages are used the meter is connected in the grid circuit of the last limiter, as shown in Figure 4. This really converts the last limiter value into a vacuum tube voltmeter.

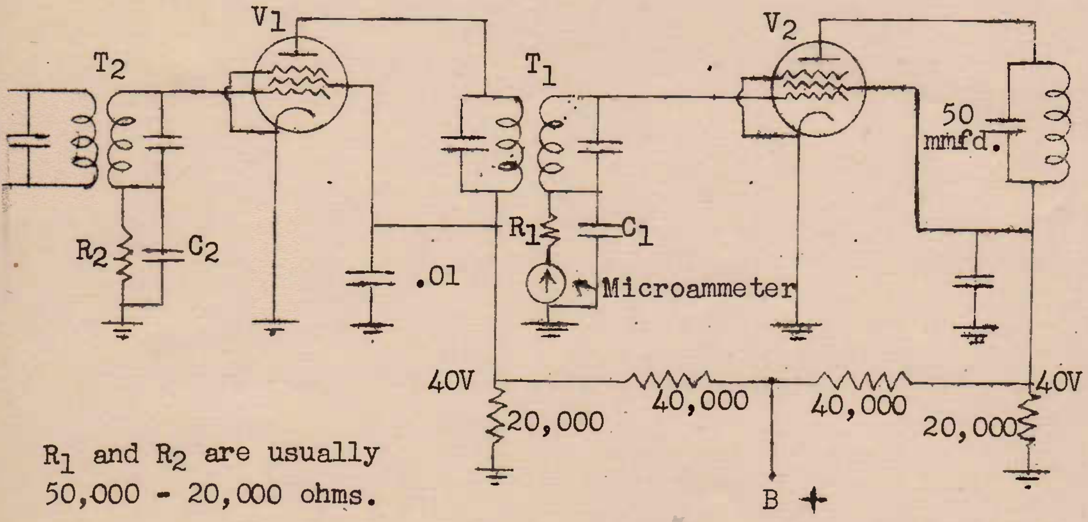


F = Centre Frequency.

FIGURE 3.

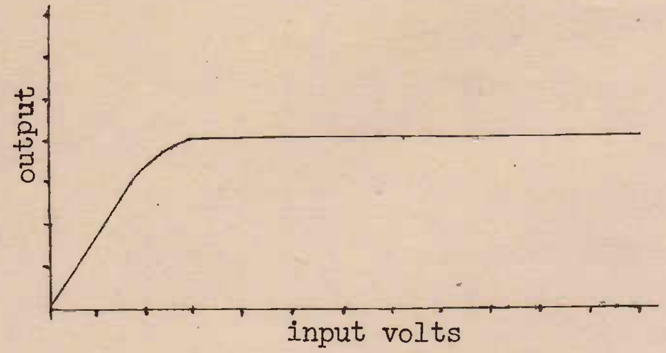
The circuit of Figure 4 is a typical two-stage limiter. The transformer between the limiter valves V1 and V2 is in every respect similar to those in the preceding I.F. stages (not shown), and it must be aligned together with the others to the correct I.F.

The initial rough procedure is as follows:- Having connected the microammeter in series with R_1, as shown, the signal generator is adjusted to the correct centre I.F. value, and the output applied to the grid of V_1, (Figure 4). The secondary of transformer T_1 is first adjusted for a peak reading on the output meter, then the primary of the same transformer is similarly adjusted. In making these adjustments it is important to keep the strength of the signal generator output low - only just sufficient to produce a decided peak in the meter reading when making the adjustments. The reason for this to ensure that the limiters are operating below the "threshold" level, i.e. below the "knee" of the curve shown in Figure 5, where saturation occurs. When the signal is



R_1 and R_2 are usually 50,000 - 20,000 ohms.

A TWO-STAGE LIMITER CIRCUIT SHOWING METHOD OF CONNECTING MICROAMMETER FOR I.F. ALIGNMENT.
FIGURE 4.



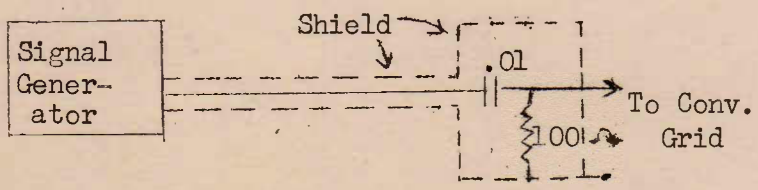
LIMITER CURVE.

FIGURE 5.

sufficiently weak to ensure that this occurs the first limiter V_1 of Figure 4 acts as an ordinary linear amplifier with a gain between 10 and 20. If the limiters were operated to saturation by the signal very little peaking of the transformer would be observed on the meter, because the limiter action is such that it tends to flatten out the output, and so obscure the resonance effect of the tuned circuits.

Having adjusted the <u>last</u> I.F. transformer (T_1) Figure 4, the signal generator output is moved to the grid of the preceding tube (not shown in Figure 4) and the transformer T_2 is aligned as before, adjustment being made to the secondary first, then the primary. The signal generator is again moved to the grid of the next valve, moving back towards the converter, and the I.F. transformer following this value aligned, and so on. Finally to align the I.F. transformer immediately following the converter stage the signal generator is connected to the converter grid itself.

Compared with the gain found in an ordinary A.M. receiver it will be found that the gain in the F.M. receiver is extremely high. To give a typical example a 20 micro-volt signal on the converter grid should produce 20 microamperes in the output meter for a value of R_1 (Figure 4) of 50,000 ohms. This represents a voltage gain of 100,000. The converter usually has a gain of between 5 and 10, while the I.F. stages each yield a gain in the region of 50 or 60. Great care is therefore necessary in connecting the signal generator to the converter grid, if oscillations due to input-output coupling are to be avoided. A suitable method is indicated in Figure 6. First the connection from the r.f. circuit to the grid lug on the converter valve is unsoldered. This is necessary because this r.f. circuit is tuned to 88 - 108 m.c. and would act as a short-circuit to ground for the output of the signal generator which is at the I.F. (usually 10.7 m.c.). The end of the shielded signal generator cable is terminated with a 0.01mf. condenser, loaded by a non-inductive resistor of low value, say 100 ohms. The condenser and resistor must be contained within a shield. The condenser prevents damage to the signal generator in the event of the lead being accidentally connected to a high voltage point. The resistor damps out any oscillations due to feedback.



TERMINATION FOR COUPLING OF I.F. SIGNAL GENERATOR TO CONVERTER INPUT OF F.M. RECEIVER.

FIGURE 6.

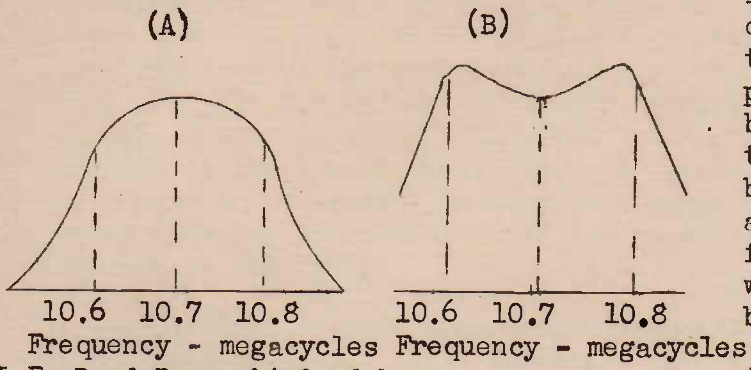
In carrying out the alignment process described above a most important point to keep in mind is that as the signal generator is moved back stage by stage towards the converter, <u>its output should be progressively attenuated</u> so that only the <u>smallest useful reading</u> is obtained on the output meter. This, of course, is to prevent the limiters from operating above the threshold level.

SYMMETRICAL PEAKING OF THE I.F. STAGES:

In some receivers the above simple procedure may be quite sufficient to adjust the I.F. stages for efficient reception. In other receivers, however, it will be found that although the transformers have been peaked for maximum response, they have not been symmetrically aligned with respect to the centre I.F. At this stage it should be remembered that the I.F. transformers are designed to pass a wide band of frequencies - at least 150 K.c wide. This wide band-pass is obtained, as has already been explained by two main methods :

(1) Heavy damping of the tuned circuits.

(2) Over-coupling of the circuits to yield the double peak effect - or a combination of both of these.



I.F. Band-Pass obtained by
A. Heavy Damping, and B. Overcoupling.
FIGURE 7.

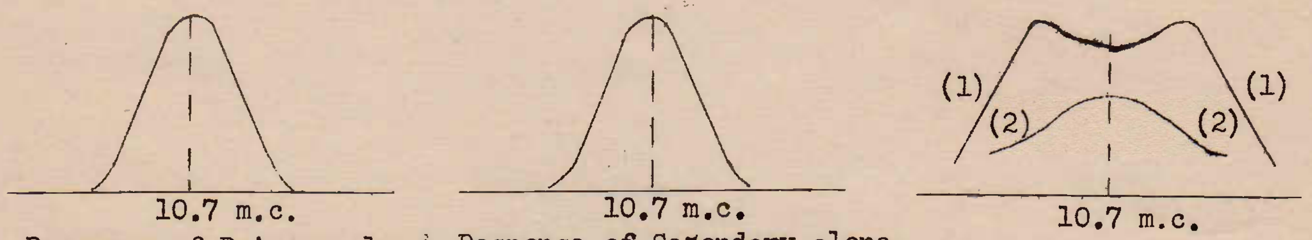
Figure 7 shows the two main characteristics. If heavy damping alone is resorted to the only peak in the curve occurs at the centre frequency of the I.F. channel. In this case the procedure described above, if carefully carried out, should be sufficient to obtain correct alignment.

It is a good idea, however, to check the over-all I.F. characteristic after the initial aligning process described above, and to make minor adjustments to each tuned circuit if necessary. This checking of the over-all characteristic is done by leaving the signal generator at the converter grid, but re-tuning it to a frequency which is 40 K.c below the centre frequency, and noting the reading on the output. Then the frequency is adjusted to a value of 40 K.c. above the centre frequency, and noting the response on the meter again. These two readings should be equal if the curve is to be symmetrical about the centre-frequency. The procedure is then repeated for frequencies which are ± 75 K.c off the centre frequency. For a good over-all alignment these readings should again be equal, and should not be less than 1/10 of the reading obtained at the centre frequency. If it is found that unequal readings are obtained for a pair of off-centre frequencies, small adjustments may be made to the various stages (leaving the signal generator at the converter grid) until a symmetrical response is obtained.

It may be found that no symmetrical response can be obtained by small re-adjustments to the transformers. This indicates that the I.F. characteristics are of the double peak type shown at B Figure 7. In this event the stages should be completely re-aligned using one of the methods described below.

ALIGNING OVER-COUPLED I.F. TRANSFORMERS:

If the I.F. stage design is such that the response characteristics have the double-peak as shown at B Figure 7, the simple method of adjustment for a maximum response with the signal generator set at the correct centre value of the I.F. will give an unsymmetrical alignment. This means that although the I.F. transformers give a



Response of Primary alone.
A

Response of Secondary alone.
B

C

1. Combined response for above critical coupling.
2. Combined response when coupling has reduced below critical by heavy damping.

FIGURE 8.

maximum response at the centre I.F., this latter frequency does not lie at the centre of the pass-band of the circuits. Instead the centre-frequency (10.7 m.c) would fall at a point relative to the curve which would correspond to one or the other of the side peaks (See Figure 7B). The result, when receiving a signal, would be that either the upper or lower side-band (depending upon which peak the circuits happended to be aligned at) would be much stronger than the other, resulting in serious distortion. Two main methods of aligning double-peaked circuits may be employed.

FIRST METHOD:

One method is to align each stage roughly as before, starting at the last stage before the last limiter and working back towards the converter, as described. The process is then repeated while heavily damping, by means of a resistor, one winding of each transformer while the other winding is being tuned. This damping reduces the co-efficient of coupling between the circuits below the critical value, and so temporarily eliminates the double-hump effect. The theory of the method will be understood by reference to Figure 8. Each circuit of a transformer is, or should be tuned individually to the correct I.F. centre frequency, as shown at A & B. When coupled above the critical point, however, the individual resonance peaks disappear, and are replaced by two peaks lying above and below the separate resonance frequencies, as shown by curve (1) Figure 8 C. If one of the coupled circuits is damped heavily enough to reduce the coupling to avalue below the critical value, the double peaks of the combined curve disappear, and are replaced by a single peak at the correct centre frequency, as shown by curve (2) Figure 8.

SECOND METHOD:

A more accurate method of aligning double-peak circuits is as follows. If the alignment is not too far out the signal generator is connected to the converter grid. The frequency of the generator is then swept on each side of the centre frequency noting the meter responses (meter still connected in the grid return of the limiter). In this way the two correct peaking frequencies are found. These should lie symmetrically on either side of the correct centre frequency. Unequal meter responses for the two peak frequencies indicate the alignment is somewhat off. Having noticed carefully (from the signal generator calibration) the frequency of <u>one</u> of the peaks, (say the lower) we start to align the I.F. amplifier stage by stage, starting from the last and working back towards the converter as previously described. In this process, however, we align on the <u>lower</u> peak alone, the frequency of the signal generator being set at the value previously noted for it. After the entire I.F. amplifier has been aligned,we now set the signal generator to the correct centre I.F. (10.7 mc.) and connect it to the converter grid, and note the meter response. Then the signal generator is adjusted to a frequency 75 K.c above the centre frequency and the response noted. Finally a frequency 75 K.c. below the centre frequency is applied and the response again noted. The latter two readings should be equal, if not the entire process must be repeated.

THIRD METHOD:

Sometimes the alignment is initially so poor that it is difficult to determine the correct peaking frequencies. It is then best to set the signal generator at a frequency which is 50 K.c. below the correct centre frequency (viz. at a frequency equal to 10.65 M.c) and then to align stage by stage for maximum response at this off-centre frequency. Here again we begin with the stage next to the limiter and work back towards the mixer. In making the adjustments the trimmer condensers are first set towards <u>maximum capacity</u> setting and then reduced until maximum response is obtained. This ensures that the transformers will be aligned on the <u>lower</u>, and not the <u>higher</u>, peaks. The signal generator is then set at frequencies 75 K.c. first above, then below the centre frequency, the output being applied to the converter grid. If the over-all transmission curve is symmetrical these two responses should be equal. Also test for frequencies ± 50 K.c from the centre frequencies. Again the meter responses should be equal. If this is so it indicates that we <u>guessed</u> the peaking frequency correctly when we initially set it 50 K.c. off centre. If the responses for the frequencies ± 75 K.c. off-centre were not equal it indicated that the <u>incorrect</u> off-centre peaking frequency was assumed. The entire process is then repeated with a somewhat <u>higher</u> off -centre frequency while aligning the individual stages. If the alignment proves to be even more unsymmetrical than before (as indicated by the meter responses for ± 75 K.c. off-centre, and also ± 50 K.c. off-centre frequencies) this indicates that the correct peaking frequencies lie <u>closer</u> to the centre frequency than 50 K.c. The alignment is therefore repeated for an off-frequency of somewhat <u>less than</u> 50 K.c. The process is repeated until equal symmetrical peaks with respect to the centre frequency are obtained.

If the correct off-frequency for the double peaking was <u>guessed</u> correctly in the first place, the process is just as rapid as for aligning single-peaked circuits, since the alignment is based on obtaining readings only for the lower peak frequency, <u>or</u> for the upper peak frequency. Usually the manufacturer provides information for the correct peaking frequencies, so the method of repeated alignment may not be necessary.

OVER-ALL CHECK OF I.F. AND DISCRIMINATOR ALIGNMENT:

At this stage it is a good idea to check the alignment so far carried out. To do this the signal generator is connected to the converter grid. The meter for measuring discriminator output is connected between points ZZ (Figure 2). The meter for measuring total diode current is connected between YY as before. First the frequency is set at the centre value (10.7 m.c). The meter at ZZ should show a zero reading, and that at YY a maximum reading (noted by swinging the frequency slightly about 10.7 m.c). Next the frequency, is set at 75 K.C. above centre frequency, and then 75 K.C. below. The readings on the meter at ZZ in these latter two cases should be equal.

It should not be thought, however, that this over-all characteristic test alone is an indication that the individual stages are correctly aligned. It cannot be too strongly stressed that it is always necessary to align the separate I.F. stages as previously described. A symmetrical over-all transmission curve for the I.F. stages does not indicate that distortionless reception will be obtained. The curves for individual stages might be a long way out, yet the overall curves looks correct.

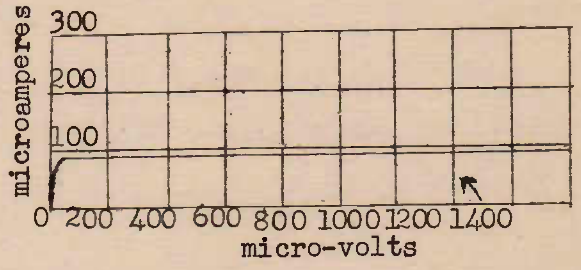
LIMITER TESTS:

Previously, before proceeding with the I.F. alignment, we checked the limiter voltages. If these were correct and circuit components were in good condition and of the values recommended by the manufacturer, the limiter should function normally. However if there is any doubt about the limiter operation, the following simple test may be carried out. The meter (preferably 0-100 μ.A.) is connected in the diode return lead at YY (Fig. 2). The signal generator, set at the correct centre I.F. is connected to the converter grid by the method previously described. A number of readings on the meter are noted for various voltages applied from the signal generator. These voltages, of course, are varied, and read off from the attenuator control on the instrument. A curve like that illustrated in Figure 9 is plotted. In a typical receiver a curve something like that shown should be obtained. Note that complete limiter saturation occurs above a signal voltage of about 50 micro-volts at the converter grid. If the "threshold" level was very much above this figure it would indicate that the limiter would not be sufficiently effective in reducing noise interference on the weaker signals.

R.F. and OSCILLATOR ALIGNMENT:

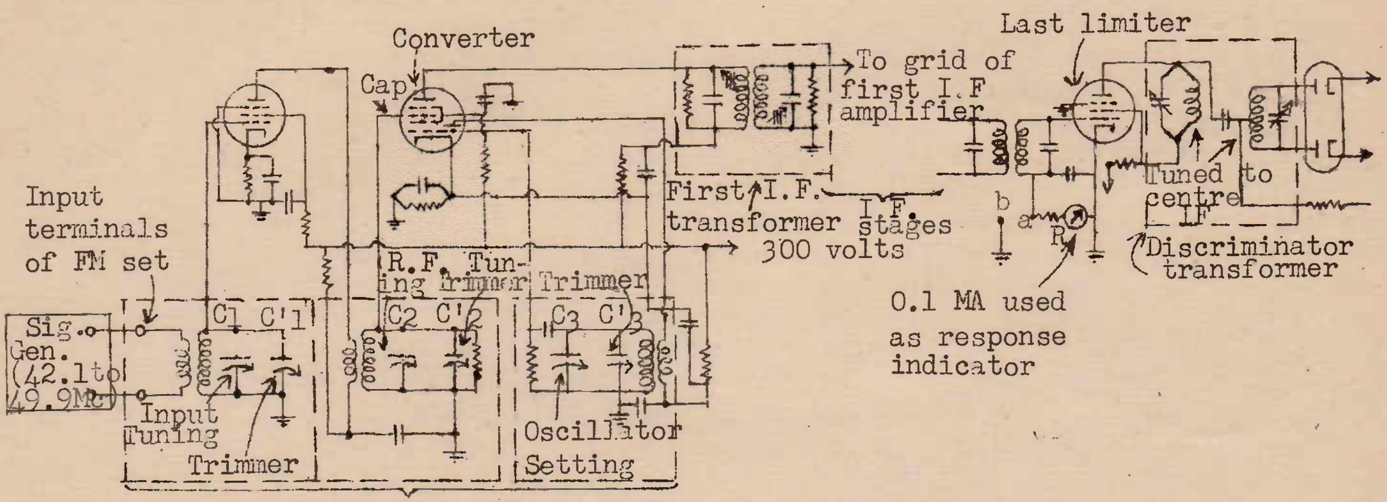
For these adjustments an unmodulated signal generator covering the band 88 - 108 m.c. is required. Actually a generator operating up to 54 m.c. would be satisfactory, for the second harmonic of the output could be used.

The signal generators output is applied to the input terminals of the receiver as shown in Figure 10. For these adjustments the 0 - 100 microammeter connected in the grid return of the last limiter is again used as an output meter. First the signal generator is adjusted to produce a frequency of 108 m.c. per sec. and the tuning dial of the receiver adjusted so that it reads 108 m.c. per sec. The oscillator trimmer C_3 (Figure 10) is



TYPICAL LIMITER CURVE MEASURED BETWEEN CONVERTER GRID AND DISCRIMINATOR OUTPUT.

FIGURE 9.



Trimmer condensers C'1, C'2 and C'3 have to be adjusted in the alignment of the input tuner.

FIGURE 10.

now adjusted for maximum response in the output meter. It is important at this stage to reduce the signal generator output until it is only just sufficient to indicate decided maximum effects on the meter. The R.F. and aerial trimmers C'_1 and C'_2 are now also adjusted for maximum meter response. A further reduction in generator output may be required when making these adjustments to prevent saturating the limiters.

The next stop is to check the tracking. This is done by setting the frequency of the signal generator to such frequencies as 107, 106 and 105 m.c. in succession down to 88 m.c. In each case the dial of the receiver is set for maximum response as noted by the grid-current meter of the limiter tube. For proper tracking the microammeter indications should be practically equal in all cases. If this is not so a compromise has to be made with respect to the trimmer C'_1 and C'_2 settings, as in ordinary A.M. technique.

It has been pointed out that a receiver may be designed to operate with the oscillator frequency (F_o) either above or below the tuning frequency (F_1). With an intermediate frequency as high as 10.7 m.c. no possibility of adjusting the oscillator frequency on the wrong side of the tuning frequency exists, providing the following check is made.

After making the initial adjustments at 108 m.c. suppose it is found that the tracking cannot be improved by re-setting trimmers C'_1 and C'_2. This indicates that the receiver was designed for the oscillator frequency on the other side of the tuning frequency as shown on the dial. Hence the necessary correction may be made, the alignment process of the tuning circuits being repeated.

In carrying out the alignment of the r.f. stages, difficulties due to double-peaking circuits (as described in connection with some I.F. stages) never occur. These r.f.

circuits are more than adequately damped for the required band-pass by the high r.f. losses which occur at 88 - 108 m.c. Hence if correctly peaked by the simple procedure described, the band-pass requirements in this section of the receiver will take care of themselves.

ADDITIONAL EQUIPMENT FOR DYNAMIC TESTS OF THE I.F. & DISCRIMINATOR STAGES:

The tests and alignment procedure previously described were carried out by using an unmodulated signal generator. To check the band-pass of the I.F. stages we varied the frequency step by step, taking separate readings on the output meter for each setting. Since an F.M. receiver is sensitive to frequency variations, rather than to amplitude variations, it would be an advantage if we had available a signal generator whose signals were frequency modulated with a deviation of ± 75 K.c.

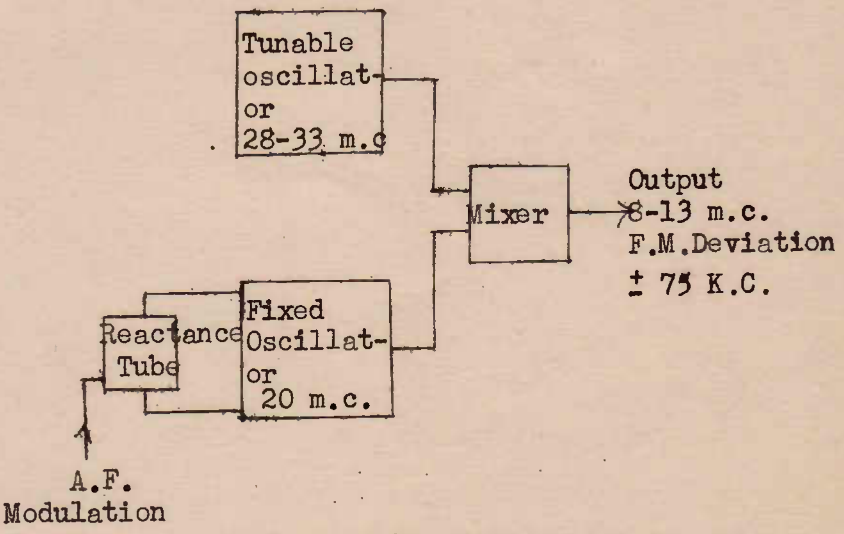
A FREQUENCY MODULATED SIGNAL GENERATOR:

A suitable instrument of this type consists of a fixed oscillator operating at a frequency of say 20 m.c per sec. which is frequency modulated by means of a reactance tube to whose grid a suitable A.F. voltage, say 400 c. per sec. may be applied. The output of this oscillator is heterodyned with that of another oscillator tunable between, say, 28 and 33 m.c. per sec. The resulting output will be a frequency modulated signal, tunable between 28 - 20 = 8 m.c. and 33 - 20 = 13 m.c. This covers the I.F. (10.7 m.c.) of an F.M. receiver. The arrangement is shown in block form in Figure 11.

For fidelity tests this signal generator must be applied at the receivers converter grid. This is good enough for fidelity tests, because the broadly tuned r.f. circuits have little effect on the receivers over-all fidelity. By using the instrument together with a cathode-ray oscilloscope (described below) an actual visual picture of the I.F. curve may be obtained.

THE CATHODE RAY OSCILLOSCOPE (OR OSCILLOGRAPH):

Some mention was made of this instrument in a lesson on cathode ray tubes in the Television Section. The device consists of an ordinary electrostatic type cathode ray tube fitted with suitable power supplies



An F.M. Signal Generator suitable for I.F. Tests.

FIGURE 11.

for the filament heating and high electrode voltages. In addition it has a saw-tooth voltage generator (usually of the gas filled triode type), whose frequency is variable over a considerable range (say 20 - 50,000 c. per sec). The output of this oscillator is applied to the "horizontal" plates, and produces a linear "sweep" horizontally across the screen of the tube. The effect of this sweep is to produce a bright narrow line of light across the tube. The voltage which is to be tested or observed is applied to the vertical deflection plates. These plates are usually provided with a high fidelity video amplifier, so that weak voltages may be amplified. The instrument is, of course, fitted with controls to adjust the beam intensity, focus, and positioning of the spot on the screen (the latter involving vertical and horizontal shift controls). A block diagram of a typical oscilloscope is shown in Figure 12. The general appearance of the instrument is illustrated in Figure 1. Say a sine-wave voltage of 400 cycles per sec. is applied, via the vertical amplifier to the vertical deflection plates of this instrument. In the absence of any horizontal deflection, the effect would be simply to move the spot of light up and down on the screen, to produce a vertical line of light.

Suppose now that a saw-tooth voltage, also of 400 cycles per sec. were applied from the sweep oscillator to the horizontal deflection plates. In the absence of the sine-wave voltage on the vertical plates a straight horizontal line of light would appear across the screen. The spot would move through successive positions 0, 1, 2, 3, 4, 5, 6, 7, 8, as shown in Figure 13. For a frequency of 400 cycles per sec. the time taken to move from one of those positions to the next would be $\frac{1}{400} \times \frac{1}{8} = \frac{1}{3{,}200}$ sec., and the movement would thus occur at a uniform speed. On reaching position 8, the spot would then, in a very short period of time (the fly-back time), return to position 0, and the next cycle would commence.

In the presence of both voltages the sine-wave voltage on the vertical plates, and the saw-tooth one on the horizontal plates, the spot would be forced to move in both vertical and horizontal directions. If both voltages commenced their cycles at the same moment the spot would move, due to these simultaneous movements, successively through positions a, b, c, d, e, f. g, h, and i., so tracing out a curved line of light, which would be a visual representation of the sine-wave voltage under test. On reaching position 8 (or i) the spot is rapidly shifted to position 0 (a) again, and the same movement is repeated. Due to the "persistence" of vision effect a continuous and stationary sine-wave

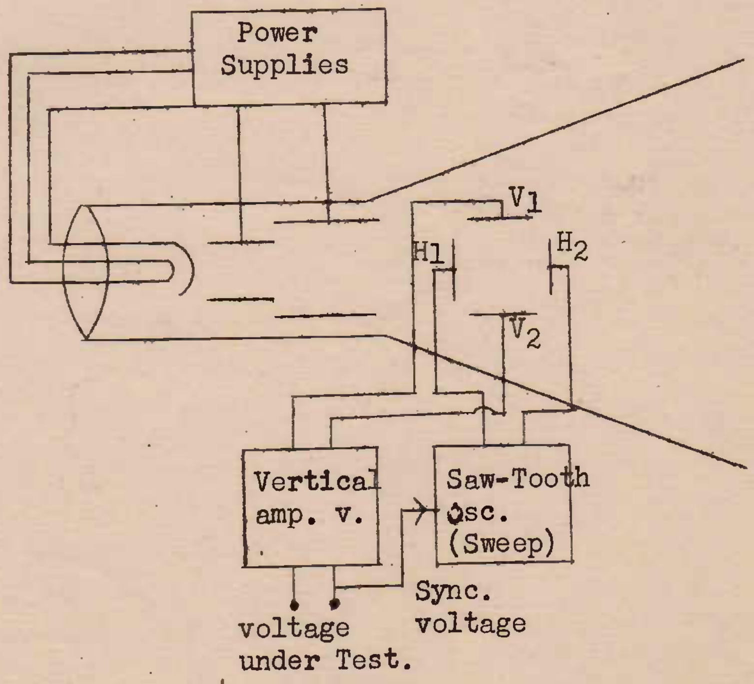


FIGURE 12.

curve would be seen just as though such a curve were drawn on paper.

In this way the cathode-ray oscilloscope (abbreviated C.R.O) allows us to obtain on a screen a graphical representation of any alternating voltage under test. The action is not limited to a sine-wave form. For example a square-wave voltage, or any other type, would produce its exact wave-form on the screen.

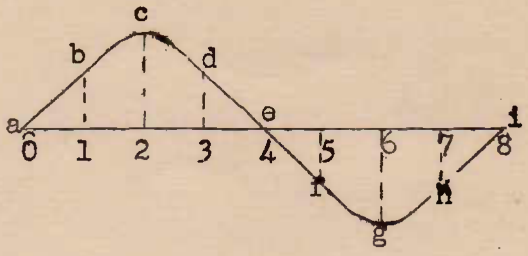


FIGURE 13.

To produce a stationary picture of the wave on the screen it is necessary that the voltage under test and the sweep voltage are correctly synchronised. This means that their frequencies must bear exactly a certain relationship to each other. In the case of the example explained, where a single cycle of the test voltage was observed, the two must have exactly equal frequencies. If the latter differs slightly the trace appears to drift continuously across the screen in one or the other direction. If the sweep voltage frequency were exactly one-half the frequency of the voltage under test, two complete stationary cycles of the latter would be observed; for the test voltage would perform two complete cycles in the time taken to move the spot once horizontally across the screen. Thus to observe two or more stationary cycles the sweep saw-tooth voltage must have a frequency which is an exact sub-multiple of the voltage under test.

To obtain this necessary synchronisation for test voltages of various frequencies, the sweep oscillator is provided with a frequency control knob, usually providing settings between about 25 cycles per sec. to 50,000 cycles per sec. Exact synchronisation is obtained by injecting a small portion of the test-voltage into the grid circuit of the sweep oscillator tube(see Figure 12). In practice the trace is made as stationary as possible by adjustment to the sweep frequency knob. Then the sync. control, which controls the amount of voltage applied to the grid of the sweep oscillator tube is turned up, just enough to cause the trace to "lock" on the screen. This synchronising action was explained in the second lesson devoted to Television Receivers. In the case of the sweep generators in video receivers the sync. voltages which set and hold the frequencies of the generated saw-tooth voltages are, of course, the sync pulses which are separated from the incoming signal. Here the sync. voltage is a portion of the voltage under observation.

DYNAMIC METHOD OF ALIGNING I.F. STAGES:

The use of the F.M. signal generator, together with a C.R.O. provides a speedier method of aligning the I.F. stages, and at the same time shows the operation of the receiver under conditions which closely approximate actual reception of an F.M. wave.

The F.M. signal generator is provided with a saw-toothed voltage at audio frequency usually by taking some of the saw toothed voltage from the sweep oscillator in the oscilloscope. This audio signal is fed into the generator via the grid of the modulating reactance tube as shown in Figure 11. The centre frequency of the resulting F.M. voltage from the generator is adjusted to 10.7 m.c. and applied to the receivers converter grid, using preferably the method illustrated in Figure 6.

The vertical plates of the cathode ray oscilloscope are connected between points "a" and "b" in the grid circuit of the last limiter of Figure 10. Note that this connection means that the voltage developed across the limiter grid resistor by the rectified grid current flowing through it is providing the vertical deflection on the screen of the C.R.O.

If the I.F. stages of the receiver are already correctly aligned, a stationary picture of their characteristic somewhat like that shown in Fig. 14 should be obtained on the screen of the CRO. No difficulty will be experienced with synchronisation because the frequency deviation of the oscillator is produced by voltage from the oscilloscopes saw tooth oscillator circuit and must at all times be synchronised with the horizontal movement of the light spot.

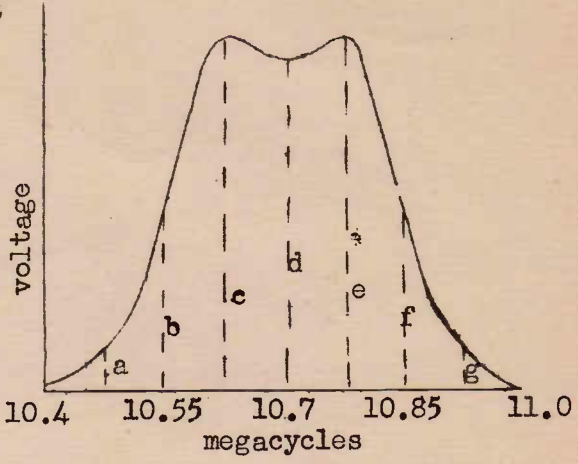


FIGURE 14.

In order to understand how such a picture is built up, suppose that the r.f. output of the signal generator is frequency modulated at 400 cycles per sec. and that a deviation of ± 300 m.c. per sec. (0.3 m.c. per sec) is being produced. Then the signal applied to the receiver is being "swept" over a frequency range of 10.4 m.c. per sec. (10.7 - 0.3 m.c) to 11.0 m.c. per sec. (10.7 + 0.3. mc.).

Now although the <u>amplitude</u> of the r.f. voltage applied to the converter of the receiver remains constant for all instantaneous frequencies, the <u>amplitude</u> of the voltage applied to the grid of the limiter will vary with these instantaneous frequencies. The reason, of course, is that the signal has passed through the I.F. tuned circuits which are <u>frequency selective</u>, i.e. the amplitude of the voltage passed depends upon the instantaneous frequency, as shown by the dotted lines a, b, c, d, e, f and g of Fig. 14. The D.C. voltages applied to the vertical plates of the C.R.O. will also vary as the lengths of those dotted lines, for the grid circuit of the limiter simply rectifies the r.f. voltage of varying amplitude which is applied to it. Hence the vertical displacement of the spot on the screen of the C.R.O. will depend upon the instantaneous frequency of the generator, in the same manner as the lengths of the dotted lines vary with the frequency as shown in Figure 14.

Simultaneous with the above, the C.R.O's saw-tooth oscillator sweeps the spot across the screen from left to right. During one of these horizontal movements the vertical displacement will pass through successive values proportional to a, b, c, d, e, f, g (Figure 14). The result will be that the spot follows the curve, and will trace out a line of light of the shape shown. On reaching the right-hand side of the screen the spot is abruptly moved to the left-hand side again, and a new trace begins. As a result of the rapid rate at which the curve is repeatedly traced out (about 400 times per second), and thanks to the "persistence of vision" effect, a continuous and steady line, representing the overall characteristic of the I.F. stages, is seen.

If a good symmetrical curve like that shown is not obtained <u>no attempt should be made to improve it just by random adjustments to the I.F. transformers</u>.

Just as in the case of the static method of alignment previously described the stages should be separately adjusted commencing with the last one before the limiter. Hence the F.M. signal from the generator is applied to the grid of the last I.F. valve. First the secondary, then the primary of the following transformer is adjusted for a good shaped curve. Next the F.M. signal is applied to the previous grid, the amplitude of the signal being reduced to give a curve the same height as before, and the second last transformer aligned, and so on. Finally a compromise setting is made for all I.F. stages until a good-looking response curve is obtained. These compromise settings should on no account vary much from those obtained for the single-stage adjustments.

FAULTS PECULIAR TO F.M. RECEIVERS:

AMPLITUDE DISTORTION DUE TO SIDE-BAND CUTTING:

In the case of A.M. reception inadequate passing of the side-bands results only in a reduction of fidelity due to excessive loss, before detection, of the higher audio frequencies of modulation. We have seen that a characteristic of the F.M. system is that the higher side frequencies are only produced on the peaks of modulation, i.e on the loud sounds. Any action within the receiver which restricts the passage of those side-frequencies which lie well out from the centre-frequency of the signal will result in an undesired type of volume compression, which, if severe, will be observed as a severe distortion on reception of loud music etc.

Assuming that the receiver has been correctly designed in the first place, and also assuming that the audio section is in order, this type of distortion is usually traced to one of the following causes :

(1) Incorrect alignment of I.F. (including discriminator) transformers.

(2) Unequal, or broken down, discriminator load-resistors (R_1 and R_2 Figure 2).

(3) Mis-match between discriminator diodes.

With reference to (1) above, the obvious remedy is to re-adjust each I.F. transformer separately, as already described. Once again the importance of <u>individual</u> alignment of each transformer by one of the methods given is stressed.

Loss of balance between the discriminator load resistors is a common fault, particularly in a receiver which has been in use for some time. It is most important that these resistors, which have a typical value of 100,000 ohms each, should be <u>equal</u> within about 10%. A breakdown of one resistor will, of course, completely unbalance the discriminator and ruin reception. Serious unbalance, however, can also be present in the absence of a complete breakdown. Carbon resistors have a habit, with age and use, of increasing in value far above their ratings. Such an increase in resistance may go unnoticed in the case of a resistor anywhere else in the receiver, but it is most important that discriminator load resistors are maintained at values which approximate closely to each other.

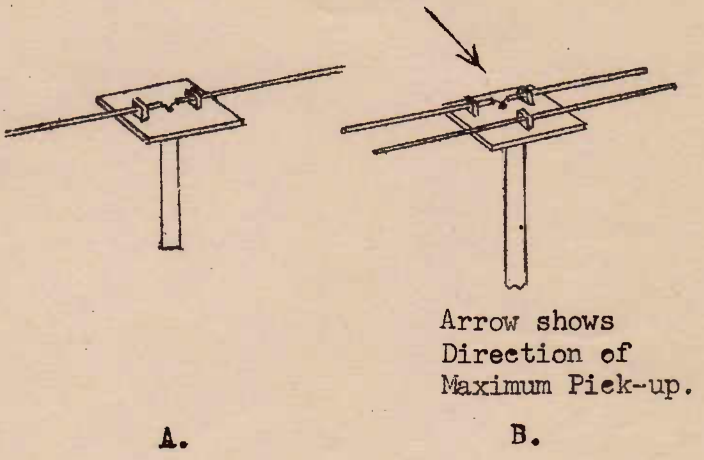
Complete or partial loss of emission of one of the discriminator diodes (fault (3) above) will have the same effect as unequal load resistors. This fault will mean that unequal voltages will be developed across the latter even though the I.F. voltages applied to the two diode plates are equal.

Actually the presence of unequal discriminator load resistors, or mis-matched diodes will be indicated when attempting to align the discriminator transformer. If it is found that a correct balance of the stage is impossible to obtain by following the methods described then the diodes and resistors should be tested and replaced if necessary.

RECEIVER INSTALLATION - ANTENNAS:

The home installation of an F.M. receiver involves no new problems to the service engineer, except insofar as the antenna system is concerned.

For reception of a powerful signal it may be found sufficient simply to ground one of the aerial coil terminals and to connect a short piece of wire of several feet (10 ft. at the most) to the other. Or again pick-up may be used from the power lines as is sometimes done for A.M. receivers.



Arrow shows Direction of Maximum Pick-up.

FIGURE 15.

Normally however the resonant dipole is to be preferred in all cases. The resonant effect obtained from such an aerial gives an additional high-frequency gain of several times. In addition, since the matched lead-in used with a dipole is free from signal pick-up, ignition noise and other forms of undesired interference are greatly reduced.

For F.M. both horizontally and vertically polarised waves are used (see Lesson on Television Antennas). For reception of a vertically polarised wave the dipole is mounted normally, in a vertical position, while for horizontal polarisation the aerial should be parallel to the ground. Figure 15A shows a simple method of mounting a pair of stiff metal rods to form a dipole for reception of a horizontally polarised wave. The method would serve equally well for vertical mounting.

Sometimes, due to certain ground effects and reflections of the wave the "plane of polarisation" of the signal may be rotated or twisted, with the result that best reception may be obtained with the dipole neither horizontal or vertical, but set at some other angle to the ground. Such effects cannot be predicted, and therefore a certain amount of experimentation in setting up the antenna is required.

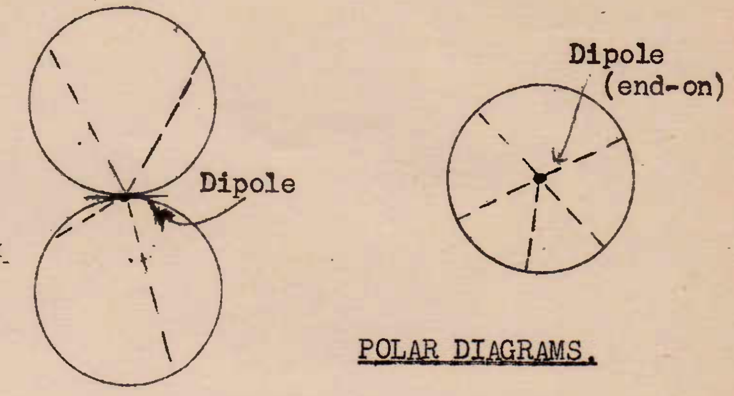
It will be remembered that a dipole has pronounced directional properties as indicated by the horizontal and vertical polar diagrams of Figure 16. Maximum pick-up occurs when a wave is striking the antenna at right-angles to its axis. Zero (or minimum) pick up occurs for a signal arriving end-on.

The polar diagram of Figure 16A shows that in the case of horizontal polarisation the the receivers antenna will favour some signals more than others. This property may be taken advantage of to reduce the pick-up from a powerful signal and to increase that from a weaker signal. It is simply a matter of setting the aerial so that best all round results are obtained from the different transmitters operating.

If vertical polarisation is used, Fig. 16B shows that the antenna, which is in this case mounted vertically, will favour all signals equally well.

REFLECTORS:

A reflector is simply a metal rod of length equal to, or a little greater than, the total length of the dipole, and separated from it by a distance equal to one-quarter (¼) of a wavelength. With such an arrangement the aerial pick-up for a signal arriving in the direction of the arrow (Figure 15B) is increased over and above what it would be in the absence of a reflector. Conversely, for a signal arriving from the opposite direction the pick-up is correspondingly reduced.



POLAR DIAGRAMS.

A. Dipole mounted Horizontally.

B. Dipole mounted Vertically.

FIGURE 16.

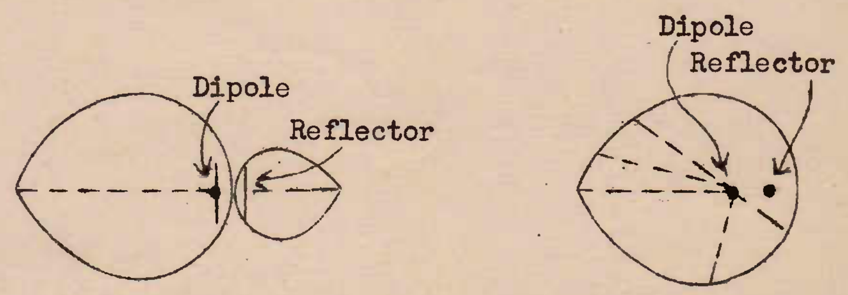
Vertical and horizontal polar diagrams for a dipole with reflector are shown in Figure 17. As will be seen from these diagrams a reflector may be used to increase the pick-up from a weak signal arriving from one direction, while at the same time decreasing that from a powerful signal coming from the opposite direction. This is true whether a horizontal or vertical dipole is used. Note, however, that in the first case signal pick-up arriving from a direction at right angles to that which gives maximum, is still practically zero, while in the second case this pick-up is still considerable.

MOUNTING AND INSTALLING THE ANTENNA SYSTEM:

It will be remembered that the dipole type of aerial should have a physical length of about 95% of one half-wave length of the signal it is desired to receive. A convenient formula for calculating the length of each rod (i.e. half the dipole) is :-

$$L\ (\text{inches}) = \frac{2,770}{F\ (\text{megacycles})}.$$

If it is desired to use the dipole for reception of any station within the F.M. band (as is usually the case) F should be taken to represent the mean frequency of the band. The latter extends from 88 to



A. Horizontal Polarisation

B. Vertical Polarisation.

EFFECT OF REFLECTORS ON DIPOLES.

FIGURE 17.

108 m.c., and the mean frequency is $\frac{88 + 108}{2} = 98$ m.c.

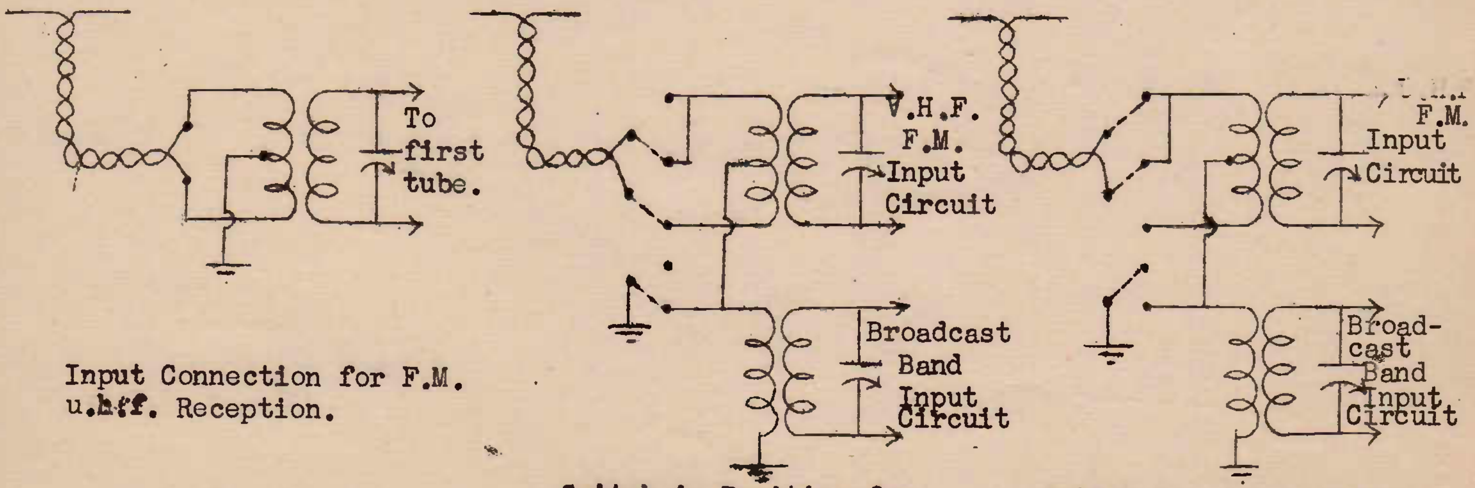
LOCATION OF AERIAL:

It is normally essential, as in television work, that the dipole aerial be located high enough to be in a direct line of sight with the transmitters radiator. In the case of a receiver located in a large block of flats this may mean a little extra work in placing the dipole near the top of the building. The difficulties associated with such an installation, however, are not as great as first may be imagined. The dipole itself is quite small, anf if the transmission line is correctly matched and "balanced" with respect to the input circuit no pick-up of noise will result. A long lead-in of this type will simply mean some loss of signal strength.

USE OF U.H.F. ANTENNA SYSTEM FOR BROADCAST RECEPTION:

It will be remembered that the transmission line lead-in from a resonant aerial is connected as shown in Figure 18 at A. In this way the equal voltages induced in the pair of feed-in wires oppose and cancel each other in the r.f. input transformers primary. The signal pick-up is confined entirely to the dipole itself.

Now many receivers are designed to operate on the broadcast band as well as the u.h.f. band for F.M. reception. Such receivers, of course, have separate sets of coils (r.f., converter and I.F.) for the two bands. A switching system allows instantaneous change-over from F.M. reception to A.M. reception on the broadcast band. With such an arrangement the difficulty arises that the short dipole may not give sufficient pick-up on these lower frequencies. Remember that no resonant effect will occur on the broadcast band. To avoid the use of a separate aerial for A.M. reception a common arrangement is shown at B and C Figure 18. A three-pole two-way switch is hooked up as shown. Actually this switch would form a section of a multiple wave-change switch which controls the change-over from F.M. to A.M. in other appropriate parts of the dual-



Input Connection for F.M. u.h.f. Reception.

A.

Switch in Position for F.M. Reception.

B.

Switch in position for Broadcast band reception.

C.

FIGURE 18.

receiver. With the switch in the position shown at "B" (Figure 18) the connections are identical with those at "A" for u.h.f. F.M. reception. Note that the broadcast circuit is earthed. When the switch is thrown to the other position shown at "C" the two wires of the transmission line are connected together, and the pair are in effect connected through one-half of the u.h.f. coil across the broadcast transformers primary. Now the pair of wires of the transmission line will act as a single conductor, and the lead -in will behave as an ordinary untuned aerial. The half of the u.h.f. coil will not affect the broadcast signal, since it will act as a short-circuit at these comparatively low frequencies. The noise reducing properties of F.M. equipment give this type of transmission considerable advantage over A.M. for use at high carrier frequencies and without any doubt, it will be used both for commercial communication purposes as wellas high quality broadcast entertainment in the future.

LESSON T. FM & F. 18

QUESTIONS.

(1) Which voltages in an F.M. receiver do you consider the most critical (i.e. require the most accurate adjustment ?).

(2) State approximately the value of the voltage you would expect to find on a limiter screen. What would be the effect if this voltage were too large ?

(3) Referring to Figure 2 explain why adjustment to the discriminator transformers secondary would have a greater effect upon the reading in the meter at ZZ than would adjustment to the primary circuit.

(4) Why is it desirable that the characteristic curve of a discriminator is linear over a frequency range considerably wider than the bandwidth of the signal (150 K.c. per sec) ?

(5) In carrying out I.F. alignment describe with the aid of a circuit diagram how you would observe the I.F. stages response.

(6) Does maximum response, as measured in the meter in Figure 4, always indicate correct alignment of an I.F. stage ? Explain.

(7) Give two reasons why a dipole is to be preferred to an untuned aerial, even when the signal field-strength is high.

(8) Calculate suitable lengths for the two halves of a dipole to cover the band 88 - 108 m.c. per sec.

(9) What is a "reflector" as used in an antenna installation ? State the correct length and positioning of such a reflector. What advantage does it confer ?

(10) If you find it impossible to obtain a correct balance of the discriminator, what faults would you look for ?

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LESSON NO.19.

FACSIMILE TRANSMISSION.

The elementary principle of Facsimile transmission has been explained in Lesson 1, the appropriate section of which should be revised before proceeding with this and the next lesson.

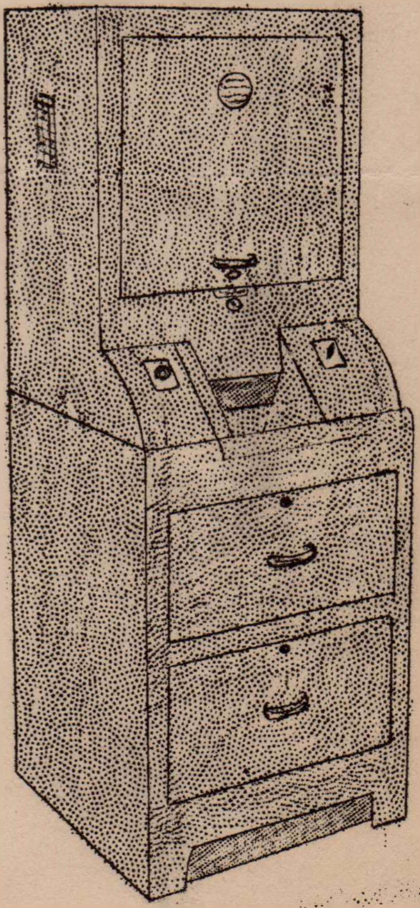
IMPORTANT DIFFERENCES BETWEEN FACSIMILE & TELEVISION:

As has been explained in Lesson 1 the same general principle of scanning is common to both Television and Facsimile systems. In both systems a light spot(or its equivalent) traverses the picture area to be transmitted, dealing with each picture element sequentially (i. e. in turn). The variations in reflected light as these picture elements are traversed give rise (in a photo-electric cell, or equivalent device) to the pulsating video signal. In both systems this signal is used to modulate a carrier wave which may be despatched over a wire or radio link, to the distant receiver. At the receiver, the picture signal is recovered (by "detection" of the carrier), and used to re-construct an image of the original. This involves, as we have seen, the use of a scanning system in the receiver, locked in synchronism with that at the transmitter.

Beyond the above similarities in principle Television and Facsimile show striking divergences in technique. These arise from the difference in the requirements of the two systems, which are :

(1) Facsimile is required to produce a permanent record of the transmitted picture, whereas Television produces a non-permanent or transient reproduction.

(2) In order to produce a "moving" picture by taking advantage of the eye's persistence of vision, television must handle a large number



Automatic Telegraph Facsimile Transmitter.
FIG. 1.

(2) of complete scannings per second, whereas in facsimile work the picture may (contd.) be scanned as slowly as desired (theoretically at least).

The point made under (1) above leads to great differences in the picture reproducing equipment of the two systems. In the place of the cathode-ray tube in a television receiver the recorder in a facsimile unit traces a permanent record on photographic film, from carbon paper, on electro-chemical sensitised paper or by one of several other methods to be discussed in due course.

With reference to point (2) above the fact that there is no theoretical time-limit on the scanning rate is most important from the technical point of view. It means that the band-width of the picture signal may be very narrow compared with that of a Television signal. This in turn makes it possible to send the signal on low and medium frequency carriers, such as those already in use for ordinary radio broadcast purposes. Hence the problem of special ultra-high frequency transmitting and receiving equipment does not arise. In fact, we can, if we desire, use a carrier frequency lying in the audio range - as low as 1,000 or 2,000 cycles per sec. Carriers such as these are actually used, especially for land-line, as distinct from radio transmission.

A clear perspective of the difference in scanning rates of the two systems should be visualised. In television the picture or scene is completely scanned in 1/25th second. A facsimile equipment, on the other hand, may handle a given picture, diagram, or print, by a single scanning in several minutes. If it is remembered that the "dot" frequency of the picture (video) signal is proportional to the scanning rate (for a given number of scanning lines) the much lower frequencies at which facsimile operates will be appreciated. To quote some comparative figures, many facsimile systems do not involve picture signals higher in frequency than about 1,000 cycles per sec. and even the very latest and fastest systems involve frequencies which do not exceed about 13,000 cycles per sec. which can easily be handled by a conventional F.M. transmitter (which is designed to handle modulation frequencies up to 15,000 cycles per sec). Compare these figures with the video frequency of a high-definition television system - say 4,000,000 cycles per sec.

A further implication of the comparatively low scanning rate is the suitability of mechanical methods of scanning which greatly simplify the production of a permanent copy of the subject matter at the receiver. Actually nearly all facsimile systems utilise mechanical scanning devices at both transmitter and receiver. These are cheaper and simpler in general than any possible electronic alternative.

PRACTICAL APPLICATIONS OF FACSIMILE TRANSMISSION:

The electrical transmission of pictures, prints and diagrams has many applications. A few of these may be listed :

(1) Transmission of news photographs as between city and city, country and country. (Radio or Telephone line link).

(2) Radio Weather Map Service - to ships at sea.

(3) Industrial Plant Facsimile System - for sending permanent facsimile copies of plans, diagrams, specifications etc. between different sections of a factory, or between plant and plant.

(4) Tape Facsimile Systems. These send copies of type-written information on a continuous tape, at reading speed, and may replace Tele-type apparatus for communicating market and financial information.

(5) Facsimile Duplicating Apparatus - for Office use. In the case of this equipment the "transmitter" and receiver are situated at the one spot. A diagram etc. from which a large number of copies are desired is scanned by the "transmitter" and the receiver recorder produces a stencil from which any number of copies may be prepared by ordinary office methods. The apparatus has been reduced to such a degree of simplicity that untrained office personnel can easily operate it.

(6) Automatic Telegraph Facsimile System - For regular telegraph business chargeable at telegraph rates, the addressee receiving a teleprinter or facsimile process telegram. In this system the transmitter resembles an ordinary letter box in the street, on a railway station, or at some other busy location. The customer merely presses a button on the cabinet and inserts the written telegram in a slot. A facsimile recorder at the receiving post-office reproduces an exact copy which is delivered to the addressee.

(7) Home Broadcast Facsimile - This is, of course, the branch of the facsimile art in which we are most interested. For over one hundred years a tremendous amount of experimentation has been devoted to developing and perfecting facsimile transmission. Much of this work has been carried out by individuals and large corporations in connection with the first six applications listed above. Nevertheless it would be safe to say that the driving force underlying nearly all the work done has been the desire to provide the public with a home service to supplement sound broadcasting. Such a service, of course, needs to be nearly 100% automatic and fool-proof in operation. Moreover it should turn out the printed information as it is received, without any processing operation whatsoever, and at a reasonably rapid rate. It is only in very recent years that these requirements have been satisfied.

TRANSMITTING PROCESS :

The processes involved in a facsimile transmitter are :

(1) Scanning of the picture to produce the electrical picture signal.

(2) Modulation of a carrier or Sub-carrier.

(3) Production of synchronising and/or phasing (framing) signals.

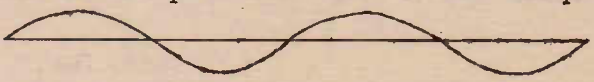
The picture signal produced from the scanning process in most systems does not exceed one or two thousand cycles per second. Even in the latest and fastest systems developed for home broadcast purposes it falls well short of the highest audio frequency (say, 15,000 cycles per sec). Hence, generally speaking it is possible to use this signal to modulate a carrier (or sub-carrier) which itself is of audio frequency. Such a sub-carrier is almost universally used whether the transmission is to be over telephone line or by means of a radio transmitter. It might well be asked why the necessity of this sub-carrier ? Why is the picture signal not amplified directly and in the case of land-line communication passed directly over the line ? In the case of radio transmission why is not the picture signal used for direct modulation of the radio frequency transmitted wave ?

REASON FOR THE SUB-CARRIER:

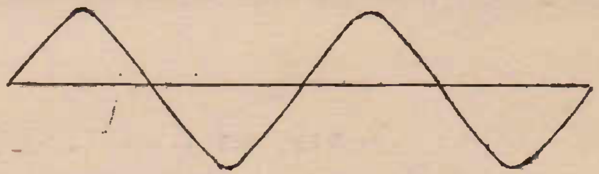
The main reason for the sub-carrier is that the picture signal varies in frequency from zero (direct current) upwards. This signal is of course obtained from the output of a photo-tube, which is normally very weak. Before it can be used for modulation of a powerful radio carrier, or passed over large lengths of telephone line it must be amplified. The amplification of such a signal (extending down to zero frequency) would require a d.c. amplifier. Such amplifiers are subject to gradual changes of frequencies often termed "drift" and are therefore avoided. The difficulty is overcome by the use of a comparatively weak sub-carrier which is directly modulated by the output from the photo-cell. To illustrate this point suppose that the picture signal has a frequency range 0-600 cycles per sec. Modulating a sub-carrier of frequency say 1300 cycles per sec. would give rise to a modulated signal having side-bands ranging from 700 cycles per sec. (1300 - 600 cycles per sec) to 1900 cycles per sec. (1300 + 600 cycles per sec). Such a signal can now easily be raised in level, by the use of conventional audio amplifiers to any desired level, for subsequent modulation of an r.f. carrier, or for direct transmission over telephone lines.

It should be observed that in the case of the figures chosen, the lowest frequency to be amplified is 700 cycles per sec, instead of zero. Hence no special precautions are required in the design of the amplifiers from the point of view of low-frequency response.

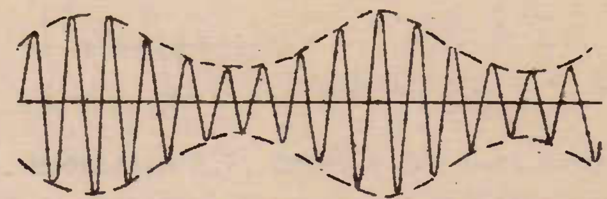
The point is that the use of a sub-carrier takes care of the "D.C. level" of the signal, for this level is represented by the amplitude of the sub-carrier. To illustrate this point suppose the light spot is scanning a uniform dark grey (no detail) part of the picture. The photo-tube signal will be a small direct current and the sub-carrier will be a current of 1300 cycles per sec. of small amplitude. If now the light-spot passes to a portion of the picture which is a uniform white the photo-tube output will be a direct current of larger value than before, and the sub-carrier will be a larger amplitude A.C. still of 1300 cycles per sec. frequency. Thus we see that the D.C. levels of the picture are represented by the levels (amplitudes) of alternating currents which relative levels will be maintained even after passing through many stages of conventional amplification and through the process of modulation of the radio-frequency carrier - see Fig. 2. Note that the radiated r.f. wave in the case of radio transmission always has a modulation (that of the



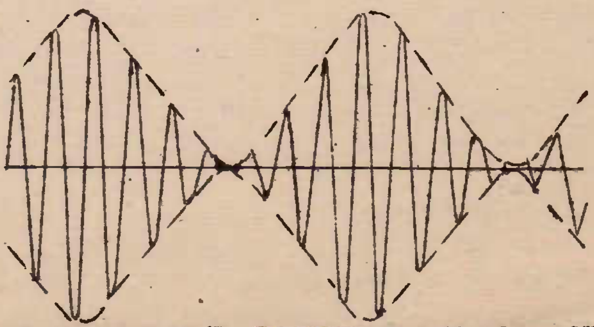
A. Sub-Carrier for uniform Dark Grey.



B. Sub-Carrier for Uniform White.



C. Modulated R.F. Carrier for Dark Grey (A)



D. Modulated R.F. Carrier for Uniform White(B)

FIGURE 2.

sub-carrier) superimposed on it. It is stressed that the diagrams of Fig. 2 are for a signal transmitting no detail. When the picture signal (from the photo-tube) is a varying current, due to the scanning of picture detail the sub-carrier itself will be modulated, and the modulation envelopes of graphs C and D (Fig. 2) will themselves have a modulated form.

The difference between the technique of maintaining correct D.C. level in facsimile and television systems should be carefully noted. In television we depend upon the more complicated method of establishing a D.C. level by special circuits in the transmitter, and the practice of restoring this level by the use of D.C. restorers in the final stage of the receiver. This method further involves the difficulty of designing video amplifiers of good low-frequency response. The easier facsimile technique is made possible by the comparatively slow scanning speeds, and low frequency picture signals involved.

The use of the sub-carrier has a further advantage in the case of telephone line transmission. If the picture signal were amplified directly (by D.C. amplifiers) and sent over the lines the latter would have to handle a frequency range from 0 to 600 cycles per sec. (in the example quoted). In this instance the ratio of highest frequency to lowest is infinity. Now transmission lines have different attenuation (loss) characteristics for different frequencies, and great distortion would result in the case of such a ratio of maximum to minimum frequency. When the sub-carrier is used the highest frequency is 1900 cycles per sec. and the lowest 700 cycles per sec, a ratio of only $\frac{1900}{700} = \frac{19}{7}$ = 2.6 to 1 (approx.). Ordinary telephone lines can easily handle such a ratio without selective attenuation.

TRANSMISSION METHODS:

The methods of changing variations in picture density into corresponding electrical impulses by the process of scanning, fall into two main classes :

A. Electro-mechanical.
B. Electro-optical.

In the case of electro-mechanical systems (which are now rarely used) a current is caused to vary by some mechanical device operated by raised surfaces constituting the picture surface or object to be transmitted. The first system of electrical fascimile used this method, which takes us back to a date over a century ago (1842) when an English physicist, Alexander Bain, devised an apparatus which incorporated all the essentials to be found in a modern facsimile system. For this reason it will be briefly described.

A simplified sketch of Bain's system taken from his original patent is shown in Fig.3. This sketch shows only the basic elements of the transmitting and receiving apparatus. Briefly the operation was as follows :- Printers metal type was used at the transmitting end. A pendulum carrying a light, resilient contact swung past the face of the type, completing a battery circuit between transmitter and receiver whenever it touched the raised portions of the type. For each beat of the pendulum the type was dropped down a step at a time. Thus each letter of the type was "scanned" in roughly horizontal lines. At the receiving end a similar pendulum and contact operated over a paper soaked in potassium iodine solution (a chemical which turns dark brown when an electric current passes through it). The paper was traversed past the pendulum in the same manner as the type at the transmitter. An electrical arrangement was provided whereby if one pendulum preceded the other slightly it was held back until the other reached the same position and both started together. Current from a cell, switched by the transmitting contact passed via the receiving contact through the paper producing a brown stain.

Bain's system as an example of electro-mechanical scanning was, of course, in a very crude form. It gave only pure brown and white representations with no gradations in tone. It will be observed, incidentally, that the use of pendulums for synchronisation of transmitter and receiver anticipated by many years a method which, until very recently, was considered to be the best frequency standard available. Bain's transmitter was very little used, but his recorder, known as Bain's Chemical Telegraph was used for many years for recording Morse Code signals.

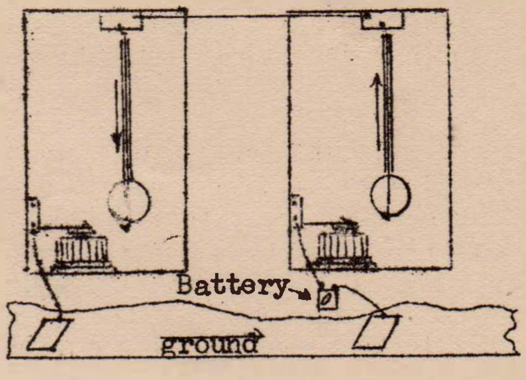


FIGURE 3.

Another example of the Electro-mechanical scanning method was a system (Belin, 1897) in which the photograph for transmission was reproduced in relief on a special gelatine surface. This was scanned by a stylus, which as it traversed the hills and hollows of the picture surface worked, mechanically, a rheostat, which in turn created variations in the electric current. In 1909 the rheostat was replaced by a microphone, whose diaphragm was vibrated by the stylus as the latter moved over the rough surface of the picture. This system gave quite good graduations of tone in the finished product. Belin's system proved quite practicable.

Turning now to the Electro-optical systems, it will be understood that these are systems in which variation in light originate the electrical picture signal. Practically all modern systems are of this type. The "heart" of such a system is, of course, the photo-cell, already explained in the television lessons. In all of these systems a brightly illuminated portion of the picture is focused on to the photo-cell, usually with a microscope "objective" lens. The most usual arrangement is to wrap the picture around a cylindrical scanning drum, the latter being rotated and at the same time "traversed" in a direction parallel to its axis relative to the scanning area or spot. The result is that the picture is scanned in a spiral position. The principle of this type of scanning has already been explained in Lesson 1.

In order that the photo-cell is affected only by a single small element of the picture two methods are used. In the first a small spot of light is focussed on the picture by means of a "condenser" lens a small aperture being included in the system to ensure that the light spot has the correct size depending upon the number of scanning lines and the size of the picture. In the other arrangement the picture is flood-lit and a picture element is selected by placing a small aperture in the objective lens system which focusses the light on the photo-cell. The two methods, it might be observed, correspond exactly to the old "flying-spot" and to the flood-light systems, respectively, in television. The two possible arrangements are illustrated in Figs. 4 and 5 .

In each case the lens system is so designed that the photo-tube receives, at any one moment, light reflected from an area of the picture <u>equal to the aperture dimensions</u>.

Hence the aperture is made to have a size equal to the scanning spot dimensions required by the system. These dimensions depend in turn upon the number of scanning lines per inch. The aperture is usually rectangular, one side being equal to the width of a scanning line (e.g. 1/100 inch for 100 lines per inch scanning). It is found in practice to be better to have the other side of the aperture slightly less than this, in order to give greater definition (detail) measured <u>along</u> a scanning line.

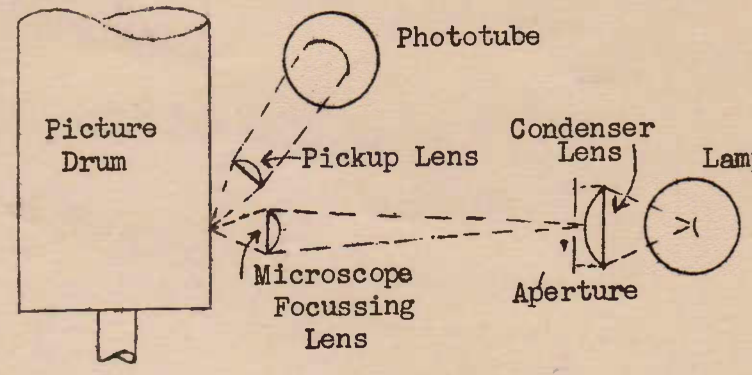


FIGURE 4.

It will be observed that in the case of the so-called flood-lit system (Fig.5) the <u>whole</u> of the picture area facing the light source is <u>not</u> illuminated. For economy of light, "condensing" lens are used to concentrate the light on a comparatively small area. This illuminated portion, however, is very much larger than the scanning "spot". The advantage of this arrangement is that any wrinkling of the picture on the drum does not shift the position of the transmitted image.

For certain commercial applications (e.g. photos transmitted for newspaper reproduction) it is desirable to operate directly from the photograph negative. This requires transmitted rather than reflected light, i.e. the photo-tube must pick up light which has passed through the picture, rather than light which has been reflected from its surface. If a scanning drum is used this would appear to necessitate placing either the light source or the photo tube inside a transparent drum. A more convenient arrangement is that shown in Fig. 6

Here use is made of a glass prism to turn, by reflection, a beam of light through a right angle. The prism is a wedge-shaped piece of glass as shown in Fig. 7. A

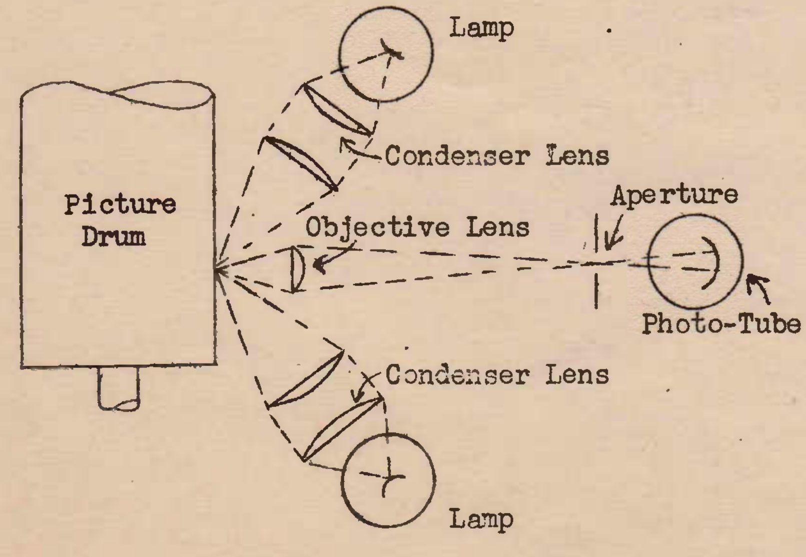


FIGURE 5.

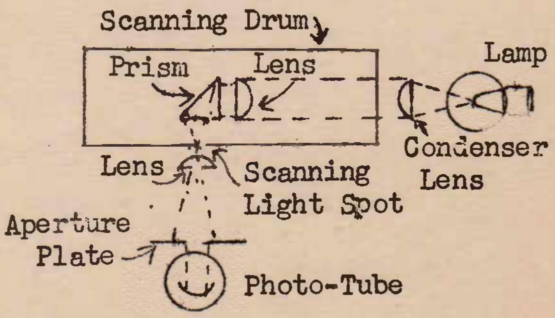


FIGURE 6.

light ray OX entering the prism through the surface A.B.C.D. continues on to the point X on the surface B.C.F.E. Providing the angle at which the ray OX meets this surface is less than a certain critical value (depending upon the optical properties of the glass) the ray will not emerge from the surface but will be reflected in the direction XY. This is called "total internal reflection". Thus although the glass is perfectly clear and is not coated with any metallic material the surface B.C.F.E. acts like a perfect mirror.

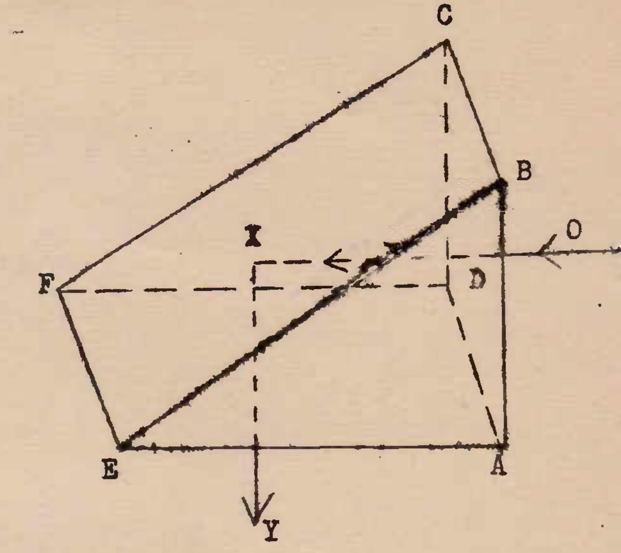


FIGURE 7.

Returning to Fig. 6., the light from the lamp passes into the drum, parallel to the axis of the latter. The lens inside the drum would, in the absence of the prism, focus the beam to a point somewhere to the left of the prism. Due to the presence of the latter, however, the light rays are turned downwards and focussed rather sharply on the transparent film which is wrapped around the drum (the drum material itself must, of course, be transparent). The amount of light passing through the film will depend upon the shade of grey of the particular portion of film being scanned. This "transmitted" light is picked up by another lens and after passing through the aperture (which determines the exact size of the spot being scanned) falls upon the photo-tube. The chief advantage of this method is that more light may be transmitted through a negative than may be reflected from a paper. Hence a less sensitive amplifier is required.

TECHNIQUE OF MECHANICAL SCANNING:

The simple principle of the drum method of spiral scanning has already been explained. The picture or printed matter to be transmitted is wrapped around the drum which is rotated at a constant rate by a motor. At the same time the drum is given a slow longitudinal movement, parallel to its axis, relative to the light source, often by means of a fine screw thread. The result is that the scanning spot traversed the picture in a spiral manner around the drum. The mechanical arrangements which have been used to achieve this are extremely numerous, and there is no point in attempting to describe the details of various designs. However, Fig. 8 is included to show a typical arrangement which illustrates in simplified form the basic principles of most systems.

The drum, motor and gears together with a "lead screw" are mounted on a framework which can move along a slide attached to the main frame. Also fixed to the latter is a nut which engages the lead screw. The electric motor drives, through suitable gears both the rotating drum and the lead screw. The latter is simply a shaft of steel which is threaded somewhat like an ordinary bolt. Since the nut is fixed the lead screw, as it rotates must move bodily from right to left. In so doing it carries with it the framework which also carries the drum. Hence the latter is given both a rotational and a longtitudinal movement. Since the light source is fixed it is easily seen how the scanning spot traces out a spiral path around the cylinder.

In order that the scanning lines which encircle the drum lie adjacent to each other the rotational speed must bear a definite relationship to the speed at which the drum is moved

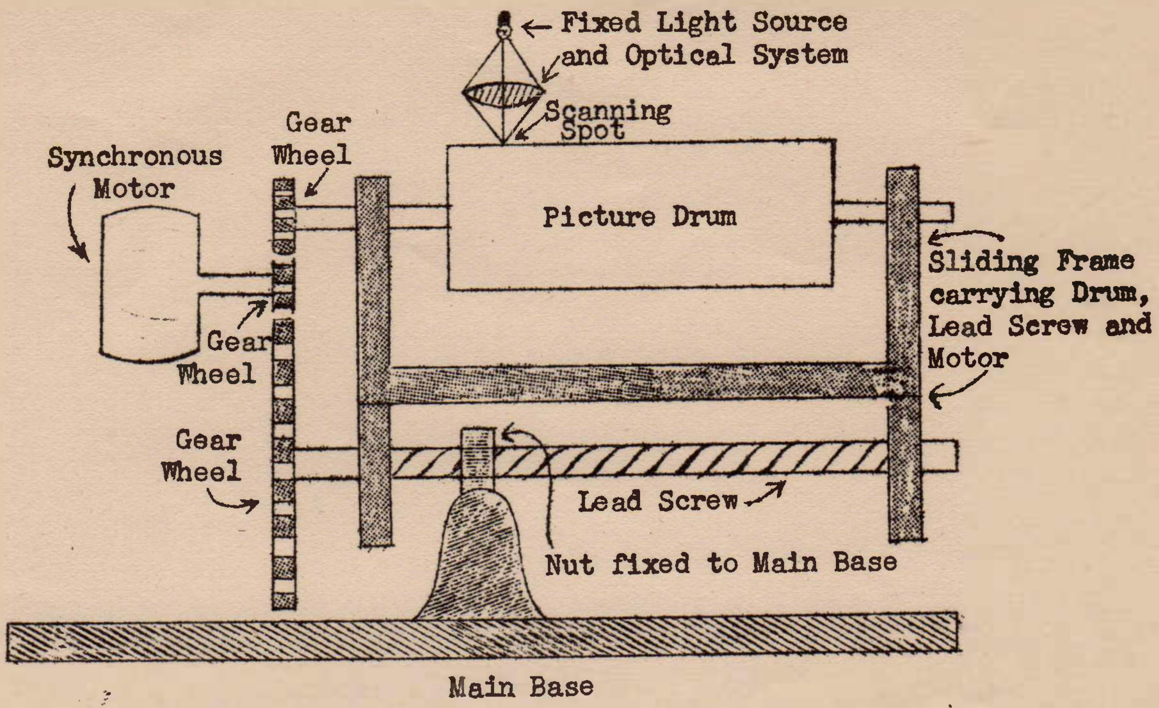


FIGURE 8.

along. The distance moved in one revolution of the drum should be equal to the width of a scanning line. If, for example, 100 lines per inch are used, the lead screw should shift position of the drum through only one-hundredth of an inch for each revolution. These conditions are obtained, and are fixed for good, by correct design of the gearing ratios in conjunction with the screw pitch.

The reason for the popularity of this drum spiral method of scanning is that both motions required for scanning are obtained from rotational movements. The method lends itself to great accuracy in tracing the scanning lines, and in synchronising receiver with transmitter (synchronisation is dealt with in detail in the next lesson).

The disadvantages of the system are :

(1) The sheet of material to be transmitted must be of the special dimensions to fit the drum.

(2) It does not lend itself to continuous operation of transmitter and receiver. When one sheet has been sent the apparatus must be stopped at both transmitting and receiving ends. This renders purely automatic operation at the receiving end impossible (see next lesson).

CONTINUOUS SCANNING METHODS:

Broadcast Facsimile for home purposes could never be really acceptable until satisfactory methods of continuously scanning a long roll of paper were developed. This necessitates the tracing of horizontal lines across the paper in a manner similar to that of television.

Various arrangements whereby the scanning "head" is given a reciprocating movement, moving the scanning spot to and fro across the paper, which is at the same time drawn slowly between rollers, have been tried. These, however, are, intrinsically, mechanically complicated, inaccurate, and difficult to synchronise.

One such arrangement, nevertheless, has proved fairly satisfactory. This utilises a special reverse lead screw. The latter consists of a shaft of steel having two screw grooves cut around it. One groove passes down the shaft rotating in, say, a clockwise direction. The other passes down the shaft rotating counter-clockwise. The two grooves are really continuous - each joins the other at both ends of the shaft. The construction of this ingenious device may better be realised by referring to Fig. 9. The reverse screw is placed lengthways at the base of the transmitter, and is stationary, except of course, for its rotational motion which is obtained from the synchronous motor. A "follower" engages the screw thread. This follower is simply a piece of metal shaped at one end to fit the groove. The follower cannot rotate, but is free to move along a slider parallel with the lead screw. As the latter rotates the follower moves at a uniform rate, say from left to right along the screw. When it reaches the end of the screw the grooves reverses as shown in the sketch, and the follower begins its reverse journey along the screw.

The follower conveys moving force to the analyzing head, consisting of the light source and optical system for focussing the light to a spot. In this way the scanning spot is given a regular to and fro horizontal movement. The transmitted information is printed on a long roll of paper which is passed between rollers, correctly geared to the motor. Hence as the paper passes slowly downwards in front of the analyzing head, the latter scans it in horizontal lines. Of course the speed of horizontal motion of the scanning head must bear a proper relationship to the speed at which the paper is passed through the rollers, in order that the scanning lines lie adjacent to each other.

It should be observed that this device gives a scanning action in horizontal lines somewhat similar to that made use of in television. There is one important difference, however. The reverse screw makes the analyzing head work in both directions; there is no quick "fly-back" as in television electronic scanning.

A continuous transmitter scanner which avoids the use of reciprocating parts is illustrated in Fig. 10. The paper to be scanned is moved, by means of friction rollers lengthwise along a semi-cylindrical surface. The picture is scanned by light spots through a slot cut across this semi-cylindrical form. The optical system consists of a pair of lens and prism "microscopes" which rotate on the axis of the semi-cylinder.

Suppose that the optical system is rotating clockwise when looking at it from the right-hand end of the diagram (Fig. 10A). Further suppose that at this instant the light-spot marked "A" (from the

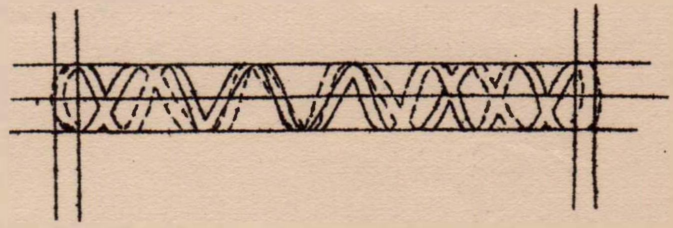
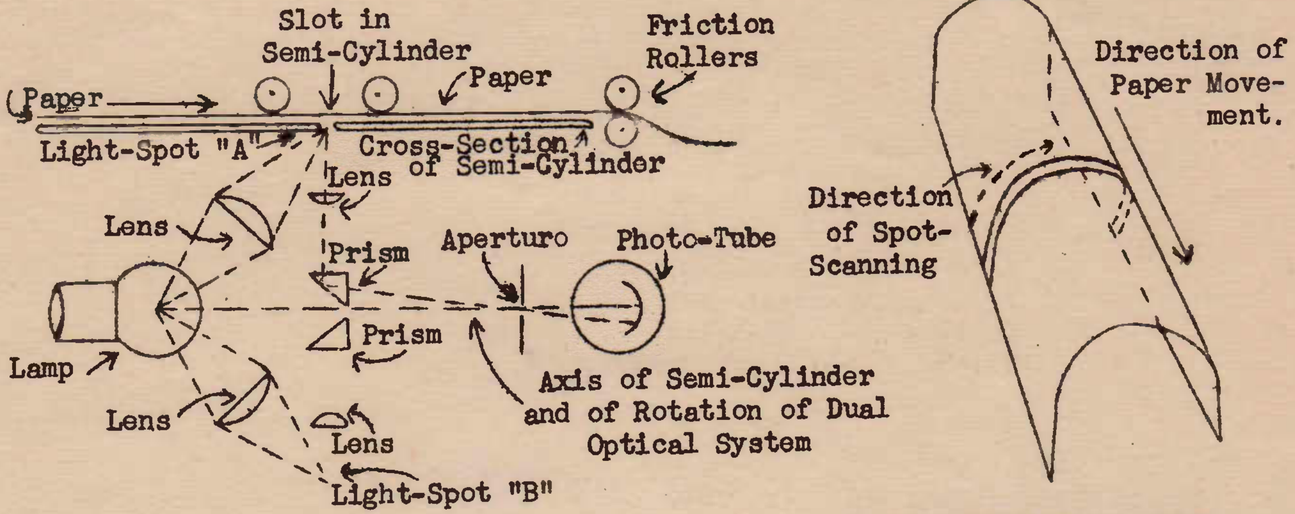


FIGURE 9.



B. CONSTRUCTION OF SEMI-CYLINDRICAL GUIDE.

THE ALEXANDERSON SCANNER.
A CONTINUOUS TRANSMITTER SCANNER.
FIGURE 10.

upper lens-prism system in the figure) is just commencing to move along the slot at the left-hand edge of the paper. For the next half-revolution of the "scanning head" light-spot A will be scanning the paper. By the time this spot has passed right around the semi-circular groove light-spot B will just be commencing to scan along the latter from the left-hand edge of the paper. In the meantime, of course, the paper has been shifted through a small distance along the length of the semi-cylindrical guide, at right-angles to the groove. Hence the paper will be scanning by a series of nearly horizontal scanning lines. Note that the scanning occurs in one direction only across the paper, as in television.

The photo-tube is actuated by light reflected from the paper passing over the groove. This light is focussed and deflected on to the photo-tube by means of a lens and a prism, as shown.

This type of continuous scanner may be operated using a long length of paper unwinding from a spool at one end of the semi-cylinder on to another spool at the other end. Alternately individual pictures or articles of printed matter may be inserted at will into the scanner while the latter remains in continuous operation. There is no necessity to stop the scanning process in order to change copy or re-load. The only condition which needs be satisfied is that the width of the paper does not exceed the semi-circumference of the scanning surface.

MODULATION METHODS:

The lowest frequency of the picture signal is, theoretically, zero (an even picture tone). The highest frequency occurs when scanning the finest detail. In most commercial applications, such as newspaper photo facsimile the highest frequency rarely exceeds 1,000 cycles per sec. and may be much less (e.g. 500 - 600 cycles per sec.). This permits of the direct modulation of a sub-carrier - the advantages of which have already been discussed. In the case of the commercial applications referred to the sub-carrier usually has a frequency of 1200-1300 cycles per sec. Home (broadcast) Facsimile usually demands a higher transmission speed, which produces a picture signal of higher frequency. This in turn means that the sub-carrier must be raised in frequency so that at least several cycles of sub-carrier are included in the highest picture frequency element. For broadcasting over an ordinary amplitude modulation station the highest sub-carrier which can conveniently be used has a frequency of about 3,000 cycles per sec. Such a sub-carrier could handle a picture signal ranging up to approximately 2,000 cycles per sec. This would produce side-bands (of the sub-carrier) between 1,000 cycles per sec. (3,000-2,000 cycles per sec) and 5,000 cycles per sec. (3,000 + 2,000 cycles per sec). Hence the latter figure (5,000 cycles per sec) would represent the highest modulating frequency for the <u>radio-frequency</u> carrier wave. The total band-width would be twice this, viz. 10,000 cycles per sec. which equals approximately one broadcast band channel.

Such a system as that referred to above for use in conjunction with a standard A.M. broadcast station can broadcast material at the rate of about 5 square inches per minute. This may sound slow, but it represents approximately 65-75 words per minute of ordinary printed matter.

In order to obtain faster transmission speeds the latest development in America is to make use of the F.M. broadcast stations. In this case a sub-carrier of 10,000 cycles per second is <u>amplitude</u> modulated with the picture signal. The resulting output is a band of frequencies extending from 7,000 cycles per sec. to 13,000 cycles per sec. Such a system can send 28 square inches of material per minute, which, in case of printed material, represents a rate much faster than can be read.

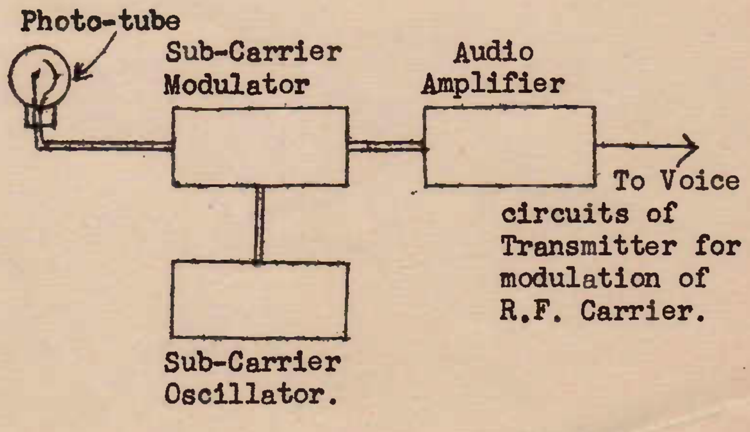
It will be observed that in each case cited so far the sub-carrier together with its picture signal modulation products lies entirely within the audio range. As a consequence the signal may, after conventional audio amplification be applied directly to the voice (microphone) circuits of a standard transmitter (A.M. <u>or</u> F.M.), as illustrated in Fig. 11.

<u>GENERATION OF THE SUB-CARRIER:</u>

Since the sub-carrier is of audio frequency it is usually generated by some non-electronic method.

One method is to insert in front of the photo-tube a chopper wheel which breaks the light-beam at a regular rate (the sub-carrier frequency). This wheel is usually driven by the scanning drive motor.

The frequency at which the light is interrupted is, of course, higher than the highest picture frequency obtained from the scanning process.



<u>FIGURE 11.</u>

When a uniform part of the picture (i.e. no detail) is being scanned the phototube output will consist of regular pulses of constant amplitude at chopper frequency. When a detailed part of the picture is scanned the reflected light varies with the detail, and the amplitude of the chopped pulses will vary accordingly. The result is really a modulated signal. Since the chopper rate is an audio frequency (say 3,000 cycles per sec) the output may be handled by a conventional audio amplifier.

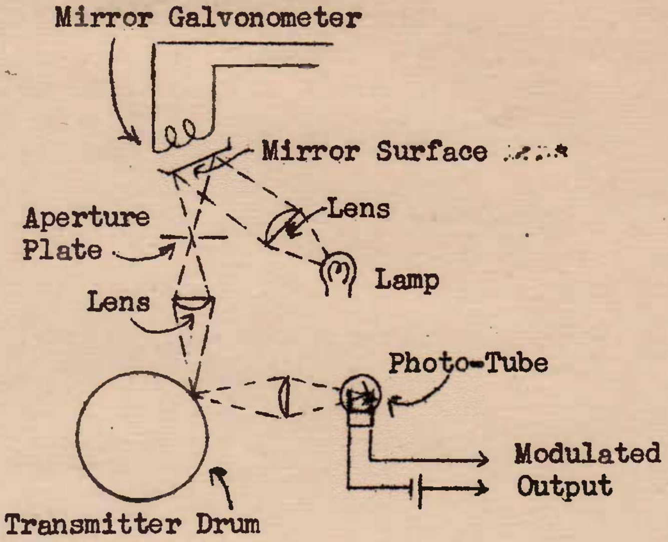


FIGURE12.

A modulated sub-carrier may similarly be obtained simply by supplying the photo-tube from an A.C. source (at sub-carrier frequency) instead of using a D.C. source. The A.C. source is frequently an alternator (or A.C. generator) driven by the scanning motor, or it may be any convenient type of vacuum tube oscillator.

Another method of modulating the light-beam is that which makes use of a mirror galvanometer. The latter consists simply of a very small and light mirror suspended in the optical system of the scanner and caused to vibrate by means of an electromagnet supplied with an A.C. at sub-carrier frequency. (See Fig. 12). As the mirror vibrates the amount of light which it passes through the aperture, and hence the intensity of the scanning spot varies. The result will be that the photo tubes output will be a pulsating current, modulated by the picture signal.

FREQUENCY MODULATED SUB-CARRIER:

In order to minimise the effects of electrical interference (including atmospherics)

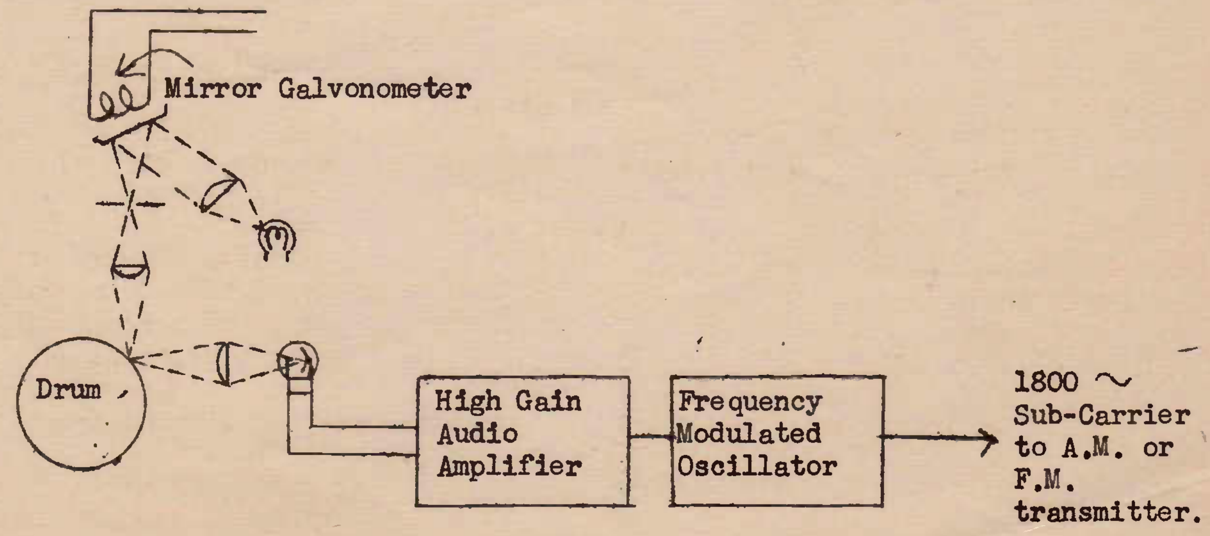


FIGURE 13.

frequency modulation of the sub-carrier is also used. One such system is illustrated in Fig. 13. Where an initial amplitude modulation is first produced by means of a mirror galvanometer (or chopper wheel etc.) This initial A.M. is introduced in order that the signal may be raised in level (by means of an ordinary audio amplifier) sufficiently to operate a frequency modulator. The latter is fed by an 1800 cycles per sec. sub-carrier frequency, and modulation produces a deviation of ± 200 cycles per sec. The deviation to 1600 cycles represents black and that to 2,000 cycles represents white. It should be closely noted that the modulated sub-carrier is represented by a range of audio frequencies between 1600 and 2000 cycles per sec. The output may therefore be used in several ways:

(1) For direct transmission over a land-line.
(2) For application to the audio circuits of a broadcast Amplitude Modulation Transmitter.
or
(3) For application to the audio circuits of a broadcast Frequency Modulation Station.

Thus far we have traced the various methods whereby the visual information contained in a "still" picture or piece of printed matter may be converted into an electric signal suitable for transmission over conventional wire or radio links. It remains to investigate in greater detail the apparatus in use for reconverting this signal back into a facsimile of the original. The main problems are those associated with the "recording", in a permanent manner, of the received information, and of synchronising the receiver and transmitter apparatus. These will be dealt with in detail in the next lesson.

QUESTIONS - LESSON NO. 19.

(1) What are the two main differences in the requirements of a Facsimile system compared with those of a Television system ?

(2) Why is it possible to transmit a facsimile signal over a sound broadcast station ?

(3) Name a most important requirement of a home broadcast facsimile system which is not usually satisfied in most commercial applications.

(4) Explain the reason for the use of a sub-carrier in radio facsimile transmission ?

(5) What considerations fix the frequency of the sub-carrier in a radio facsimile system.

(6) Into what two main classes may scanning systems be placed ?

(7) A drum scanner has a circumference of 8" and a length of 12". If the drum rotates 100 revolutions per minute, and 125 scanning lines per inch are used, how long will it take to transmit the picture.

(8) What is the main disadvantage of drum (spiral scanning) methods ?

(9) Describe one method of producing a modulated A.F. sub-carrier ?

(10) Describe one method adopted to minimise electrical interference with facsimile signals.

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Use sketches and diagrms wherever possible. One diagram in many cases is equivalent to pages of explanation.

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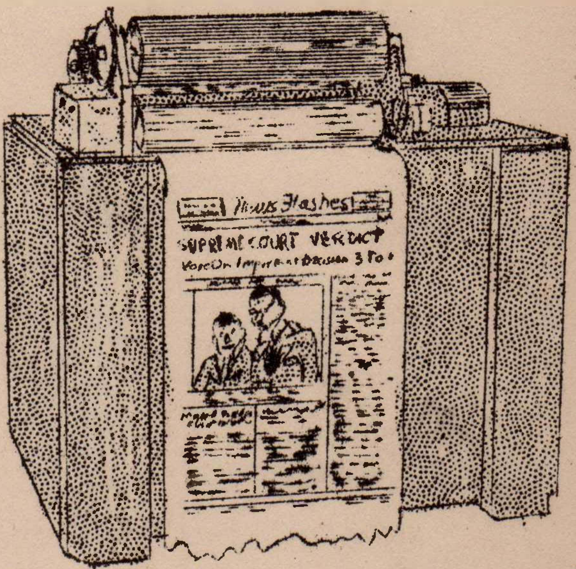
T.FM & F. - LESSON NO. 20.
FACSIMILE RECEIVERS.

When we refer to a Facsimile Receiver we naturally mean the complete apparatus which accepts the signal produced and sent out by the transmitter, and uses it to reproduce a copy of the original information. In the case of <u>radio</u> facsimile this apparatus will consist of a more or less conventional radio receiver (less audio stages and speaker) together with the "recorder". The latter comprises a rectifier (detectors), amplifier, mechanical scanning system including electric motor, and apparatus for synchronising purposes. For reception of signals sent by wire, where no radio frequency carrier is used, the receiver will consist of the recorder section only, together with an additional small amplifier similar to an audio amplifier, for raising the signal to the desired level.

As we have seen in the previous lesson the usual practice at the transmitting end is to superimpose the "picture" signal on a sub-carrier and then to use this modulated sub-carrier as the modulation voltage for the transmitted r.f. wave. Since the sub-carrier, together with its side-frequencies lies entirely within the audio frequency range, it is obvious that any radio receiver designed to operate in conjunction with the transmitter will handle the signal just as if it were handling speech or music. In fact when a broadcast transmitter is handling a facsimile signal any sound receiver tuned to the station will emit a continuous whistling sound. This sound, of course, is due to the de-modulated <u>audio</u> frequencies representing the facsimile sub-carrier and its side frequencies.



A Modern Home Recorder.

FIGURE 1.

The facsimile signal, represented by the modulated sub-carrier is taken directly from the radio receiver's detector stage. After undergoing a stage of amplification it is applied to a diode detector (rectifier) which separates the "picture" signal from its sub-carrier. It will be remembered that the sub-carrier is frequently not very much higher in frequency than the upper limit of the picture signal itself. Hence the value of the filter condenser(s), which follows the detector and whose purpose it is to by-pass the carrier while not affecting the modulation, is rather critical. Too small a capacity will not remove the sub-carrier sufficiently, while if this condenser is too large it will unduly attenuate the higher-frequencies of the picture-signal with resultant loss in detail. In ordinary sound radio work the carrier frequency is normally at least 50 times the highest audio frequency. Hence practically any small mica condenser (.0001 - .0005 mfd, say) will effectively remove the r.f. component without affecting the audio frequencies appreciably. In facsimile work, on the other hand, the sub-carrier may have a frequency only 1-1/2 or 2 times the highest picture frequency. It requires fine judgment, therefore, in choosing a capacity which will differentiate between these two frequencies. In replacing such a by-pass condenser it is important to use one having a capacity exactly equal to that originally inserted by the designer. Instead of a simple by-pass condenser a more elaborate filter, consisting of inductors and condensers tuned to resonate at and reject the sub-carrier frequency, is often used.

After detection (of sub-carrier) the picture signal is passed on to the printer amplifier, The nature of this amplifier depends upon the particular method of "recording" used (see below). In all cases, however, this amplifier must be of the D.C. type, i.e. it must not contain capacity coupling in either its grid or plate circuits. The reason for this, of course, is that the picture signal involves frequencies ranging from zero (direct current) upwards. Use of a capacity coupled amplifier would result in loss of the D.C. component of the signal, which, in turn, would result in elimination of the normal shading of the picture. Only the fine detail would be reproduced.

The circuits described above, and which normally form part of a complete recorder unit, are shown in "block" form in Fig. 2. Sub-carrier detectors and recorder amplifiers will be treated in more detail at a later stage in this lesson.

RECORDING METHODS:

Perhaps the most interesting section of a facsimile receiver is that part which gives the visual reproduction of the original information scanned at the transmitter.

A very large number of methods of recording or printing have been developed. Each of these usually has its own particular merits, and the method used in any particular instance depends largely upon the application of the facsimile systems under consideration. The chief methods may be classified under the following headings :-

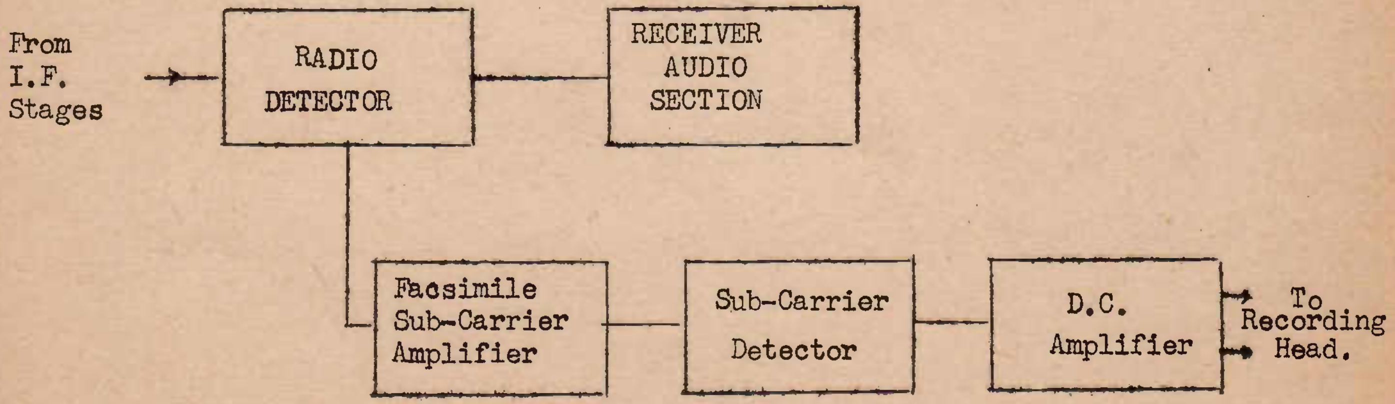


FIGURE 2.

(1) Purely mechanical.
(2) Photographic.
(3) Heat methods.
(4) Ink Spray Method.
(5) Carbon Paper.
(6) Electro-chemical (Electrolytic) Methods.

MECHANICAL RECORDERS:

Under this heading we have systems in which some kind of stencil (as used on an ordinary office duplicating machine) is wrapped around the receiver scanning drum. An electromagnetic precussion unit takes the place of the light-source of the transmitter. This electromagnetic "scanning head" punctures the stencil as dictated by the electrical signal while the scanning process proceeds. Of course, only line drawings, plans, and print can be reproduced in this way. When the process is complete the stencil is removed and may be used as a master copy on an ordinary office duplicating machine to produce as many copies of the original as desired.

For business use a transmitter and recorder may be mounted on one carriage with a double length drum. The material to be duplicated is wrapped around the drum at one end, while the stencil is wrapped around the other end. The optical system and photocell then scan the original on one half of the drum, while the precussion unit reproduces the copy as a stencil on the other half. This machine can be made to operate with a minimum of controls, and is useable by general office staff with no particular training.

PHOTOGRAPHIC METHODS:

The photographic method is still the best for re-producing a photograph of high tonal quality. Either a photographic "positive" film or "negative" paper is wrapped around a drum similar to that of the transmitter. A light source and optical system for focussing the light onto the drum is used. The mechanical scanning mechanism is usually a replica of that at the transmitter. As the photographic film (or paper) is scanned in spiral lines the facsimile signal varies the amount of light falling on it.

The light falling on the film may be varied in several ways, two of which will be described here. The first is an electrical method which is very simple. This makes use of what are variously known as "Glow Tubes", "Crater Tubes" or "Hot Dogs". These are simply tubes of the neon type constructed so that the glow takes place in a crater formed in one of the electrodes. This provides a fairly brilliant point-source of light, i.e. the light emanates from a very small area, and so may be focussed to a fine point for scanning purposes. The simple system is illustrated in Fig. 3.

The neon type lamp is used because light emitted will vary instantly with variations in signal current, and also because a small source of light may be obtained as described. Furthermore a neon tube may be operated by a very small current at one or two hundred volts. Hence it may be fed by the plate current of an ordinary valve to whose grid the signal is applied (see "Printer Amplifiers" below).

The second method of varying the intensity of the light spot is a mechanical one. Here s steady source of light from a filament type lamp is used and the method involves "valving" the amount of light reaching the film. This may be achieved by means of a mechanical "oscillograph", and light apertures as shown in Fig. 4.

Light from the lamp is focussed on to the mirror of the oscillograph. This mirror is free to turn and is actuated by a "moving-coil" in the magnetic field of a magnet. The coil of the oscillograph is fed by the rectified signal. Light reflected from the mirror is thus caused to sweep across a fixed aperture so that more or less light passes this aperture depending upon the strength of the signal. The light that passes the aperture is then focussed on to the sensitised paper or film on the drum. The aperture which receives the light reflected from the mirror of the oscillograph is specially shaped so that the variations in the amount of light which it passes, in relation to the signal amplitude, is adjusted to produce the correct tonal shadings in the reproduced picture.

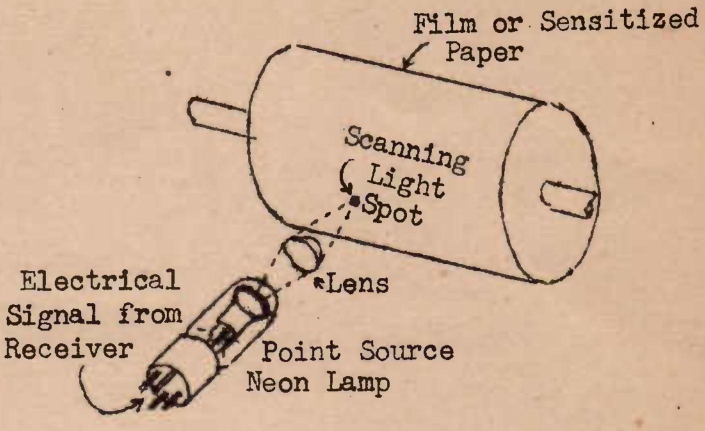


FIGURE 3.

INK SPRAY METHOD:

In this recorder a continuous spray of atomised ink projected onto the paper is used. The spray is regulated by a balanced armature magnetic driver, which is fed by the received rectified signal. The scheme is shown in simplified form in Fig. 5.

A fine jet of "atomised" ink is continuously emitted by the nozzle. The amount of ink which reaches the paper on the drum, however, is regulated by the signal which operates the deflecting wave. In this way, as the paper is scanned, the various shades of dark and light are reproduced. Plain white paper, of course, is used on the drum for recording. The picture requires no special processing after the scanning is completed.

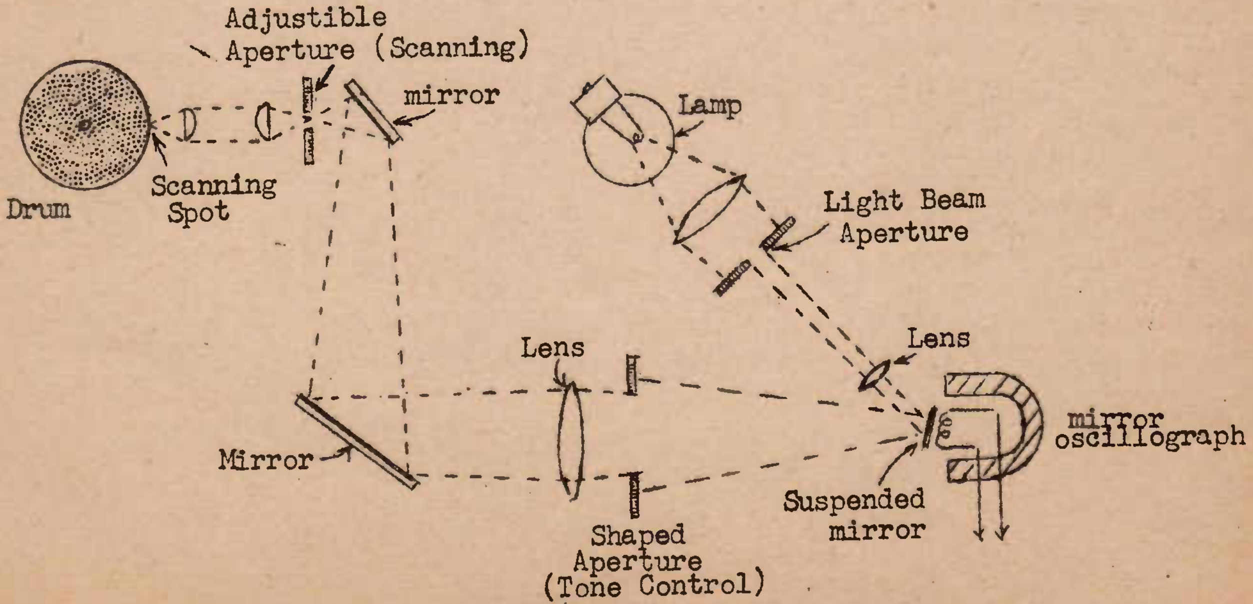


FIGURE 4.

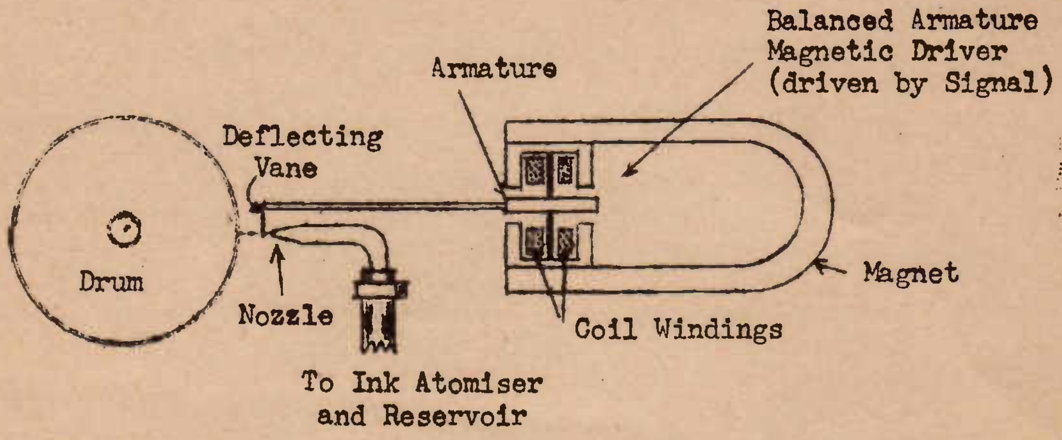


FIGURE 5.

HEAT METHODS:

There are two types of paper which are sensitive to heat: Chemically treated paper usually with a coating of some nickel salt, and waxed papers. In both cases a fine jet of heated air, regulated by the signal, is directed on to the paper surface.

In the case of the heat-sensitive paper the heat decomposes the salt on the surface leaving a black residue. The degree of darkness produced depends, of course, on the amount of heat applied, and this is regulated by the electrical signal which operates on the hot air jet.

When waxed paper is used the heat of the jet melts the wax surface. When the scanning is complete the paper is washed over with water ink. The difference in the inking between the areas of crystalline (unmelted) and melted wax provides the difference in intensity of the picture.

A third type of paper, of recent development, which might be included under this headin of "Heat methods" is that by the name of "Teledeltos". This paper is coated on one side first with a layer of carbon and then with finely divided metal. The metallised surface is placed in contact with a metal recording drum. The scanning "point" is a metal stylus which presses against the outer surface of the paper. The received signal, at about 100-200V is applied between the stylus and the metal drum with the result that burning of the paper takes place producing a dark mark. The latter is due to the black carbon showing through where the burn has occurred. The intensity of the burn depends upon the potential applied, and this is determined by the signal voltage; gradations of tone are therefore obtained.

CARBON PAPER:

In this system a sheet of plain white paper is placed on the recording drum. A sheet of carbon paper is placed face downwards over the white paper. The scanning is done by means of a metal point (stylus) actuated by a simple electro-magnet. The signal current is passed through the coil of this electro-magnet which applies varying pressur to the stylus. The heaviest pressure would produce black, and no pressure would give white.

An advantage of this carbon paper method is that as many as eight separate copies may be produced at a time with the one scanning process. Carbon paper is specially adaptable to the "helix" method of continuous scanning, described later in this lesson.

ELECTRO-CHEMICAL METHOD:

This method actually goes back to the earliest history of facsimile (Bain's system 1842); it also represents the very latest in fast, continuous recording for home receivers.

The principle of operation depends upon the fact that when an electric current is passed through certain chemicals, a chemical change, resulting in a change in colour, or darkness, occurs. Paper is impregnated with such a chemical and the rectified signal current is caused to pass through it. The paper turns dark to an extend depending upon the signal current amplitude. In earlier recorders the paper was wrapped on a metallic scanning drum and the scanning point was represented by a metal stylus. The signal was applied between the stylus and drum. In the case of the latest system the helix type scanner (see below) is used.

For many years the Electro-chemical paper recording was not very popular, for the reason that the papers available had to be wet while the recording was proceeding. Furthermore many of the papers had to be processed afterwards in order to obtain a permanent recording. However, in very recent years papers have been developed which operate in a dry condition, require no processing, and give an instantaneous record as the scanning proceeds.

REQUIREMENTS OF A HOME FACSIMILE RECEIVER:

Facsimile systems for commercial purposes have been very successfully used for a number of years. Most of these, however, are not suitable for home use, for several reasons. In the first place they usually require more or less skilled operators and are not automatic in operation. It is usually necessary to replace the paper or film on the recorder after each scanning. This re-loading process usually requires several minutes. Again many of such systems use a type of printing which requires special processing after the scanning process is complete.

The principal requirements of a home unit may be summarised as under :-

(1) The scanning should be continuous.
(2) The scanning rate should be fast - in the case of printed matter at least as fast as can be read.
(3) The printing should be visible while the recording is proceeding.
(4) The recorded material should not require any processing in order to make it visible or permanent; in addition the use of moist or wet papers for recording should be avoided.
(5) Synchronisation and Phasing (see below) should be automatic.
(6) The recording paper should be comparatively inexpensive.

Consider now the relative merits of the various recording methods which have been described. The photographic method gives the best pictures as far as tonal quality is concerned, but does not satisfy conditions (1), (3) (usually), (4) and (6) above. The heat methods frequently require special processing and utilise tricky apparatus to produce the jet of hot air. The "Teledeltos" paper, which is really a burning method has proved quite satisfactory. Ink Sprays are not adaptable to fast operation and are best suited for pure black and white reproductions. The carbon paper method is particularly adaptable to continuous recording, and immediately prior to the war was the most favoured method for home recording. The chief objection to this method is that the speed of operation is limited. This is due to the fact that the printing mechanism is mechanical, consisting usually of a stylus or printer bar operated by electromagnets. The inertia of such a system limits the scanning speeds which may be used. However, speeds which produce 4-1/2 square inches of useful recording per minute are obtainable. This represents, in the case of printed matter, 45 words per minute, of type writing, or 110 words per minute of typical newsprint. This may be regarded as satisfactory for printed material, but is really too slow when reproducing pictures, diagrams, plans etc.

Another disadvantage of the carbon paper method is that the printed matter does not show up immediately it is produced. This, of course, is due to the fact that the carbon paper obscures the recording paper. However, in some systems, it is possible to see the result soon after the signal has been received.

The electro-chemical sensitive papers were not at first suitable for home recording because they had to be used in a wet condition. Furthermore, some of them required processing to give a permanent record. However, in very recent times, papers have been developed which operate dry, which give an instantaneous impression, a permanent recording, and which are reasonably inexpensive. This development has given a tremendous impetus to home broadcast facsimile. A modern system - the Hogan system in America - uses such a recording paper and operates at a speed which gives over 28 sq. inches of material per minute. In the case of printed matter this is a speed very much faster than can be read or spoken.

CONTINUOUS RECORDING:

Continuous recording necessitates the use of a long strip of paper which may be gradually used by winding from one spool to another. The scanning must obviously be performed in horizontal lines across the width of the paper.

The earlier attempts at continuous recording involved a scanning head to which was given a to and fro (reciprocating) motion to trace out the lines. Such a reciprocating motion, however, required mechanical apparatus which was complicated and inherently inaccurate. Furthermore, the synchronisation of such apparatus was extremely difficult. This problem was solved by the development of the helix type of scanning recorder (mentioned earlier in this lesson). Since this device was developed in the first place for use with carbon paper we shall describe it as such, and then show how a slight modification (and simplification) renders it suitable for use with electro-chemically sensitive paper.

The secret of this device is the helix itself. A helix is like a single thread of a screw drawn around the surface of a cylinder, and may be visualised with the aid of Fig. 6. Starting from a point "A" at one end of the cylinder, on its surface, we draw a curve which completely encircles such cylinder once, and finishes up at a point "C" at the opposite end. One-half of this curve - from A to B - would be visible in this figure. The other half- from B to C - is on the rear surface of the cylinder and could not be seen.

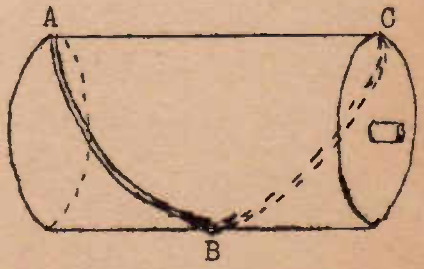


FIGURE 6.

Hence it is shown by a dotted line in the diagram.

In the actual apparatus the helix is a ridge of metal encircling a scanning cylinder. The carbon and recording paper is not wrapped around this cylinder, but is slowly drawn over it by means of rollers (see Figs 7 and 7A). The cylinder simply acts as a guide. A Printer Bar, operated by an electromagnet, bears across the whole width of the paper. The paper is "pinched" at one point only at a time - at the point where the bar is pressing against the raised helix.

Imagine now that the paper is stationary (i.e. paper feed rollers not working) but the scanning helix is rotating at 75 r.p.m. The point of intersection of the printer bar with the raised helix (i.e. the scanning "spot") will move horizontally across the paper at the rate of 1 "stroke" or line in 1/75 th of a minute. The carbon will trace out a dark line horizontally across the white paper (assuming that the printer bar is depressed). As the helix continues to rotate the same line would be traced over and over again. Suppose now that the paper rollers are set in motion drawing the paper through at a slow rate corresponding to a displacement equal to the thickness of a scanning line for one revolution of the helix (i.e. in 1/75 minute). The recorder will now trace out nearly horizontal scanning lines across the paper, each line lying adjacent to the next.

The signal is applied to the printer bar driver giving a push-pull action which raises the bar off the paper for "white", and presses it down heavily for "black". Half-tone signals will depress the bar with a force depending upon the shade of the original picture element. In this way the whole "picture" will be built up in a manner analogous to the action which occurs in a television system which does not use "interlacing" of the lines.

It should be observed (Fig. 7A) that after the two strips of paper pass under the printer bar the carbon is separated from the white. The carbon paper is led away by a guide to

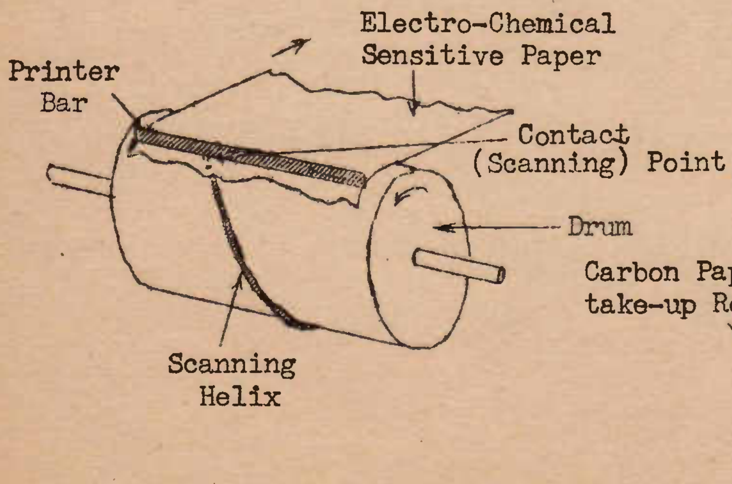


FIGURE 7.

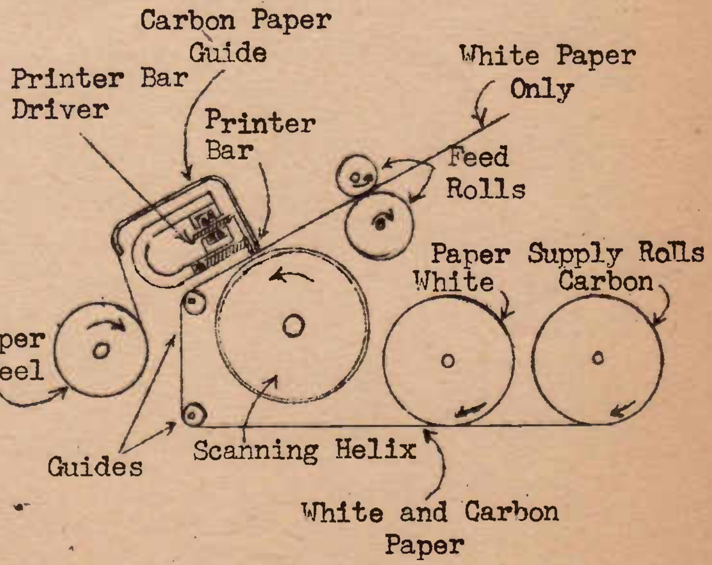


FIGURE 7A.

a separate reel which stores it until the recorder is re-loaded. The purpose of this is to allow the "reader" to see the received information soon after the actual recording takes place. Thus one of the chief disadvantages of older systems of carbon recording is overcome.

From the above description of the action of this recorder it will be seen that the speed of the linear motion of the paper through its rollers must bear a fixed relationship to the speed of rotation of the scanning helix. This relationship is easily obtained, and fixed for good, by driving both paper-feed rollers and helix from the one motor through suitable gears.

The important thing about this ingenious type of recorder is that while producing a to and fro motion of the scanning "point" there is no such reciprocating motion of any of the mechanical parts. All mechanical motions involved in the actual tracing of the lines are rotational. Hence this recorder is just as mechanically accurate in operation and as easy to synchronise as the drum type where the paper is wrapped around the cylinder.

THE HELIX RECORDER WITH ELECTRO-SENSITIVE PAPER:

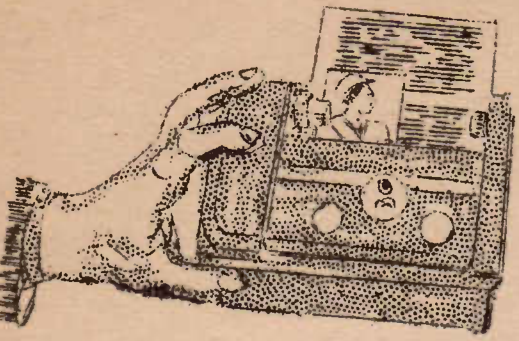
This represents the latest thing in fast, continuous, easily operated, home recorders. The printer bar is replaced by a simple metallic blade which rests across the paper very much as shown in Fig. 7. The signal, at 100-200V, from the output of a D.C. voltage amplifier is applied between the printer blade and the metal helix.

The manner in which the "lines" are traced out is exactly similar to that as described in connection with the carbon recorder. There is, however, now no motion of the printer blade. The picture signal forces a minute current through the paper which is treated with a chemical which turns dark to an extent depending upon the voltage applied. The Hogan System in America - mentioned earlier - uses this helix recorder with sensitised paper. The paper is supplied in rolls 400 ft. long and 9½ inches wide. This is sufficient for 24 hours continuous operation, or 2 to 4 weeks, of normal home service. The loading of the recorder with the paper is somewhat similar to the re-loading of a camera, and is even simpler to carry out.

In the Hogan Recorder the helix drum rotates at the rate of 360 r.p.m. This means that 360 scanning lines are traced every minute. The number of lines per inch is 105. Hence the length of paper scanned per minute is 360 ÷ 105 = 3½" (approx). Since the paper is 9½ inches wide the area scanned per minute should be 9½ x 3½ = 33¼ square inches. Allowing for margins a useful area of information equal to 28.1 square inches is actually obtained every minute.

The frequency range of the facsimile signal (sub-carrier and side-bands) is 7,000-13,000 cycles, which may be easily handled by an F.M. broadcasting system, although the frequency is too high for A.M. stations. The home recorder, complete with its associated circuits (pre-amplifier, sub-carrier detector, and recorder amplifier) is supplied for attachment to any F.M. receiver. The size of the recorder unit is about that of a typewriter.

An even smaller and cheaper recorder is represented in Fig. 8. This unit produces a single column 4.1 inches wide at the same scanning rate and speed as the unit just described, namely 105 lines per inch and approx. 3.5 inches per minute. Thus is scans approx. 14 square inches per minute.



A SMALL HOME REPRODUCER.

FIGURE 8.

HOME BROADCAST OPERATING TECHNIQUE:

The range of material which may be used for a home service is very large. We might mention, for example, the following: latest news flashes (home newspaper), weather information (including maps), diagrams, charts etc. to illustrate talks and educational topics put out over the oral system, receipes for the housewive, photographs of the latest events in the day by day life of the nation etc.

With the systems in operation at present it is not possible to send facsimile and speech over the same broadcasting station - one would interfere with the other. Instead broadcasting stations mainly use the hours from 12 mid-night to 6 a.m. for facsimile. In these six hours the home recorder can be continuously receiving and recording visual information. When the citizen arises in the morning he has available about 100 ft. of paper 9½" wide printed with a wide variety of information. The continuous recorder makes this possible.

Although several systems of continuous scanning at the transmitter were mentioned in the previous lesson, it is not necessary to use these in a system designed for continuous automatic recording in the home. The helix arrangement is not suitable for adaptation to transmitter scanning, and the other types described in the last lesson have disadvantages which usually outweight their advantages. As a result the drum method of spiral scanning is still largely in favour.

In order to see how spiral drum scanning may be used in conjunction with helix continuous recording we shall describe what is done in the case of the Hogan system.

At the transmitter the information is printed on sheets 9½" wide by 12" long. A drum of length 12" and circumference 9½" (diameter approx. 3") is used. A sheet is wrapped in the drum so that its 9½" dimension passes around the drum, the 12" dimension being along the drum. Note that the lines of printed matter will encircle the drum. With spiral scanning the length of a scanning line is approx. equal to the circumference of the drum - in this case 9½". If now both transmitter drum and receiver helix are rotated at the same speed (360 r.p.m. in the case of the Hogan system) the "lines" will be traced at the speeds at both transmitter and receiver. When the whole length (12") of the transmitter drum has been scanned, the home recorder will have printed a strip of paper 12" long (and 9½" wide).

It must be remembered that the home recorder is passing paper through continuously. In order that no large blanks appear on the paper it is important that no time is lost at the transmitter between the end of the scanning of one 12" x 9½" sheet and the beginning of the next. This is simply taken care of by providing several drum scanning units at the transmitter. By the time one scanning is complete the transmittion of the next sheet is commenced by switching from one scanning unit to the next.

RECORDER AMPLIFIERS:

By the "Recorder Amplifier" we mean a circuit which will accept the signal (modulated sub-carrier, from a conventional receiver) and then perform the two functions (1) Detect the modulated sub-carrier, (2) Amplify the separated picture signal in a manner suitable for operation of the particular type of recording unit used.

There is nothing new about the detection process. Diode detection is usually employed. However, full-wire rectification (as in an ordinary receiver power unit) is generally the rule. The advantage of this is that the sub-carrier component which has to be filtered out after rectification has <u>double</u> the frequency of the sub-carrier itself. This may be seen by referring to Figure 9, and also by considering the action of the conventional power-supply rectifier. Thus the filtering (by-passing) of the carrier component from the picture signal (represented by the modulation) is more efficiently carried out.

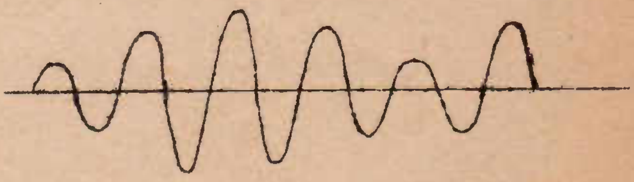
The final recorder amplifier itself must be , as already stated, of the D.C. type. Recorder amplifiers may be classified thus:-

(1) Those giving increased output on "black" signal, i.e. on decrease in sub-carrier amplitude.

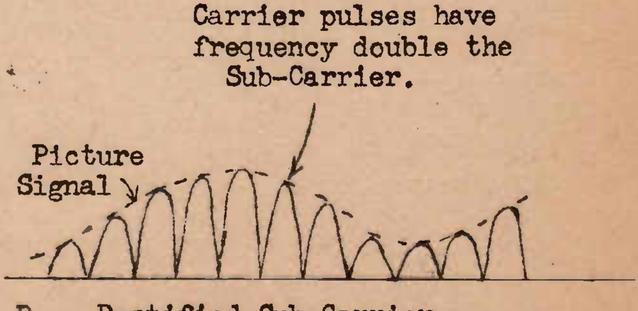
(2) Those giving increased output on "white" signal, i.e. on increase in sub-carrier amplitude.

(3) Those designed for operation of a "push-pull" printer as used in ink, carbon etc. recorders.

It will be recalled that the transmitter photo-tube's output is a maximum when scanning white. Further, since direct modulation of the sub-carrier is used the latter will have maximum amplitude for white and minimum for black. In all those recorders which print on white paper the amplifiers output should be zero on a "white" signal (maximum sub-carrier amplitude) and the output should be a maximum on a black signal. If this is the case a white signal will leave the white paper unmarked and a black signal will actuate the printer (mechanically, photographically or mechanically) to produce a dark mark. On the other hand an increased output from the amplifier might be required to produce a white mark on the finished product. This is the case when recording on a photographic "negative" film. It is also the case with some types of electrically sensitive paper where the paper itself is black, or coloured, and the signal breaks the coloured chemical down to produce white.



A. Modulated Sub-Carrier


Carrier pulses have frequency double the Sub-Carrier.

B. Rectified Sub-Carrier
(Full Wave Rectification)

FIGURE 9.

An example of type (1) amplifiers is shown in

Fig. 10. The modulated sub-carrier is applied to the detector (a duo-diode) through an audio frequency transformer having a centre tapped secondary. The rectified output

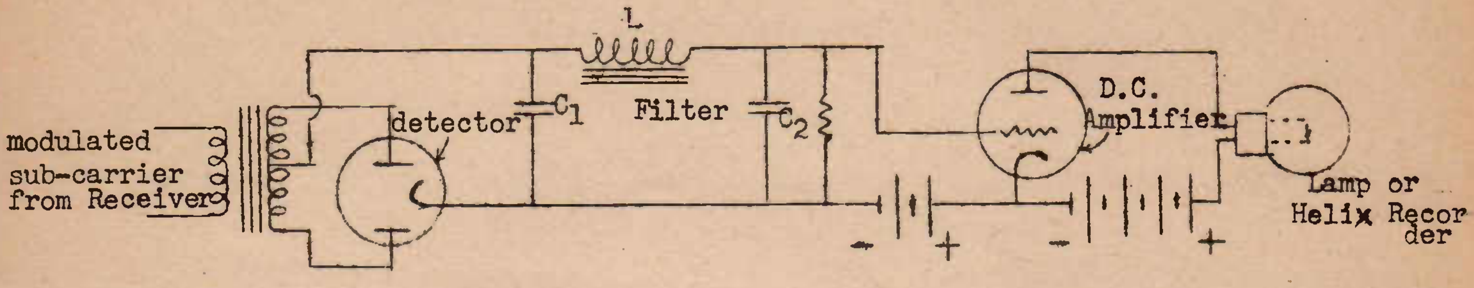


FIGURE 10.

is filtered from the sub-carrier component by means of the filter L C_1, C_2 and directly coupled to the amplifier valve. The latter is biassed by means of the battery (or equivalent) and the output from the detector. The bias is such that when "white" is being transmitted (maximum amplitude sub-carrier) the tube is cut-off. Any decrease in sub-carrier amplitude due to a darker portion of the picture being scanned will reduce the negative potential of the transformer centre-tap (measured relative to the rectifier's cathode). This reduces the negative bias on the amplifier grid, and plate current will flow through this tube. When sub-carrier amplitude is a minimum (pure black) the plate current should have its maximum allowable value.

By reversing the output from the filter section to the amplifier this circuit may be converted into the type (2) above. In this case the bias should be adjusted so that its nett value when sub-carrier is at minimum amplitude (black) is at the cut-off point. Then any increase in amplitude (change towards white) will reduce the negative bias allowing plate current to flow.

With reference now to the third type of amplifier specified above it should be pointed out that any mechanically operated recording "head" (e.g. stylus, printer-bar) could be operated with an electro-magnet driver applying force in a single direction, say downwards on to the paper when a black signal is received. The printing device could be lifted by means of springs for a white signal. Such an arrangement, however, due to the inertia of the "head" does not work well at high frequencies. Hence it would be suitable only for slow recording rates or where no great detail is required.

The push-pull balanced armature type drivers, as used on the helix-type carbon recorders are somewhat similar in construction to the old magnetic type speakers. A pair of coils are wound on a soft iron armature which is balanced in the field of a permanent magnet. The polarities of the coils are such that the current through one causes the armature to be pushed in one direction, while the current in the other tends to move the armature in the opposite direction. If both currents are equal the nett force on the armature is therefore zero. When, however, one current exceeds the other the armature is pushed, or turned, in a direction depending upon whichever coil is carrying the larger current. In this way a push-pull action is conveyed to the stylus or printer bar via an arm connected to the armature.

A circuit suitable for operating such a balanced armature driver is shown in Fig. 11.

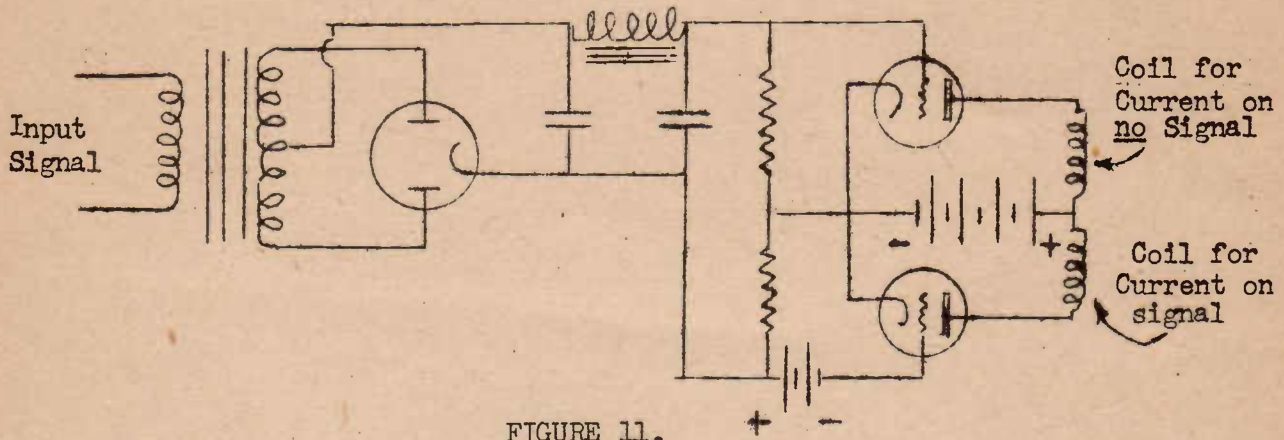


FIGURE 11.

The input system of rectification and filtering (detection) is the same as before. Two output tubes, acting as a sort of push-pull amplifier are used. When no signal (or minimum signal) is received the lower tube is biassed to cut-off, while the upper tube operates with zero bias, and therefore carries full plate current; under these conditions the upper coil would hold the stylus or printer bar hard down on the paper to produce black.

When the signal amplitude increases towards full white, a negative bias (due to the rectified signal voltage) is applied to the upper tube resulting in a reduction in its plate current. At the same time the rectified signal reduces the negative bias on the lower tube, allowing plate current to flow through the coil to which it is connected. The nett result of these two actions is that the armature pressure on the printer bar is reduced. When maximum signal (full white) is received the upper tube is cut-off and the lower carries full plate current. The effect of this is to reverse the force on the printer bar, and hold it off the paper. If the amplifier is properly designed the <u>sum</u> of the plate currents of the two tubes is constant for all input signal amplitudes.

A practical circuit, showing push-pull amplifiers connected to a <u>pair</u> of drivers working a printer bar is shown in Fig. 12. Here two full-wave rectifiers are used. The upper full-wave rectifier utilises the pair of diode plates in the 6R7 tube whose triode section is merely a pre-amplifier for the modulated sub-carrier signal. The outputs from the two rectifier systems varies the bias on the two output tubes in a manner similar to that of the previous circuit. Note that the lower tube is biassed to cut off (as in Figure 11) while the upper has zero bias when signal amplitude is zero.

The use of the <u>two</u> electro-magnetic drivers is usually considered necessary when operating a long printer bar, in order to give uniform action along its whole length, These, however, are simply connected in series with each other.

TRANSMITTER-RECEIVER SYNCHRONISATION:

So far we have been assuming that the transmitter and receiver scanning drums have been rotating at exactly the same speeds and have started off in step with each other. We

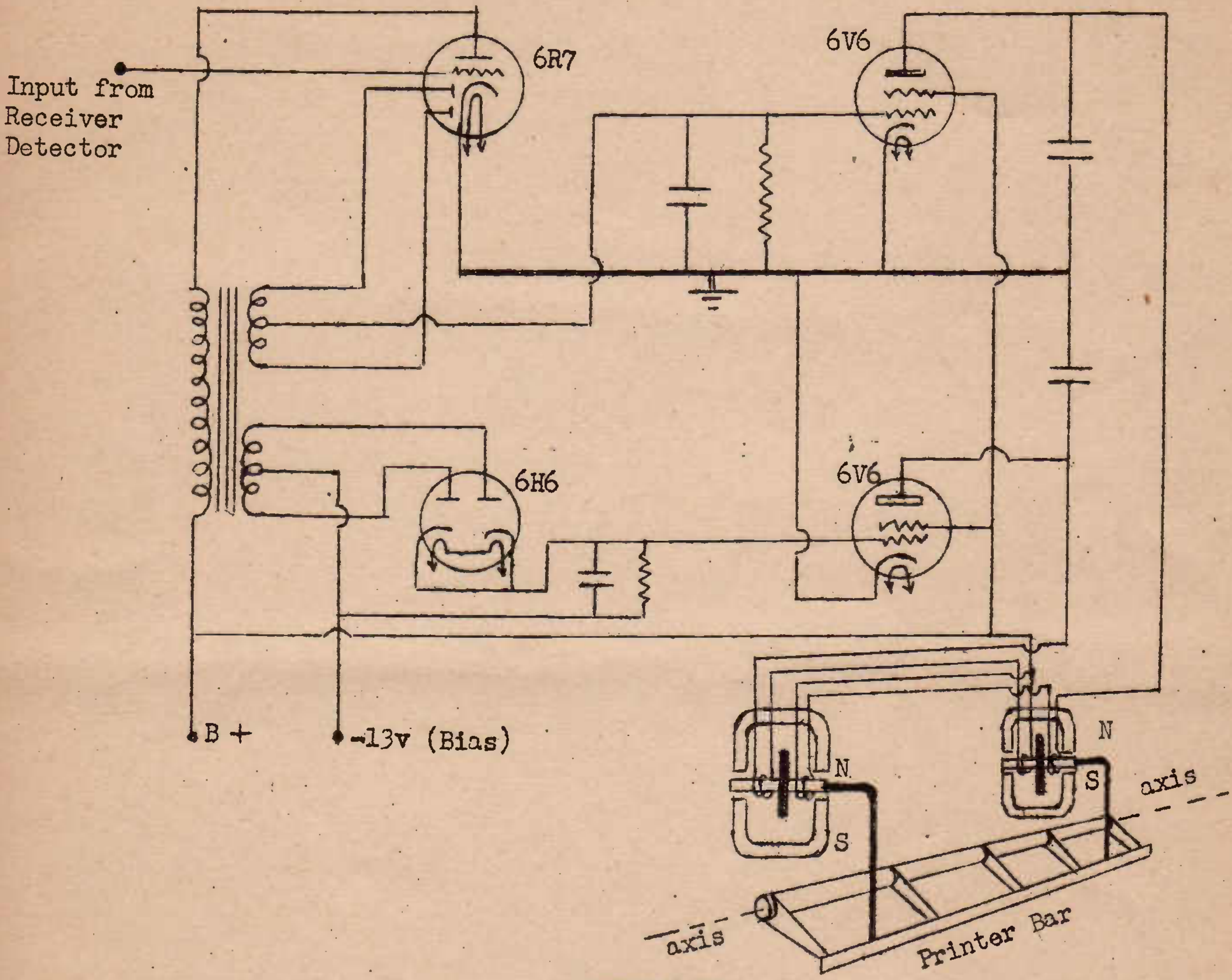


FIGURE 12.

must now examine methods which achieve this important job of synchronisation.

Visualising for the moment a system using spiral drum scanning at both ends we can easily see that synchronisation involves two aspects.

(1) Speed synchronisation.
(2) Phase synchronisation or "Framing".

By speed synchronisation we simply mean the job of ensuring that both drums are driven at the same (or very nearly the same) speeds of rotation. By phase synchronisation we mean the job of ensuring that the drums rotate so that when the transmitter scanning commences at the top of the picture the receiver recording commences at the right point on the recording paper. With good speed synchronisation it is usually necessary to obtain correct phasing only at the commencement of each scanning.

SPEED SYNCHRONISATION:

Speed synchronisation is usually achieved by driving the drums with synchronous motors. A synchronous motor is an A.C. motor which tends to rotate at one speed only, independent of the load. This speed depends directly on the frequency of the supply current, and on no other factor.

When both transmitter and receiver are operated from the same power supply system almost perfect synchronisation is obtained. Even though the supply frequency from the power house might vary through wide limits, both transmitter and receiver motors will be affected in the same way, and no loss of synchronisation is experienced.

When, however, the receiver is operated from a different A.C. supply, or a D.C. supply this method is not satisfactory. This fact may better be realised when it stated that a speed accuracy of one part in at least 100,000 must be maintained for good results. When no common power supply is available it is necessary to establish a common "frequency standard" at both transmitter and receiver. This may be done in two ways.

TUNING FORK OSCILLATORS:

The common frequency standard may be established at transmitter and receiver by using valve oscillators frequency controlled by means of tuning forks. The tuning fork here takes the place of a crystal in a crystal-controlled oscillator as it is more suitable than a quartz crystal for low frequency operation. The circuit diagram of a typical tuning-fork controlled oscillator is shown in Fig. 13.

The important fact about a tuning fork is that it vibrates mechanically at a frequency which remains very constant. An initial vibration of the fork, which is magnetised, induces an e.m.f. at the same frequency in the coil (Fig. 13). A part of this e.m.f. is fed back to the grid circuit of the oscillator tube. As a consequence the plate current varies. The magnetic field of this coil acting upon the steel fork sustains its vibration. Thus the action continues, at a frequency determined only by the tuning fork's physical construction. By using identical tuning fork oscillators at both transmitter and receiver, identical frequencies will be available for driving or controlling the drums by means of synchronous motors. The outputs from the oscillators, of course, must be subject to considerable power amplification in order to drive the drums directly. To overcome the necessity of these power amplifiers special D.C. motors have been designed whose speed may be regulated by the application of small amounts of power from the frequency standard oscillator. Most of the power used to drive the motor then comes from the D.C. source.

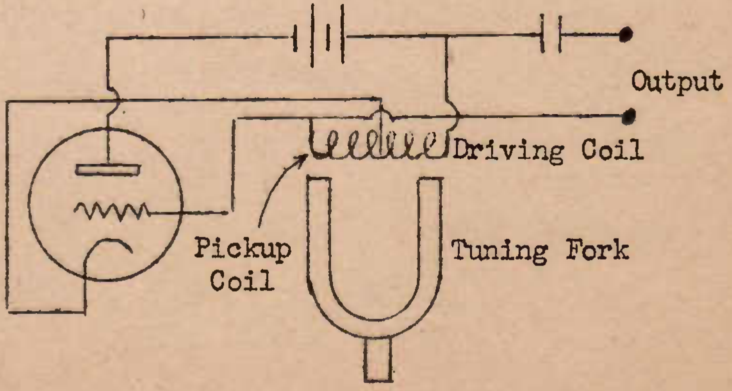


FIGURE 13.

SIGNAL SYNCHRONISATION:

The second method of establishing a common frequency standard at both transmitter and receiver involves the broadcasting of a special synchronising tone or signal from the transmitter. In order that this signal does not interfere with the picture information its frequency is usually fixed at a value lower than the lowest side frequency of the modulated sub-carrier. After detection in the radio receiver the sync. signal is separated from the modulated sub-carrier by means of a filter circuit. The tone is then amplified and used to drive (or control) the receiver's synchronous motor.

PHASING METHODS:

Methods which have been used from time to time to obtain correct phasing of the two drums are very numerous and varied. Most of these have involved manual adjustment of the receiver drum before scanning commenced. In point of fact many present day systems designed for commercial applications, where skilled operators are available, still use manual or semi-manual methods of phasing. Such methods, however, are not suitable for home reception where compact and automatic equipment is really a first essential. Most of the methods are in any case obsolete, and therefore we shall not deal with them in detail.

Typical of such systems, however, was the provision of a black band around the end of the drum at which scanning commenced. At one point on this band, corresponding to the edge of the picture (and, therefore, the beginning of a scanning line, was a white spot) see Fig. 14. At the commencement of operations both drums were set in rotation. Every time the transmitter scanning light passes the white spot a pulse was transmitted. This pulse was amplified at the receiver and fed to a neon lamp, which would therefore glow momentarily for every revolution of the transmitter drum. At the same time another neon lamp was caused to glow every time the receivers drum scanner passed the edge of the recording paper. The receiver operator, slowed his motor until both lamps were glowing simultaneously. This meant that the drums were correctly phased. The next step was to bring the receiver motor back to its synchronous speed, and thenceforth scanning proceeded, automatically. In some systems the phasing was done by ear, a loudspeaker replacing the neon lamp.

AUTOMATIC PHASING METHODS:

Most automatic phasing methods use some form of clutch between the motor drive and drum at both transmitter and receiver. The receiver clutch, which applies the drive, is engaged automatically by a phasing pulse sent from the transmitter.

One of such systems - one which operates only at the beginning of a scanning - uses a clutch at the receiver designed to slip entirely freely or grab hard. The phasing pulse is created at the transmitter by the white spot method of Fig. 14. On pressing a button at the transmitter the receiver motor starts revolving (as well, of course, as the transmitter motor and drum). The receiver clutch, however, does not immediately engage, so that the drum remains stationary in a position ready to commence the first scanning line. As soon as the transmitter pulse is

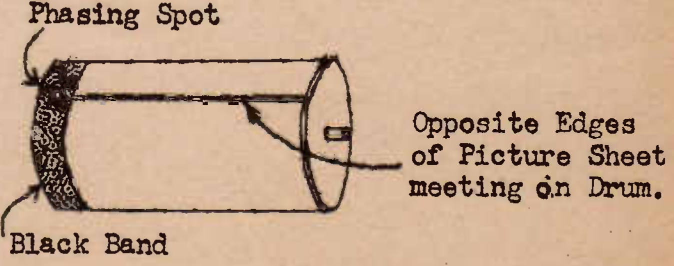


FIGURE 14.

received an electro-magnetic switch operates the clutch which suddenly grabs hard. Hence the receiver drum commence revolving in phase with the transmitters'.

Another somewhat similar method operates as follows. The transmitting driver is started by operating a switch which trips a magnetic clutch between the motor drive and the drum. This clutch has only one tooth, and so the transmitting drum always starts in the same phase relationship to the drive. A mechanical contact on this drive makes once each revolution, sending a phasing pulse to the receiver. This pulse operates an electro magnet at the receiver which trips a special clutch. This receiver clutch consists of a single pawl (ratchet) bearing a fixed angular relationship to the start of the paper on the drum which is made to engage with a 100-tooth ratchet wheel on the drive. The pawl engages the nearest tooth on the ratchet wheel when the pulse arrives. Hence the maximum phasing error that can occur is $\frac{360^\circ}{100} = 3.6^\circ$.

PHASING OF HELIX CONTINUOUS RECORDER:

Any of the above described methods could be applied to a helix type recorder. This follows because the helix drum rotates at the same speed as if a spiral scanning drum were used, further, one revolution of the helix produces a single scanning line just as in the other system. The methods, described, however, only give correct phasing at the beginning of the transmission. With synchronous motor drives this is sufficient to ensure that the phasing would remain correct during the normal scanning time for a drum - say 10 to 15 minutes. Using continuous recorders, however, where operation might proceed over a period of 6 hours the method would be unsatisfactory, as sufficient accuracy in speed control to maintain the correct phasing over such a long period, could not generally be obtained.

Continuous recorders are usually correctly phased by sending a very powerful pulse at the beginning of every scanning line. These pulses are formed by metal contacts on the transmitter drum. If the drums rotate at 360 r.p.m. (for rapid recording) the pulses would form a tone of 6 cycles per sec. This, however, does not interfere with the picture information, for the individual pulses arrive only at the end of a line (at the edge of the paper).

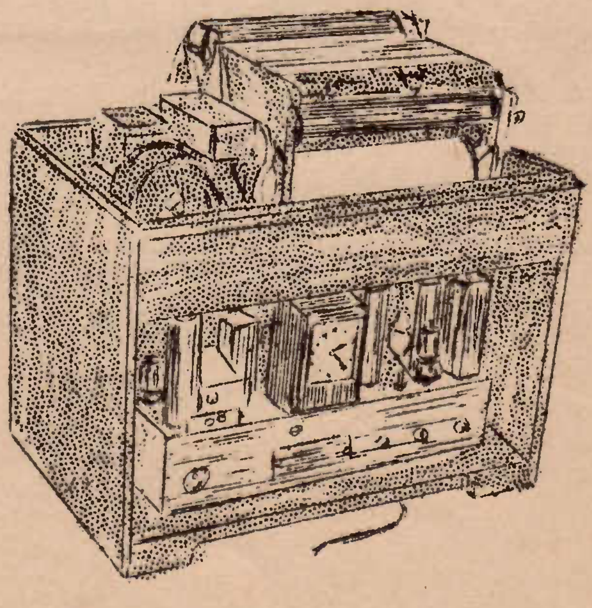
A circuit breaking device is mounted on the receiver helix drum. This device is used in conjunction with a line-framing relay. The circuit breaker carries a breaking arrangement which comes under the relay armature at the instant the scanning point goes off the edge of the paper. If the line-frame signal generated by the transmitter arrives at the same instant the circuit is such that the relay is not actuated, and the motor drives the recorder steadily in its correct line-framing position. If, however, the recorder circuit-breaking device is in another position when the line-frame signal comes in, the relay momentarily opens the motor circuit causing it to slip below synchronous speed. This occurs every revolution until the two drums work into frame again. This automatic phasing normally functions only at the beginning of a programme, the synchronous motors maintaining the correct phasing thereafter. During the programme, however, the correct phasing might be lost due to the signal fading out, or the power at the recorder failing for a short period. In such cases the machines will attempt to re-frame when normal conditions are restored, but may not complete the operation until the margin comes through at the end of the 12" sheet. The remaining pages of the programme will then be correctly recorded.

OTHER AUTOMATIC EQUIPMENT IN HOME RECORDERS:

With reference to the home recorder we have now reviewed equipment which will allow of purely automatic operation once the receiver is switched on. It only remains to make automatic this switching on (and off) process and we have the "game sewn up". The desirability of incorporating automatic switches for this purpose will be realised when it is remembered that the current facsimile broadcast practise is to send out visual information in the early hours of the morning from say 12 to 6 a.m. when the transmitter is not in use for audio purposes. The receiver, and recorder could of course be switched on before retiring and switched off when arising. But this would involve a waste of power and of recording paper.

The latest home recorders incorporate a special time switch. The latter involves a special clock (which may be set like an alarm clock) and which actuates an electro-magnet, switches or relays at the times set for the beginning and the end of the facsimile programme. Figure 15 shows the back of a modern recorder giving a view of the time-switch.

This fascinating subject of "facsimile" is only in its infancy at the present time and doubtless many remarkable improvements will be developed as time goes by. However, the principles, as explained in these papers, appear to be firmly established and once they have been clearly understood and digested, the student will find himself in a position to easily understand any gradual improvements or developments as they occur.



REAR VIEW OF HOME REPRODUCER.

FIGURE 15.

T. FM & F. 20.

QUESTIONS.

(1) Describe the circuits involved in a typical facsimile recorder unit. Give a block diagram. Why must the final amplifier be of the direct - current type ?

(2) Explain one advantage of using full-wave rectification of the facsimile sub-carrier.

(3) Make a list of the principal methods of recording, and discuss their relative merits and limitations.

(4) What is meant by a "light-value" in connection with recording equipment ?

(5) Discuss the principal features required of a home recorder.

(6) Explain briefly the principle of operation of the helix type recorder.

(7) A facsimile system is required to provide a definition of 125 lines per inch, and to print 2.5 inches of paper per minute. What must be the rate of rotation of the helix drum ?

(8) Classify recorder amplifiers into three types and explain the type of recording for which each type would be suitable.

(9) What two functions have to be performed in transmitter-receiver synchronisation ?

(10) A rectangular picture is transmitted using spiral drum scanning at both transmitter and receiver. What would be the effect on the picture if

a. Drums were started in phase, but speed synchronisation was incorrect.

b. Speed synchronisation correct, but pictures were not started in phase.