JOURNAL OF

The British Institution of Radio Engineers

(FOUNDED IN 1925 – INCORPORATED IN 1932)

"To promote the general advancement of and to facilitate the exchange of information and ideas on Radio Science."

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ON COMING OF AGE

The 21st Anniversary of the founding of the Institution was marked at the Savoy Hotel on October 31st, 1946, when some 450 members and guests sat down to dinner. Admiral the Viscount Mountbatten of Burma, received all members and guests, and from that moment of reception the occasion was successful in every way. Very few members or guests expected, however, that the 21st Anniversay would be so notably marked by the honour of His Majesty the King granting his patronage to the Institution. The announcement was made by the President of the Institution, and was greeted with tremendous enthusiasm.

The Future

The honour of His Majesty's patronage will inspire the future development of the Institution; that the officers and Council are fully alive to the Institution's problems was evidenced in the speech of Mr. L. H. Bedford. In his reply to the Toast of the Institution, proposed by the President of the Royal Society, Mr. Bedford referred to the fact that the Royal Society was the oldest of our learned Institutions, whilst the Institution was one of the youngest; possibly our greatest handicap was our juniority, a state which only time and the continued existence of the Institution would remedy.

Mr. Bedford also dealt with the contention that radio development was largely empirical. His reply to this criticism dealt with the need for a general theoretical background to our work, and the essential need for practical experience coupled with the right methods for ensuring exchange of information and ideas. Indeed, one of the greatest justifications for the existence of the Institution lies in its activity as a means of disseminating knowledge.

Even though, by the mediums at its disposal, the Institution is able to offer a platform for the dissemination of knowledge, it must be borne in mind that the publication of an original piece of work was of great importance to the author who, very naturally, considered publication in terms of what it meant by way of réclame; it was in this respect that a junior Institution was handicapped—a handicap which the Brit.I.R.E. had, to a considerable extent, already overcome. We could, not, however, yet be satisfied, when considering the British Commonwealth and Empire as a whole, that the membership was sufficient. The growth of membership throughout the Empire and Commonwealth was very encouraging and should be more gratifying as further Empire Sections were founded. Much more must be done in order to ensure justification for the claim of being the recognised Institution for British radio engineers.

Such thoughts as these formed the theme of the speech of one of the Institution's officers and were a sober reminder that whilst we have now reached a degree of maturity, we also have a great honour and responsibility to ensure that the Institution's membership continues to develop and that the standard of its proceedings is maintained.

Immediately, Council is able to report that membership development is being well maintained; paper restrictions make it impossible to publish the Journal so frequently as members would like, although the papers and discussions at the various Section meetings give sufficient material for the publication of a monthly Journal.

There is not, however, any restriction on the meetings which may be held by the Institution and the long planned Convention is now to take place in May, 1947. A balanced programme has been arranged to give as wide a survey as possible to the whole field of radio science.

Great interest has been exhibited in the Convention, which should provide ample opportunity to show appreciation of His Majesty's Patronage by making a major contribution to the Institution's main object, that of promoting the science of radio.

THE 21st ANNIVERSARY DINNER

The Toast to the President, Admiral the Viscount Mountbatten of Burma

proposed by

Leslie McMichael (*Immediate Past-President*)

(*At the 21st Anniversary Dinner of the Institution held on October 31st, 1946*)

To-night we mark, in appropriate British fashion, the coming of age of our Institution and, at the same time, express good wishes to Admiral Mountbatten on his acceding to the office of President.

To-night's gathering is well timed because it was actually on October 31st, 1925, that the first general meeting of the Institution was held. Twenty-one years may be a short spell of time to many of us here, but to the older members of the Institution it represents a period not only of growth and achievement but also a period of high endeavour, often with frustration, stretching back, it seems to us, into a remote age. We experienced all the hardships and heartaches which have characterised the founding of nearly every learned society and, of course, in that respect, we have much in common with the earlier years of the older Institutions, and have come to understand that professional acceptance is traditionally a matter of time, and proof of maintenance of standards.

Whilst for those first years the Institution's progress may have been slow and in keeping with the traditions of professional Institutions, our President's progress on the other hand, has been the very opposite. It is a coincidence that, in May, 1925, Lieutenant Lord Louis Mountbatten, as he then was, completed his final Signals Course which resulted in his obtaining first place and securing the Jackson Everett Prize, which is the highest award at the Naval Signal School. Subsequently, Admiral Mountbatten held a number of radio appointments in the Royal Navy, including that of Fleet Wireless Officer, Mediterranean Fleet; Flotilla Signal and Wireless Officer with the Second Destroyer Flotilla; and senior Wireless Instructor at H.M. Signal School.

It was whilst serving with the Mediterranean Fleet that Commander Lord Louis Mountbatten became a Member of the Institution. This very brief reference to our President's earlier work in the Navy also emphasises that the Senior Service recognised the possibilities of radio long before radio engineering became such an established industry and profession as it is to-day. Indeed, the demands of the fighting Services, especially during the two world wars, have given considerable impetus to the development of radio science, and in return, we believe that the achievement of British radio engineering played no small part in the success so magnificently won by our fighting forces.

In the light of present-day achievements, it seems hard to believe that as recently as 1925, radio was primarily regarded as a legitimate hobby for anyone who had experienced the joys of trying to construct a crystal set! The British Broadcasting Corporation was then only a Company and had not yet embarked upon those ambitious programmes which, whilst being the headache of the radio engineer, did so much to stimulate the development of radio communications, from which experience the radio engineer of to-day not only encompasses the world but is able to apply radio technique to the needs of almost every other industry.

Looking back over the past 21 years, one finds that in 1925 the comparatively few radio engineers of this country were discussing in technical journals the very first short wave transmission to Australia on 18 to 21 m., and an article in a technical journal was devoted to the construction of a loud speaker receiver working from A.C. mains! In those same journals, there was mention of the formation of the British 'Institute' of Radio Engineers. My friend, Mr. Pocock, whom I am so pleased to see here to-night, played no small part in being responsible for the original formation of our Institution, for it was through the two journals with which he is now associated—*The Wireless World* and *The Wireless Engineer*—that correspondence and editorials were published in 1924 and 1925 advocating and discussing the need for a separate Institution. Those journals were, and still are, the well-thumbed reference works of radio engineers, and when one reads the volumes for those early years one can begin to appreciate the tremendous strides which have been made in the advancement of the particular branch of engineering which we now call radio.

Returning to the subject of title, however, I well recall the editorial published in *The Wireless Engineer* stating that if the Institution was indeed to be a British Institution, the international word "radio" should be used instead of the term "wireless." Mr. Pocock's advocacy did not, however, find favour with us until late in the 30's and so, for the first decade of the Institution, we were perhaps, handicapped by using the old-fashioned title "Wireless Engineers."

I am glad to be able to record how very much Admiral Mountbatten encouraged and helped us in those difficult years to which I have referred. Before the war, he was the senior Vice-President of the Institution and had already been proposed for the office of President, which is the highest honour that we can confer. It is only in this year that he has been able to accept this election, and although he now enters this office with great honours and reputation, we still regard him most affectionately for the help he has always given and the great interest he has always had in our Institution. For his greater achievements and services to civilisation during these recent years we all honour him as members of a free British Empire and are proud indeed that throughout these greater services to his country, he has always retained a keen interest in his membership and office in the British Institution of Radio Engineers.

Our great Universities and cities have given just praise and honour to Admiral Mountbatten for his outstanding achievements as a guardian of our freedom, but in those greater services it may be overlooked that he also made a valuable contribution to learning, for the first serious instructional radio manual—The Admiralty Handbook on Wireless Telegraphy—was revised by Admiral Mountbatten whilst he was at H.M. Signal School. He was also responsible for the writing of the very first Admiralty Handbook on Wireless Telegraphy Sets.

As I have said, Admiral Mountbatten's final radio appointment was as Fleet Wireless Officer of the Mediterranean Fleet, in which he served under Lord Chatfield and Sir William Fisher. During that time our President introduced a number of innovations and I have no doubt that it was during the holding of these appointments that he decided to help us to encourage a higher standard of efficiency by instituting the award of the Mountbatten Medal. As members know, this award has been made annually since 1939 to the most outstanding candidate in the Army, Navy or Air Force taking the Institution's Graduateship Examination.

Since then, our Institution has indeed assumed an international outlook, both in its activities and in its membership. As you are aware, Mr. President, there is a very close relationship between ourselves and the Australian Institution of Radio Engineers, and your Council is now actively considering the development of sections of the Institution in New Zealand and throughout the British Empire. It is most gratifying to us to have so many good wishes from our members and friends overseas who have not been able to be with us to-night. I am hoping, Mr. President, that in your speech, which is to be broadcast, you will acknowledge and return the good wishes which we have received from Australia. There, you may know, they have a Radio Founders' Day, and this year all the broadcasting stations in Australia carried a message from the Governor General of Australia, His Royal Highness The Duke of Gloucester. We were very pleased to hear, in that broadcast, a message of goodwill to this Institution from His Royal Highness.

The membership you take over, Mr. President, is international, but it is predominantly spread throughout the British Empire; my colleague, Mr. Adorian, will refer in greater detail to the guests who are here to-night, but looking around at our own membership, I see such a number of representatives from the Services that I am reminded of our President's successes in organising combined operations! With our President, I believe in the need for co-operation, and it says much for the success of our Institution that membership from the regular Services keeps pace with the membership from Industry and the Universities.

I think that one of the most important aspects of the Institution's work is the bringing together of all who are engaged in the development and practice of radio engineering; we all know that science cannot rest on the fundamental discoveries of past generations, and means must exist, or be agreed upon, for free discussion and the spreading of knowledge.

There are so many problems in radio which have to be solved, just as there are problems in aviation and every other field of science, and the more we pool our problems, the greater will be the prospect of science working for the greatest benefit of mankind. As an engineering body we are just as much interested in fundamental research as in the application thereof, for who can say when research ceases to be of merely academic interest. It is not, for example, so many years ago that the phenomena known as radio echo was almost of purely academic interest—to-day, the outcome of this particular research has proved to be the basis of many new industries, producing a variety of equipment for wide application in times of peace, having already played an enormous part in winning the war.

We have had then our difficulties as an Institution, but we have overcome them in the main by team work and a striving for high standards by a keen membership. We are alive to the obligations imposed upon us by the terms of the incorporation of the Institution, and to achieve these objects sound leadership is essential and, Admiral Mountbatten, we are highly honoured to elect you as the Tenth President of our Institution.

In wishing you a happy and successful year of office, I do so in the knowledge that you will have at your command the full co-operation of a membership, that is, in every respect, in keeping with the British tradition of engineering societies and an influence for public good.

The Council and Committees which have recently been elected for this year reflect every sphere of activity in which our members are engaged and are moreover, experienced men, well able and most anxious to support you in furthering the objects of the Institution. And, finally, to support and aid your Council, is a Secretary and Staff whose loyalty and energy are beyond praise.

Mr. McMichael then formally proposed the Institution's Toast to the new President, which was received with great acclamation.

THE PRESIDENTIAL ADDRESS

of

Admiral the Viscount Mountbatten of Burma, K.G., G.C.V.O., K.C.B., D.S.O., A.D.C., LL.D., D.C.L.

(Delivered in London on October 31st, 1946)

In thanking the members of the British Institution of Radio Engineers for the high honour they have paid me in electing me President, I would like to say what a pleasure it has been to be associated with the Institution for more than half its life. Though I did not join till 1935, I passed my qualifying examinations in 1925, the year of its birth.

I am extremely grateful to Mr. McMichael for the kind things he has said about me, and I particularly appreciate his references to my service as a Wireless Specialist.

I would like to pay tribute to all those who have served the Institution, and enabled it to negotiate the very difficult war years successfully ; and in particular to our Secretary, Mr. G. D. Clifford. I would also like to remind you of the very large part played by my predecessor, Mr. McMichael, in establishing the Institution in the status which it now enjoys.

Mr. McMichael has referred to the message of greetings from our counterpart in Australia, with which we have such close ties, and of which I have the privilege to be a member ; and since what I am saying now is going out in the overseas broadcast, I should like to take this opportunity of thanking our colleagues for their kind message, which is much appreciated and heartily reciprocated.

I feel that it is a fitting recognition and a splendid climax to Mr. McMichael's years of office, that I am able to announce to-night that His Majesty the King has been graciously pleased to honour us by granting his patronage to the British Institution of Radio Engineers.

In the past 21 years the science of electronics has made great strides ; but, as we know, there has been a gap between scientific theory and practical application. During the war a wonderful opportunity of closing this gap came to scientists in every field, and it would be impossible to overestimate the part they played in bringing about victory.

I am not thinking now of the pulverisation of Hiroshima, but of the countless ways, many of them still undreamt of by the public, in which scientists were able to place not only their specific inventions but also their special qualifications, as well as their particular aptitude for scientific thinking, at the disposal of the war machine. I am happy to feel that I was able, in a small way, to contribute to bringing about this state of affairs.

In 1941, I found myself in charge of Combined Operations, one of whose principal tasks was to develop the technique and appliances needed for the large-scale amphibious assaults which would culminate in the Normandy invasion. I had spent eight years as a wireless specialist, serving continuously in wireless appointments. I had received as much scientific training and experience as a naval officer can ; and I naturally took a particular interest in the wireless aspect of Combined Operations.

It was clear that an operation like "Overlord", with its heavy concentration of a great diversity of fighting units, would not be possible without the highly integrated application of modern radio science ; and the first thing I did was to import some of my old pupils and colleagues to help me in tackling this side of the problem.

First of all a Landing Ship Headquarters was devised, to control an Army Division with the corresponding naval and air components during the assault and the early phases of the landing. The first headquarters ship fitted out was the *Bulolo*, with 20 transmitting and 60 receiving sets ; several other British headquarters ships followed, and the Americans also followed this idea, putting even more transmitters and receivers into their ships than we had ! These headquarters ships proved invaluable in amphibious operations in providing the commanders, jointly and individually, with an up-to-date picture of the situation, and for enabling them to give instantaneous directions to large forces in a rapidly changing situation.

What were called Fighter Direction Ships were also devised : comparatively small ships, crammed with radio and radar equipment, which enabled the R.A.F. controller on board to form a complete picture of the fighting in the air, and to give instructions to our own aircraft, while they were actually fighting.

But even these were not enough. Wireless telegraphy was too slow a medium to enable commanders to collect information and transmit directions at the rate which would be necessary to keep up with the progress of the assault. So we found it necessary, in addition to the many wireless telegraph links we already had, to set up a special network of radio-telephone beams, and to integrate it with the normal inland telephone service. This enabled commanders ashore and afloat to communicate with their opposite numbers —both afloat, ashore, and later on the Continent— almost as easily as they could telephone between their ordinary shore offices. The B.B.C. commentaries broadcast from France soon after D-Day were transmitted over these beams ; so many of you here to-night must have heard them in use.

This special network, which was initiated at Combined Operations Headquarters, offers one example—among so many—of inter-allied, inter-service planning and co-operation. It was entirely due to the fact that this inter-allied, inter-service co-operation was achieved, that the congestion in the ether did not result in complete chaos.

For tactical wireless communications were multiplied to such an extent that the available frequency spectrum in the ether was actually allotted several times over ! That is to say, that whereas in normal times a single frequency allocation would be used by only one wireless link, in this case most of them were shared by three, four or even five separate links, usually operated by different services.

In the earliest days of Combined Operations planning, the existing variations in equipment procedure, and general technique, presented a great obstacle ; and it soon became clear that, if the three services were to think, speak, plan and act as an integrated whole, this would involve integrating the technique of service communications to the greatest possible degree. The value of having done this was fully confirmed in the Normandy invasion.

I have introduced this question of integration, and the advantages of a high degree of standardisation of equipment and practice in communications because it is one which is up for consideration at the present time. At the Bermuda Telecommunications Conference a year ago, Major-General Stoner stressed the need for a world standard telegraph technique, and for a unified world-wide wireless telegraph network, based on the lines he had so admirably pioneered in the U.S. Army. A number of committees on which the fighting services, as well as civil and commercial interests in the British Commonwealth are represented, are now studying this question.

Not only is it hoped that a standard system will be evolved, in which morse operators will be replaced by automatic apparatus such as the teleprinter, and probably in certain circumstances by facsimile transmitters, but it is hoped that a single unified world-wide network of stations may be set up over which messages will be passed automatically or semi-automatically, from origin to destination, without appreciable delay at any necessary intermediate stations.

The messages will be typed in the first instance at the office of origin, after which there will be no further typing or writing until they emerge, typed on a sheet of paper, at their destination, which may be a shore office, a ship, or an aircraft, anywhere in the world. Moreover, if the plan allows for a sufficient number of stations, correctly situated, it will be possible, by varying the routes over which messages are sent, to ensure a 24-hour service between any two given stations.

It is encouraging that the three fighting services of the British Commonwealth should now be considering the possibilities of a single unified and integrated network of this kind. I hope they will be able to reach an agreed solution, and take what may well prove to be the first step towards an international system over a world-wide network.

The war not only taught us a great deal about techniques, but it proved the occasion for new departures in application. When I went to South East Asia, my Signal Officer-in-Chief devised a flying wireless and cypher station, consisting of a Dakota with a high-frequency transmitter which could be operated when the machine was on the ground. For more than two years this aircraft, which we christened the *Mercury*, accompanied me on trips totalling more than 200,000 miles ; and it enabled me to remain in constant touch with my headquarters, and thus with London and with every part of my theatre.

The war also provided a great stimulus to all forms of electronic research, and much of this is now being directed to inventions for purely peacetime purposes.

Many devices have been developed in the field of electronics, which enormously augment our present human senses. The best known of these, of course, is Radar, which augments to a remarkable degree our sense of sight, not only as regards distance but also in its capacity to penetrate fog or darkness.

By pooling and transforming the potentialities of other forms of radiation (such as light, heat, sound, X-rays, gamma rays, and cosmic rays), we may in future be able to receive the counterpart of Radar screen pictures, from inside our bodies, or even from inside individual body cells. Or perhaps we may receive them from the interior of the earth, or from the stars and galaxies.

And the sense-machine may present us with information not only visually, but also in the form of sound, or even of feeling. For there is reason to believe, also, that facilities for impressing information and knowledge on the human brain, at present largely limited to sight and sound, may be extended by the direct application of electrical currents to the human body or brain.

This extension of the sense of feeling is still in its infancy ; but even now it is possible to connect an electronic circuit with a bar of iron—such as a girder in a bridge—and to apply its currents to a human arm, so that a man can feel indications of the stresses and strains to which the girder is being subjected.

So the information from the sense-machine may very well come to us in forms which will be unintelligible until we have not so much developed new senses as developed our present sensibilities and trained ourselves to interpret new ranges of sight and sound and feeling, just as we had to learn to interpret the information depicted on the radar screen.

Those adjustments will not be necessary just yet. At the present time, however, we can benefit in rather more mundane ways : a new type of electronic cooker, for instance, can now generate heat inside food by induction, instead of the heat having to be conducted through the crust or skin and diffused slowly through the food. This cooker will bake gingerbread in one minute, and cook a chicken in four !

Electronic devices fit into two main categories : one which aims at saving labour, and the other which aims at saving thought. Along the labour-saving line, this means extending our invention in the field of action-control machinery.

In place of the machines introduced by the industrial revolution, which needed direct and local control by human beings (often at the cost of heavy physical labour), we first devised the pilotless plane, controlled from a distance ; and we now have the pilotless plough, controlled by an absent ploughman (but not, let us hope, by an absent-minded one !)

What I may call the thought-saving line of electronic research covers anything from calculating machines to the automatic finger print sorting machine used in modern criminology.

Our present methods of indexing knowledge are antiquated and illogical. Our normal index systems trace an item by initial letters, or by classes and sub-classes.

But the human brain does not operate like that : it establishes instantaneous association between one item and another by means of some intricate concatenation carried in the cells of the brain.

One can hardly hope to reproduce by artificial means the speed, the intricacy of the connecting links, and the detailed pictures of the human mind ; but man is learning a great deal from the workings of his own brain.

It is in this domain that the stage is now set for the most Wellsian development of all : the Electronic Brain.

In the human brain, as we know, the portion at the back of the head takes charge of the automatic movements of the body such as breathing, walking and balancing. This portion receives signals indicating whether, for instance, the lungs are empty, and want refilling ; when it promptly transmits to those muscles whose duty it is to keep the various functions operating correctly.

Except in the case of the heart, which is purely automatic, this brain process is subject to only very general directions from the intellectual portion of the brain at the front of the head. If we had to think out every single muscular movement every time we took a breath or walked a step, we should not have much mental energy left for creative thought.

It is now considered possible to evolve an electronic brain which will perform functions analogous to those at present undertaken by the semi-automatic portion of the human brain.

That is to say, it will receive information about the situation of the machinery under its control, and will provide an intelligent—I repeat, intelligent—link between that information and the action necessary to keep the machinery in general conformity with the overall directions given to it by man. In providing this intelligent link between this information and the action necessary to control the machinery, the electronic brain will enormously extend the scope of the human brain, not only in essence but also in distance.

This will be done by radio valves, activating each other in the way that brain cells do ; and one such machine, the Electronic Numeral Integrator and Computor (ENIAC) employs 18,000 valves, and consumes as much power as 100 electric radiators.

A machine of this kind will receive information supplied to it by the various information systems ; it will sort out this information, acting in accordance with overall directions given to it by human beings ; even at a distance it will obey its orders.

The ENIAC can solve complicated mathematical problems in a fraction of the time taken by a mathematician.

The answer to one particular problem, for instance, which concerns the trajectory of projectiles in flight, and takes a mathematician about ten days to find, can be extracted from this machine in four seconds, so that abstruse calculations on which mathematicians might spend years, can now be solved in a few hours.

The solution of many mathematical problems, particularly in integral equations, requires the exercise of choice and discrimination on the part of the mathematician, which he is able to exercise as a result of experience.

Even this factor can be covered ; for machines now actually in use can exercise a degree of memory ; and some are now being designed to exercise those hitherto human prerogatives of choice and judgment. One of them could even be made to play a rather mediocre game of chess !

In the field of memory alone, however, it seems likely that man is to be provided with vastly greater and speedier access to the inherited knowledge of the ages than he is able to command at the present time.

In this connection, I am indebted to Dr. Vannevar Bush, Director of U.S. Office of Scientific Research and Development, with whom I had some dealings during the war, for some extremely interesting notes he has sent me about an electronic memory machine.

Dr. Bush points out that our present methods of storing knowledge are extremely cumbersome, most of it being put into book form, which occupies 10,000 times the space that micro-film storage of the same information need take up.

Moreover, the arduous process of writing, printing and publishing could be replaced by directly recording human speech on to a sound track in legible form ; and I actually mean "legible," though to accomplish this it would probably be necessary to redesign present languages on a more mechanical basis.

It is beginning to seem possible that electronic techniques can be developed which will enable us to store items of our ever-increasing range of human knowledge in compact and yet far more accessible form.

The reference library of the future will be a kind. of memory machine, of the size of a large desk It will store such a fantastic amount of information that it would take hundreds of years to fill if the user inserted every day the equivalent of what is now 5,000 pages of material.

The owner of this magic desk will, in fact, have at his disposal in compact form what would nowadays be the whole contents of a colossal reference library of millions of volumes. Moreover, by a system of indexing and automatic cross-reference, based on electronic selection, he will be able to extract what he needs by pressing a few keys, instead of going through the long process that is now necessary in public libraries.

As we move towards the abolition of routine mental work as well as of routine physical labour we are being enabled not only to accomplish achievements far beyond the scope of present human attainment, but also, theoretically at any rate, to free the human mind for creative purposes.

I say theoretically, because it is not quite sure that all of us spend every moment rescued by labour-saving and other devices, in listening-in (as we should be doing !) to the Third Programme instead of filling in football coupons !

But perhaps by the time the machines are doing all our routine work, and all our routine thinking for us, we shall have attained a stage where we can make proper use of the time gained.

Now that the electronic brain and memory machine are upon us, it seems that we are really facing a new revolution : this time, not an industrial one, but a revolution of the mind. And in this revolution the responsibilities facing scientists to-day are formidable and serious.

At the time of the industrial revolution forces were released, before the general intellect and conscience of mankind had been sufficiently indoctrinated to control and direct them for the benefit of man.

If such a gap is again permitted to arise, in the course of the scientific revolution we are now living through, only disaster can result.

I have already pointed out how in the late war it was found imperative that the gap between pure and applied sciences should be closed; and how scientists were brought in, and operational research divisions set up, on military staffs.

In my own case I was fortunate enough to be able to obtain permission to appoint as members of my staff, both in Combined Operations and South East Asia, some of the most eminent scientists in the country—men like Bernal, Zuckerman, and T. W. J. Taylor.

These men of science not only worked with the Naval, Military and R.A.F. officers who formed my newly created Directorate of Experiments and Staff Requirements, but became members of my inter-service operational planning staff.

Here they were able to gain first-hand experience of military planning, and to learn what the planners wanted to accomplish. At that point, their function was, as Sir Henry Tizzard, the Chairman of the new Defence Research Policy Committee, put it, to give the planners not what they wanted but what they needed.

For, as a scientist on my staff, quoting Chesterton, said of my planners: "It isn't that they can't see the solution: it is that they can't see the problem."

We are now, it seems, to have a peace-time counterpart to the military operational research staff. I am delighted to hear that a special research unit is being set up by the Board of Trade, and will be linked with Social Survey and to a statistical group under the Department of Scientific and Industrial Research.

It will study civilian peace-time needs, and relate them to the resources which science has at its disposal. If the maximum advantage is to come from this new venture, scientific institutions and bodies, as well as individual scientists, will all have to play their part.

The war, in a very special way, "put science on the map," and it is up to every scientist to do his bit to see that it stays there.

He has been too much inclined to sit in his ivory tower, washing his hands of the results of his discoveries and inventions. This Pontius Pilate attitude is out of date to-day—it is worse than out of date, it is anti-social. The world is moving very fast, and it is largely up to the scientist to see that it does not move down-hill.

Learned societies and institutions, such as this one of Radio Engineers, have a great responsibility. Let us see to it that we not only insist on being allowed to shoulder it, but that when we have established our right we can also prove our fitness.

SPEECHES AND ATTENDANCE AT 21st ANNIVERSARY DINNER

Limitations of paper do not permit publication, in this issue of the Journal, of all the speeches made at the 21st Anniversary Dinner.

In addition to the speech of Mr. Leslie McMichael, and the Presidential Address of Admiral the Viscount Mountbatten of Burma, who also proposed the Loyal Toast, the Institution was honoured by Sir Robert Robinson, President of the Royal Society, proposing the Toast of the British Institution of Radio Engineers.

Sir Robert referred to the fact that the Royal Society was the oldest Institution of its kind in the world and was indeed, now celebrating its 284th Anniversary. It is hoped to publish his speech in a subsequent issue of the Journal.

Mr. Paul Adorian (Vice-President of the Institution) welcomed the guests and the response was made by Professor Sir William Lawrence Bragg.

The musical programme was provided by the Orchestra of the Royal Marines (Chatham Division).

During the evening, some 200 letters, telegrams and cables were received, conveying the good wishes of members at home and overseas who were prevented from attending. Those members will be particularly interested in the following list of some of the guests who attended the celebration.

The Presidential Address of Admiral the Viscount Mountbatten of Burma was broadcast " live " by the British Broadcasting Corporation on the General Forces Programme ; the B.B.C. recording was later broadcast in the B.B.C. Home Service which, for this purpose, remained open after 11 p.m.—for the first time since the new closing down time was introduced on the inauguration of the Third Programme. The recording was also transmitted on the North American, Latin American and other B.B.C. services.

Brigadier St. J. D. Arcedeckne-Butler, C.B.E.
(*Ministry of Supply*).

Sir Ulick Alexander, K.C.V.O., C.M.G., O.B.E.
(*Keeper of the Privy Purse and Treasurer to H.M. the King*).

Sir Amos L. Ayre, K.B.E.
(*President, Institute of Marine Engineers*).

Professor J. D. Bernal, M.A.
(*University of London*).

Commander K. B. Best, M.V.O., R.N.
(*Director of Communictions, Home Office*).

Lord Brabazon of Tara, M.C., P.C.,

Professor Sir William Lawrence Bragg, O.B.E., M.C., F.R.S.
(*Cavendish Laboratory, University of Cambridge*).

Mr. J. N. Briton, B.Sc.
(*Representing the Australian Institution of Radio Engineers*).

Mr. F. Brundrett. B.A.
(*Scientific Research Department, Royal Navy*).

Professor D. Brunt, M.A., Sc.D., F.R.S.
(*President, Physical Society*).

Captain G. F. Burghard, D.S.O., R.N.
(*Admiralty Signal Establishment*).

Wing-Commander A. Campbell-Johnson, O.B.E.

Mr. J. A. Camacho
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Lord Winster, P.C., J.P.
(*Minister of Civil Aviation*).

Paper limitations prevent publication of the members and officers of the Institution who attended, but in addition to Mr. Leslie McMichael, three other Past-Presidents attended: Sir Arrol Moir, Bart., Dr. C. C. Garrard and Mr. S. A. Hurren. Sir Louis Sterling was in America and was unable to return in time for the dinner.

FOURIER TRANSFORM ANALYSIS

by

M. M. Levy (*Member*)*

SUMMARY

The paper is a study of the properties of Fourier transforms and examples of applications to various radio problems.

Exponential and trigonometrical expressions of the Fourier transforms are given and the conditions of validity indicated. The exponential form is a short-hand very useful in nearly all applications provided that the meaning of the symbols is clearly understood. A new notation to designate Fourier transforms is used throughout the paper.

The applications of Fourier transforms to radio problems are classified into two main categories: direct application and more advanced applications.

In the first category enter all problems where it is required to know the Fourier transform of a function or, inversely, a function whose Fourier transform is already known.

Since the Fourier transform of a function represents its frequency and phase characteristics, it can be applied to the study of the frequency spectrum and phase characteristics of electric signals.

Frequency spectra of many typical signals such as square, triangular and other types of pulses, sinusoidal signals and modulated carrier, are given. The relation between the shape of the signal and its frequency spectrum is studied, and it is shown that a convenient shape avoids a large radiated band-width.

The inverse problem: to calculate a function whose Fourier transform is known, comes naturally in the study of transmission of signals through networks.

It is first shown that the response of a network to a sharp impulse applied at the input is a signal whose Fourier transform represents the frequency and phase characteristics of the network. It is also a characteristic of the network itself and can be used to determine the distortion produced on a signal by transmission through the network.

The impulse responses of typical networks are given. The networks are divided into three classes: networks with sharp cut-off, with progressive linear cut-off, and with any frequency and phase characteristics. In the first two classes the impulse response of linear phase-shift and 90° out of phase networks is calculated. In the third class it is shown how divergence from linearity in the frequency and in the phase characteristics produces echoes of the ideal response.

The transmission of signals through networks is then considered, and it is shown that the distortion produced by networks can be calculated either directly by means of Fourier Transforms, or with the help of the impulse response of the network.

The category of more advanced applications is too broad to be investigated in detail in this paper: only a summarised review of the methods used to tackle some typical applications is given.

Three applications are mentioned:

In the first, a short account of Brillouin's study on the propagation of signals through dispensive media is given.

In the second, some fundamental properties of the author's "Theory of selective transforms" are explained and some applications indicated.

Finally, it is shown how Fourier transforms can be used to study pulse modulation and demodulation in pulse broadcasting.

Contents

* Research Laboratories of The General Electric Co., Ltd., Wembley, England. MSS. first received March, 1946.

(1) Introduction

The study which follows is part of a general study on Fourier series, Fourier transforms and Laplace transforms.

In Part I* a general survey of the properties of Fourier series and their application has been given. It has been shown that Fourier series can be applied to the analysis of non-periodic curves by a limiting process.

In this paper the limiting process is used to obtain the Fourier transform formulæ which are such powerful tools for the analysis of non-periodic functions.

A special notation has been adopted throughout the paper. The Fourier transform of a function is designated by an F lying over the symbol representing the function. Thus, the Fourier transform of $f(t)$ is $\overset{\urcorner}{f}(\omega)$. For simplicity the small bar of the F is suppressed. This notation is very similar to the one adopted by Millman in his paper on "Laplacian transform analysis."[21] The Laplace transform is designated by a wavy bar over the symbol representing the function. Thus, the Laplace transform of $f(t)$ is $\tilde{f}(\omega)$. In a study on Laplace transforms the author replaced the wavy bar by an L lying over the symbol. Thus, the Fourier and the Laplace transforms of $f(t)$ are represented respectively by $\overset{\urcorner}{f}(\omega)$ or $\overset{\urcorner}{f}(\omega)$ and $\overset{\ulcorner}{f}(\omega)$. This notation is very practical and will make easier the reading of the paper.

Great emphasis has been given to the exponential form of the formulæ. This form is very compact, nearly similar for both the direct and the inverse formulæ and very practical for use in nearly all applications. However, the way to apply it varies slightly from one application to another, and a variety of examples has been given in order to make the reader familiar with the use of this form.

Fourier transforms have a very wide field of applications in radio. A very good reference list of publications is given by Sullivan in his interesting paper on Fourier series and integrals.[26] This list is reproduced at the end of this study together with some additions.

* *J. Brit. I.R.E., March-May 1946, p. 64-73.*

The author was unable to go through all the literature and took the material for this paper mainly from his own studies.

In the application of the Fourier transform method it is usual to calculate the frequency spectrum of the step function and the response of networks to this function. In this paper the step function is practically ignored and the impulse function is used instead. The latter has the advantage of being simpler for analysis by Fourier formulæ since $\int_{-\infty}^{+\infty} f(t)dt$ is convergent and the further advantage that it is fundamental for a simple physical conception of Laplace transforms and of the Selective transform theory.

Although the author was strongly tempted to give a detailed survey of some advanced applications of Fourier transforms such as the propagation of signals through dispersive media, and his own studies on the theory of selective transforms and pulse modulation and demodulation, he has not done so because these studies are of a very delicate nature and cannot be reported extensively in a general survey.

(2) Fourier Transform Formulæ

Fourier transform formulæ are very frequently called Fourier integrals. However, the word "transform" seems more appropriate with the expansion of transform theories. They are derived from Fourier series formulæ by a limiting process which is to increase to infinity the period T_0 of the periodic function considered in Fourier series expansions. Fourier transform formulæ are applicable to non-periodic curves. They can be written in two forms: the exponential and the trigonometric. The first is compact and practicable in nearly all applications, and the second is practicable in cases of symmetric functions.

(2.1) Exponential Form

Let $f(t)$ be any function. For $-\frac{\pi}{\omega_0} < t < +\frac{\pi}{\omega_0}$, where ω_0 has an arbitrary value, the function can be described by a Fourier series expansion:

$$f(t) = \frac{1}{2}\sum_{-\infty}^{+\infty} \mathbf{C}_n e^{in\omega_0 t} \quad \text{.................(1)}$$

where

$$\mathbf{C}_n = \frac{\omega_0}{\pi}\int_{-\frac{\pi}{\omega_0}}^{+\frac{\pi}{\omega_0}} f(t)e^{-in\omega_0 t}\,dt \quad \text{...........(2)}$$

and $\mathbf{C}_n = C_n e^{i\phi(n\omega_0)}$ ....(3)

with the convention:

$$\left\{\begin{matrix} C_{-n} = C_n \\ \phi_{-n} = -\phi_n \end{matrix}\right\} \quad \text{.......................(4)}$$

A detailed account on these formulæ is given in Part I [formulæ (10) to (14)].

In order to describe the original function more and more completely, the boundaries $-\frac{\pi}{\omega_0}$ and $+\frac{\pi}{\omega_0}$ are made to approach infinity. Then ω_0 approaches $d\omega$, summation (1) becomes an integral and the modulus of $\mathbf{C}_n$ becomes an infinitely small quantity. Put $\omega_0 = d\omega$, $n\omega_0 = \omega$ and

$$\mathbf{C}_n = \frac{1}{\pi}\,\overline{\mathbf{f}}(\omega)\,d\omega \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Then (1) and (2) become

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} \overline{\mathbf{f}}(\omega)\, e^{i\omega t}\, d\omega \quad \ldots\ldots\ldots\ldots(6)$$

$$\overline{\mathbf{f}}(\omega) = \int_{-\infty}^{+\infty} f(t)e^{-i\omega t}\, dt \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

where

$$\overline{\mathbf{f}}(\omega) = \overline{f}(\omega)e^{i\phi(\omega)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

and

$$\left.\begin{array}{l}\overline{f}(-\omega) = \overline{f}(\omega)\\ \phi(-\omega) = \phi(\omega)\end{array}\right\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

$\overline{\mathbf{f}}(\omega)$ contains both the frequency spectrum $\overline{f}(\omega)$ and the phase characteristic $\phi(\omega)$.

These equations can be applied to any type of time function provided that

$$\int_{-\infty}^{+\infty} |f(t)|dt \ldots\ldots\ldots\ldots\ldots\ldots(10)$$

is convergent. They are called Fourier transforms or Fourier integrals. For homogeneity with Part III the first expression will always be used. Some authors prefer to split the $1/2\pi$ factor into $(1/\sqrt{2\pi})$ $(1/\sqrt{2\pi})$ and associate one part with each transform.

In this paper $\overline{\mathbf{f}}$ will be called the "transform of $f(t)$" and $f(t)$ the "inverse transform of $\overline{\mathbf{f}}(\omega)$"; $\overline{f}(\omega)$ will be called the "frequency characteristic" or the "frequency spectrum" or the "selectivity function"[18] of $f(t)$. $\phi(\omega)$ will be called the "phase characteristic" of $f(t)$.

In writing the Fourier transform formulæ, the author has adopted a new notation which requires some comments and justification. Fourier transformers are not the only transform formulæ. In general, any system of paired equations correlating one function with another and inversely can be called transform equations. It happens that Fourier transforms have a considerable field of application and have been the first to be studied and extensively applied. In recent years, however, other systems of transforms have been considered with growing interest. The "Laplace transform,"[4,5,21] for instance, by its orderly and rigorous procedure, appears to be rapidly replacing the quasi-empirical methods of the Heaviside operational calculus.* The "selective transform" theory[15-18] has been developed and applied in many practical problems. It appeared to the author that a uniform notation should be used for transforms. The notation adopted here is similar to that adopted by Millman[21] for Laplace transforms, but has the advantage of being applicable to any type of transform. In Fourier transform theory, equation (7) transforms a function of time $f(t)$ into a function of frequency. This is indicated by a capital F or Γ over the symbol representing the function. Thus $\overline{\mathbf{f}}$ is read the Fourier transform of $f(t)$. In addition, if $\overline{\mathbf{f}}$ is a complex expression, as in equation (7) it will be represented by a symbol written in **sick character.** In Laplacian transform theory, a function of time is transformed to a function of a complex variable. This is indicated by a capital L over the symbol representing the function. Thus $\overline{f}$ is the Laplace transform of $f(t)$. If another type of transform operation is used the same type of notation can be used without fear of confusion. Example: the transform of $f(t)$ is

Fourier transform $\overline{\mathbf{f}}(\omega)$ or $\overline{\mathbf{f}}(\omega)$

Laplace transform $\overline{f}(z)$

X type of transform $\overline{f}(y)$

(2.2) Trigonometric Form

(2.2.1) Formulæ in the General Case

Equation (6) is easily transformed into a trigonometric form by grouping together under the integral sign the expressions corresponding to $+\omega$ and $-\omega$, giving

$$f(t) = \frac{1}{\pi}\int_{0}^{\infty} \overline{f}(\omega)\cos[\omega t + \phi(\omega)]\, d\omega \quad \ldots\ldots(11)$$

The other equation is evidently

$$\overline{f}(\omega) = \sqrt{[\overline{f}_s^{\,2}(\omega) + \overline{f}_c^{\,2}(\omega)]} \quad \ldots\ldots\ldots\ldots(12)$$

with

$$\overline{f}_s(\omega) = \int_{-\infty}^{+\infty} f(t)\sin \omega t\, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

$$\overline{f}_c(\omega) = \int_{-\infty}^{+\infty} f(t)\cos \omega t\, dt \quad \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

* See also Part III of this Paper.

$$\tan \phi(\omega) = \frac{\overline{f_s}(\omega)}{\overline{f_c}(\omega)} \quad \ldots\ldots (15)$$

(2.2.2) Simplified formulæ for Symmetrical Functions

1. If the function is even, that is if $f(t) = f(-t)$ $\overline{f_s}(\omega) = o$ and $\phi(\omega) = \pm\ 2K\pi$, the equations become

$$f(t) = \frac{1}{\pi}\int_o^{\infty} \overline{f_c}(\omega) \cos \omega t \, d\omega \quad \ldots\ldots (16)$$

$$\overline{f_c}(\omega) = \int_{-\infty}^{+\infty} f(t) \cos \omega t \, dt \quad \ldots\ldots (14)$$

If the function is even with respect to $t = t_0$, that is if $f(t = t_0) = f[-(t - t_0)]$ after changing the variable from t to $\tau = t - t_0$, the function becomes even and

$$\phi(\omega) = -\omega t_0 \pm 2k\pi \quad \ldots\ldots (17)$$

The phase characteristic is linear. And inversely.

2. If the function is odd, that is if $f(t) = -f(-t)$ $\overline{f_c}(\omega) = o$, and $\phi(\omega) \pm \frac{\pi}{2} \pm 2k\pi$, the equations become

$$f(t) = -\frac{1}{\pi}\int_o^{\infty} \overline{f_s}(\omega) \sin \omega t \, d\omega \quad \ldots\ldots (18)$$

$$\overline{f_s}(\omega) = \int_{-\infty}^{+\infty} f(t) \sin \omega t \, dt \quad \ldots\ldots (13)$$

If the function is odd with respect to $t = t_0$, it can be shown that

$$\phi(\omega) = -\omega_0 t \pm \frac{\pi}{2} \pm 2k\pi \quad \ldots\ldots (19)$$

and inversely.

(3) First Applications

Fourier transforms are mainly used for analysis and synthesis. The first equation gives the transform $\overline{f}(\omega)$ of a given function $f(t)$, that is, the frequency components in amplitude and phase. The second gives the function $f(t)$ corresponding to a given transform $\overline{f}(\omega)$; in other words, it gives the resultant of an infinite number of sinusoidal components of known frequency, amplitude and phase.

Analysis and synthesis are the main applications of Fourier transforms, but the method is capable of extension to problems involving a combination of analysis and synthesis.

As examples of analysis, the frequency spectra of typical signals such as square pulses, sharp impulses and pulse modulated carrier signals will be calculated. As examples of synthesis the impulse responses of typical networks such as ideal filters and filters with progressive cut-off will be derived. Further, as an example of combined analysis and synthesis the transmission of signals through networks will be studied.

Although the study of phase characteristics is an important application of Fourier transforms, it will not be expanded in this paper; the two main conclusions given in paragraph (2.2.2), i.e. the phase shift is linear for an even function of time (equation 17) and equal to 90° at all frequencies for an odd function of time (equation 19), will be utilised.

Applications of a more advanced type will be summarily dealt with in section (4).

(3.1) Frequency Spectra of some Typical Signals

It has been shown in Part I that Fourier series expansions can be used by means of a limiting process to calculate the frequency spectra of non-periodic functions. Fourier transforms are more appropriate for this type of application provided that integral (10)*

$$\int_{-\infty}^{+\infty} |f(t)| dt$$

is convergent.

This condition is satisfied for all finite functions vanishing at $\pm\infty$. Such functions are called **"signals,"** and are of varied types, ranging from square pulses to modulated carrier waves.

(3.1.1) Rectangular Pulse

Consider the function $P_1(t)$ representing a single rectangular pulse of height y_0 and width $t = 2\epsilon$. Let

$P_1(t) = 0$ for $t < -\epsilon$ or $t > +\epsilon$

$P_1(t) = y_0$ for $-\epsilon < t < +\epsilon$

It has been assumed that $f(t)$ is an even function in order to reduce calculations to a minimum. Replacing $f(t)$ by its value in equation (7)

$$\overline{P_1}(\omega) = y_0 \int_{-\epsilon}^{+\epsilon} e^{j\omega t} dt = s_0 \frac{\sin \omega\epsilon}{\omega\epsilon}$$

s_0 being equal to $2y_0\epsilon$, the area of the pulse. The right hand side being a real quantity $(\omega) = o$ and

$$P_1(\omega) = s_0 \frac{\sin \omega\epsilon}{\omega\epsilon} \quad \ldots\ldots (20)$$

Replacing $\overline{f}(\omega)$ in (6) by the expression given by (19)

* When integral (10) is not convergent, it is still possible in some cases to analyse the function ([2]). For instance, if the function $f(t)e^{pt}$ is such that condition (10) is satisfied, one can make p very small in the final result (or even make it tend to zero) so that the above function is equal to $f(t)$ for a large range of values of t.

$$P_1(t) = \frac{s_0}{2\pi} \int_{-\infty}^{+\infty} \frac{\sin \omega\epsilon}{\omega\epsilon}\, \epsilon^{i\omega t}\, d\omega$$

$$= \frac{s_0}{\pi} \int_{0}^{\infty} \frac{\sin \omega\epsilon}{\omega\epsilon} \cos \omega t \, d\omega \quad \ldots\ldots \; (21)$$

Thus the pulse function is composed of an infinite number of cosine components in phase at $t = o$ and whose amplitude is given by $\overline{P}_1(\omega)$. This frequency spectrum is shown graphically in Fig. 1.

(3.1.3) Other Types of Pulses

Four different types of pulses are represented in Fig. 1: rectangular, triangular, pulse formed with 4 arcs of parabolæ, and pulse formed by half the period of a sinusoidal curve. The frequency spectra of these pulses are

$$\overline{P}_1(\omega) = s_0 \frac{\sin \omega\epsilon}{\omega\epsilon} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

$$\overline{P}_2(\omega) = s_0^2 \left(\frac{\sin \omega\epsilon}{\omega\epsilon}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

$$\overline{P}_3(\omega) = s_0^3 \left(\frac{\sin \omega\epsilon}{\omega\epsilon}\right)^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

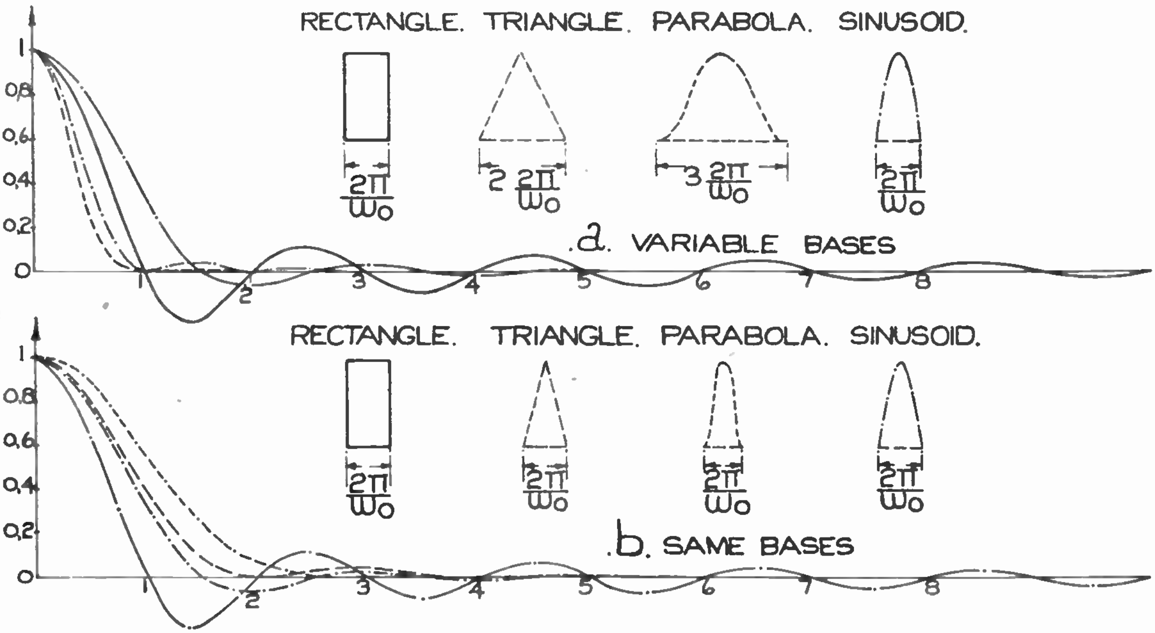

Fig. 1.—Pulse functions and corresponding frequency spectra. In Fig. (a) the triangle is obtained by transforming the rectangle by an identical rectangle; the third pulse by transforming the triangle by the rectangle.

(3.1.2) Impulse

If $\epsilon \rightarrow o$, the rectangular pulse becomes an "impulse" by definition. From (20) we see that the frequency spectrum of an impulse is

$$\overline{I}(\omega) = s_0$$

The impulse function $I(t)$ is the resultant of an infinite number of cosine components of equal amplitude i_0 and all in phase at time $t = o$.

An interesting case occurs when $s_0 = 1$. Then the amplitude of the impulse is infinite but its area is equal to unity. All the frequency components have amplitudes also equal to unity. This fact makes the use of this special impulse very practical as a standard for tests. Such an impulse function is termed " Unit impulse function."

$$\overline{P}_4(\omega) = \gamma_0 \epsilon \left[\frac{\sin(\omega\epsilon + \pi/2)}{(\omega\epsilon + \pi/2)} + \frac{\sin(\omega\epsilon - \pi/2)}{(\omega\epsilon - \pi/2)}\right] \quad (24)$$

with the notations of Fig. 1. It will be observed that

$$\overline{P}_3(\omega) = \overline{P}_1^{\,3}(\omega) \;;\; P_2(\omega) = \overline{P}_1^{\,2}(\omega)$$

These relations are not due to chance but are a direct result of a property of selective transforms.[17,18]. An explanation is given section (4.2).

Other types of pulses have been considered by various authors, mainly the exponential type and the error shaped pulse, so called because it represents the Gauss error function.[5,24] The first type is produced by a valve when a sine wave of sufficient amplitude is applied to the grid conveniently biased. The second one is similar to the first, with good approximation, and has the advantage of being easier to manipulate in calculations.[24]

(3.1.4) Recurrent Pulses

There is a very interesting relation between the frequency spectra of a single pulse and identical pulses recurrent at equal intervals of time provided that the duration of the pulse is smaller than the period of recurrency.

and hence

$$C_n = \frac{\omega_0}{\pi} \overline{P_s}(n\omega_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (26)$$

Thus the frequency spectrum of one pulse is the envelope of the amplitude of the frequency components of the same pulse in a recurrent chain, provided that the duration of the pulse is smaller than the period of recurrency.

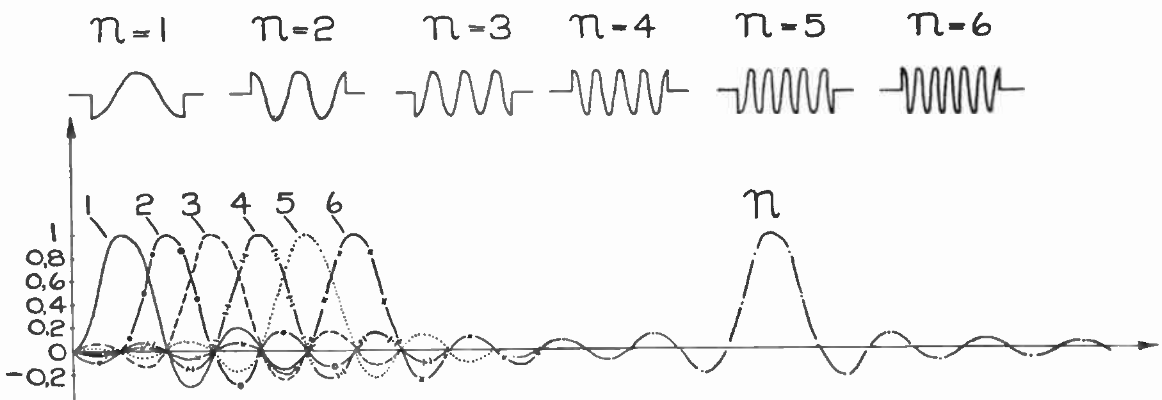

Fig. 2.—Sinusoidal pulse signals and corresponding frequency spectra. The pulse envelope is the same for all signals ; the frequency of the carrier increases from the first (n = 1) to the last signal (n = 6).

To establish this relation, write the frequency spectrum for both the recurrent pulses and the single pulse. For the first one obtains

$$P_r(t) = \frac{1}{2} \sum_{-\infty}^{+\infty} C_n \, e^{in\omega_0 t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$C_n = \frac{\omega_0}{\pi} \int_{-\frac{\pi}{\omega_0}}^{+\frac{\pi}{\omega_0}} P_r(t) \, e^{-in\omega_0 t} \, dt \quad \ldots\ldots\ldots\ldots (2)$$

the period being $T_0 = 2\pi/\omega_0$.

For the second case, take the single pulse $P_s(t)$ for which $-\frac{\pi}{\omega_0} < t < +\frac{\pi}{\omega_0}$. Then

$$\overline{P_s}(\omega) = \int_{-\frac{\pi}{\omega_0}}^{+\frac{\pi}{\omega_0}} P_r(t) \, e^{-i\omega t} \, dt$$

since $P_s(t)$ is assumed to be zero outside the boundaries $-\pi/\omega_0$ and $+\pi/\omega_0$.

Comparing the equations for C_n and $\overline{P_s}(\omega)$, leads to the relation

$$C_n = \frac{\omega_0}{\pi} \overline{P_s}(n\omega_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (23)$$

(3.1.5) Rectangular Sinusoidal Signal

Take a sinusoidal signal of frequency ω_0 starting at $-\pi/\Omega$ and finishing at $+\pi/\Omega$, Ω being such that the signal contains at least one complete oscillation ($\Omega < \omega_0$). The equation of this signal is

$S(t) = 0$ for $t < -\pi/\Omega$ or $t > \pi/\Omega$

$S(t) = \cos \omega_0 t$ for $-\pi/\Omega < t < +\pi/\Omega$

The frequency spectrum is given by

$$\overline{S}(\omega) = \int_{-\pi/\Omega}^{+\pi/\Omega} \cos \omega_0 t \, e^{-i\omega t} \, dt$$

$$= \frac{1}{2} \int_{-\frac{\pi}{\Omega}}^{+\frac{\pi}{\Omega}} e^{-i(\omega-\omega_0)t} \, dt + \frac{1}{2} \int_{-\frac{\pi}{\Omega}}^{+\frac{\pi}{\Omega}} e^{-i(\omega+\omega_0)}$$

$$\overline{S}(\omega) = \overline{S}(\omega) = \frac{\pi}{\Omega} \left[\frac{\sin \pi \frac{\omega-\omega_0}{\Omega}}{\pi \frac{\omega-\omega_0}{\Omega}} + \frac{\sin \pi \frac{\omega+\omega_0}{\Omega}}{\pi \frac{\omega+\omega_0}{\Omega}} \right] \quad (27)$$

In this equation, the first term between brackets has a predominant maximum for $\omega = \omega_0$, whilst the second has no predominant maximum since $(\omega + \omega_0)$ can never be zero. When $\omega_0 >> \Omega$, that is, when there are a great number of oscillations in the pulse, the second term is always very small and can be neglected. Fig. 2 and 3 show this very clearly.

If we neglect the second term between the brackets, equation (27) becomes similar in form to equation (20). This means that the envelope of the frequency spectrum of the sinusoidal signal is similar in shape to the frequency spectrum of the envelope of the signal. This result has been obtained by assuming a rectangular signal envelope. It will now be shown that it is applicable to any shape of pulse.

(3.1.6) Pulsed Carrier Signal

Let a carrier $\cos(\omega_0 t + \gamma)$ be modulated by a pulse function $P_{(t)}$. The frequency spectrum of the modulated carrier $C_{(t)} = P_{(t)} \cos(\omega_0 t + \gamma)$ is

$$\overline{C}(\omega) = \int_{-\infty}^{+\infty} P_{(t)} \cos(\omega_0 t + \gamma)\, e^{-i\omega t}\, dt$$

$$= \tfrac{1}{2} e^{i\gamma} \int_{-\infty}^{+\infty} P_{(t)} e^{-i(\omega-\omega_0)t} dt + \tfrac{1}{2} e^{-i\gamma} \int_{-\infty}^{+\infty} P_{(t)} e^{-i(\omega+\omega_0)t} dt$$

Thus

$$\overline{C}(\omega) = \frac{e^{i\gamma}\overline{P}(\omega - \omega_0) + e^{-i\gamma}\overline{P}(\omega + \omega_0)}{2} \quad \text{........(28)}$$

Since

$$\overline{P}(\omega) = \int_{-\infty}^{+\infty} P_{(t)}\, e^{-i\omega t}\, dt \quad \text{..................(7)}$$

Equation (28) shows that the frequency spectrum is the resultant of two curves. If the shape of the pulse envelope $P_{(t)}$ is simple, without waves, such as those of Fig. 1, for instance, it can be shown[15] that $\overline{P}(\omega)$ has a predominant maximum for $\omega = 0$ (for details see section (4.2)). In this case $\overline{P}(\omega - \omega_0)$ has a predominant maximum for $\omega = \omega_0$ whilst $\overline{P}(\omega + \omega_0)$ has no predominant maximum since $\omega + \omega_0 > \omega_0$ and has even a negligible value if $\omega_0 >> 0$. If $P_{(t)}$ is a wavy function, $P(\omega)$ has a predominant maximum for $\omega = 0$ and for the frequency of the waves[15]. The relative amplitudes of these two maxim is a function of the area of the pulse and the amplitude and number of oscillations of the waves. However, if the frequency of these waves is small compared to the frequency of the carrier, $\overline{P}(\omega + \omega_0)$ has still a small value compared to the maximum value of $\overline{P}(\omega - \omega_0)$. Thus for nearly all types of practical pulse-modulated carrier signals the frequency spectrum of the signal is similar in shape to the frequency of the envelope of the signal. More exactly

$$\overline{C}(\omega) \simeq \tfrac{1}{2} e^{i\gamma} \overline{P}(\omega - \omega_0) \quad \text{................(29)}$$

(3.1.7) Shape of the Pulse Envelope of a Pulse Modulated Carrier for Minimum Radiated Band Width

The curves of Fig. 2, especially for $n >> 1$, show that the frequency spectrum extends considerably on both sides of the carrier frequency. The mean amplitude decreases as $1(\omega - \omega_0)$, that is very slowly. Frequencies very distant from the predominant band are still radiated with a sufficient amplitude to be detected by a sensitive receiver. This is a great disadvantage in pulse radio transmissions and it shows that radiation of square pulses is is to be avoided if possible.

What has been said in the preceding section indicates that the radiated band-width will be small if the frequency spectrum of the pulse envelope has a tail going rapidly to zero. Great improvement can be obtained by choosing a triangular envelope ((section 3.1.3) and Fig. 1) and still better results are secured with a pulse formed by parabolic arcs (3.1.3), or with an exponential or an "error" shaped pulse. Some improved signals and their corresponding frequency spectra are represented in Fig. 4. However, all these types have progressively rising and falling slopes and this is a great disadvantage in most of the applications where carrier pulses are radiated (radar, pulse communication systems, etc.)

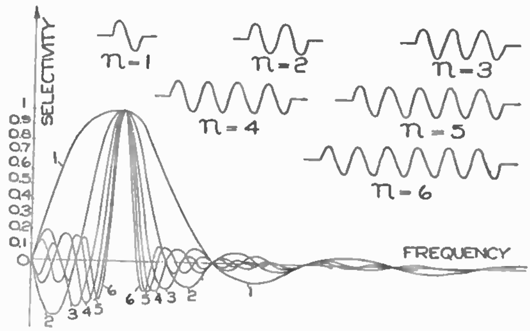

Fig. 3.—Sinusoidal pulse signals and corresponding frequency spectra. The carrier frequency is the same for all frequency but the envelope increases in width from $n = 1$ to $n = 6$.

Another way of approach is to determine theoretically the shape of the envelope which gives the minimum radiated band-width, or, more precisely, the shape which gives radiated frequencies having the same amplitude up to a cut-off frequency ω_c. The shape of the envelope $E(t)$ is then such that

$$\overline{E}(\omega) = o \text{ for } |\omega| > \omega_c$$
$$\overline{E}(\omega) = e^{i\phi(\omega)} \text{ for } |\omega| < \omega_c$$

The envelope is thus given by

$$E(t) = \frac{1}{2\pi} \int_{-\omega_c}^{+\omega_c} \overline{E}(\omega)\, e^{i\omega t}\, d\omega$$

or

$$E(t) = \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} e^{i(\omega t + \phi(\omega))}\, d\omega \qquad (30)$$

Each type of phase function $\phi(\omega)$ will give a different envelope. Since $\phi(\omega)$ is arbitrary, there are an infinite number of solutions.

A simple case is when $\phi(\omega)$ is proportional to frequency. If $\phi(\omega) = -\omega t_0$

$$E(t) = \frac{\omega_c}{\pi}\,\frac{\sin \omega_c(t - t_0)}{\omega_c(t - t_0)} \qquad (31)$$

The band-width has been condensed but the envelope has expanded considerably on both sides of the predominant maximum. It is obvious that such an envelope is not very practical.

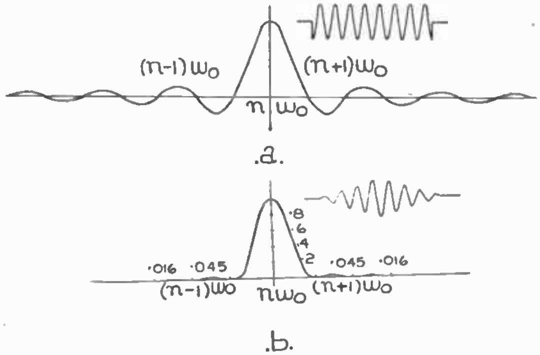

Fig. 4.—Sinusoidal signals and corresponding frequency spectra.

(a)—The frequency spectrum is of the type $\frac{\sin x}{x}$.

(b)—The frequency spectrum is of the type $\left(\frac{\sin x}{x}\right)^2$.

Another type of solution can be obtained by a physical analogy. Apply a "unit impulse" voltage (see paragraph 3.1.2) to a filter (Fig. 5). This is equivalent to applying sinusoidal components of all frequencies, of unit amplitude and having the same phase at time zero. Let $\mathbf{N}(\omega)$ be the characteristic function of the network, that is $N(\omega)$ the amplitude and $\theta(\omega)$ the phase characteristics of the network. Then the output signal $I(t)$—called "impulse response"—of the filter is given by

$$I(t) = \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} \mathbf{N}(\omega)\, e^{i\omega t}\, d\omega$$

Thus $I(t)$ represents the shape of a signal whose characteristic function is $\mathbf{N}(\omega)$. The study of the shape of the impulse response of various practical low-pass filters leads to alternative solutions.

(3.2) Transmission of Signals through Networks

When a signal is applied at the input of an electrical network, every frequency component is altered in amplitude and phase during transmission through the network. At the output a signal will appear whose frequency spectrum and phase characteristic are known and the problem is to determine the shape of this signal. In other words, it is desired to find a signal $S(t)$ whose transform $\overline{S}(\omega)$ is known. This is just the reverse of the problem studied in section (3.1).

As has already been mentioned in section (3.1.7), a particular case of interest is the "unit impulse" signal. This is equivalent to applying to the network sinusoidal components of all frequencies, of unit amplitude and in phase at the moment when the impulse appears. The output signal will be one whose frequency and phase characteristics are represented by the characteristic function of the network. This signal is thus a characteristic of the network. Let $I(t)$ be this signal. If $I(t)$ is known, the transform $\overline{\mathbf{I}}(\omega)$ is the characteristic function of the network. Conversely if $\overline{\mathbf{I}}(\omega)$ is known, $I(t)$ is also known.

In this section the impulse response of some typical networks, and of networks in general, will first be studied and then the transmission of signals of any shape will be considered.

(3.2.1) Impulse Response of Typical Networks

The impulse response of some typical networks has already been given by the author in a prior publication[19]. However, calculations were in this case based on the trigonometric form of Fourier transform. Furthermore, only filters with sharp cut-off were considered. In this section all calculations are made with the exponential form and other classes of filters are also considered.

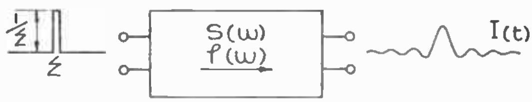

Fig. 5.—The response of a network to a unit impulse applied at its input is called the "impulse response of the network." It contains information on the frequency and phase characteristics.

The impulse response has two properties which may give at a glance useful information on the characteristic function of the network. If the impulse response is a symmetrical curve, then

(*a*) if it is even, the phase characteristic is

$$\theta(\omega) = -\omega_0 t \pm 2k\pi \qquad (32)$$

(*b*) if it is odd, the phase characteristic is

$$\theta(\omega) = -\omega_0 t \pm \frac{\pi}{2} \pm 2k\pi \qquad (33)$$

These are direct consequencies of the properties of Fourier transforms given in section (2.2.2), equations (17) and (19).

Let $\mathbf{N}(\omega)$ be the characteristic function of the network

$$\mathbf{N}(\omega) = N(\omega)\, e^{i\theta(\omega)}$$

Then the impulse response $I(t)$ is

$$I(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} \mathbf{N}(\omega)\, e^{i\omega t}\, d\omega \quad \ldots\ldots\ldots(34)$$

It is obvious that

$$\mathbf{N}(\omega) = \overline{\mathbf{I}}(\omega) = \overline{I}(\omega)\, e^{i\phi(\omega)} \ldots\ldots\ldots\ldots(35)$$

The transform of the impulse response is the characteristic function of the network.

It is more convenient for most applications to write (34)

$$I(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} N(\omega)\, e^{i(\omega t + \theta(\omega))}\, d\omega \ldots\ldots\ldots\ldots(36)$$

The right-hand side of this equation will be integrated for some typical networks. They are divided into three classes

(*a*) Ideal networks with sharp cut-off.

(*b*) Ideal networks with progressive linear cut-off.

(*c*) Networks with any shape of frequency and phase characteristic.

Classes (*a*) and (*b*) will each be considered with two types of phase characteristic: phase shift proportional to frequency (equation 32) and phase shift equal to 90° at all frequencies (equation 33).

(3.2.1.1) Ideal Networks with Sharp Cut-off

1. For this kind of network equation (36) becomes

$$I(t) = \frac{1}{2\pi}\int_{+\infty}^{+\infty} N(\omega)\, e^{i\omega(t-t_0)}\, d\omega \ldots\ldots\ldots\ldots(37)$$

since $\theta(\omega)$ is given by (32).

In this formula, substitution of $N(\omega)$ by the expressions corresponding to the kind of filter under consideration yields the impulse response.

(a) *Ideal low-pass filter.*—In this type all frequencies below the cut-off frequency f_c, are transmitted without amplitude distortion (Fig. 6a). Hence

$N_{L(\omega)} = 1$ for $-\omega_c < \omega < +\omega_c$

$N_{L(\omega)} = 0$ for $\omega > \omega_c$ or $\omega < -\omega_c$

Substitution of this expression in (37) gives

$$I_{LP}(t) = \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} e^{i\omega(t-t_0)}\, d\omega$$

$$I_{LP}(t) = \frac{\omega_c}{\pi}\,\frac{\sin \omega_c(t-t_0)}{\omega_c(t-t_0)} \ldots\ldots\ldots\ldots(38)$$

This curve is shown graphically in (*a*) Fig. 6.

(b) *Ideal band-pass filter.*—The frequency characteristic $N_B(\omega)$ is the difference of the frequency characteristics of two ideal low-pass filters whose cut-off frequencies fc_1 and fc_2 are each a boundary of the band-pass (*b*) Fig. 7. Hence the impulse response of this filter is the difference between the impulse responses of low-pass filters having cut-off frequencies f_{c2} and f_{c1} respectively

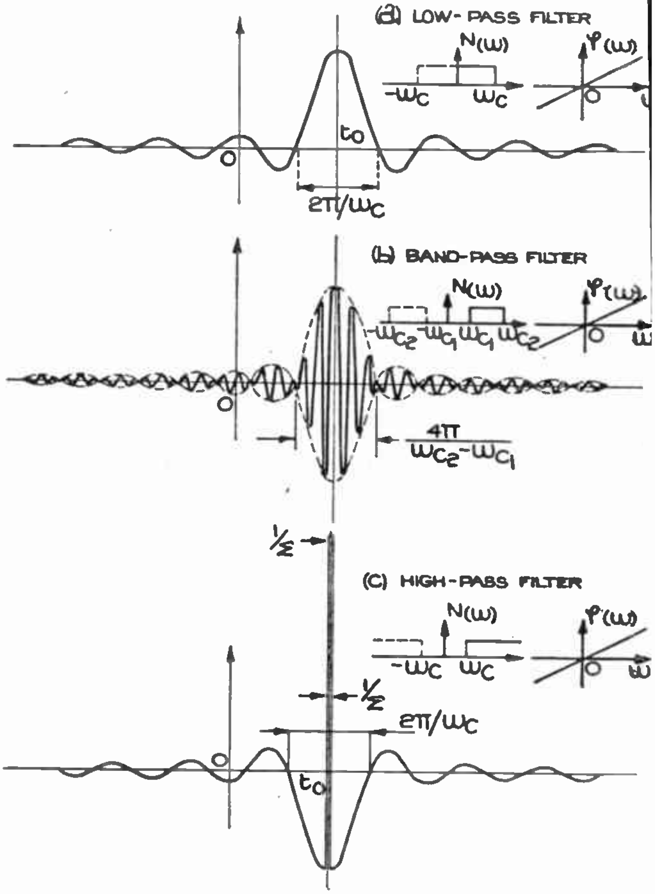

Fig. 6.—Impulse response of ideal phase linear shift filters.

$$I_B(t) = \frac{\omega_{c2}}{\pi}\,\frac{\sin \omega_{c2}(t-t_0)}{\omega_{c2}(t-t_0)} - \frac{\omega_{c1}}{\pi}\,\frac{\sin \omega_{c1}(t-t_0)}{\omega_{c1}(t-t_0)} \ldots(39)$$

This formula may also be written

$$I_B(t) = \frac{\Delta\omega}{\pi}\,\frac{\sin \frac{1}{2}[\Delta\omega(t-t_0)]}{\frac{1}{2}[\Delta\omega(t-t_0)]}\cos \omega_0 t \ldots(40)$$

This function is shown graphically in (*b*) Fig. 6.

Equations (39) and (40) can be obtained by direct calculation from equation (37). Care should then be taken to integrate in the two domains $-\omega_{c2} < \omega < -\omega_{c1}$ and $\omega_{c1} < \omega < \omega_{c2}$.

(c) *Ideal high-pass filter.*—For this type of filter

$N_H(\omega) = 0$ for $-\omega_c < \omega < +\omega_c$

$N_H(\omega) = 1$ for $\omega < -\omega_c$ or $\omega > +\omega_c$

substitution in equation (37) gives

$$I_H(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} e^{i\omega(t-t_0)}\,d\omega - \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} e^{i\omega(t-t_0)}\,d\omega$$

or

$$I_H(t) = I(t - t_0) - I_L(t - t_0) \quad \ldots\ldots\ldots\ldots\ldots\ldots(41)$$

where $I(t - t_0)$ represents a unit impulse voltage appearing at time $t = t_0$. The curve representing $I_H(t)$ is shown in (*c*) Fig. 6.

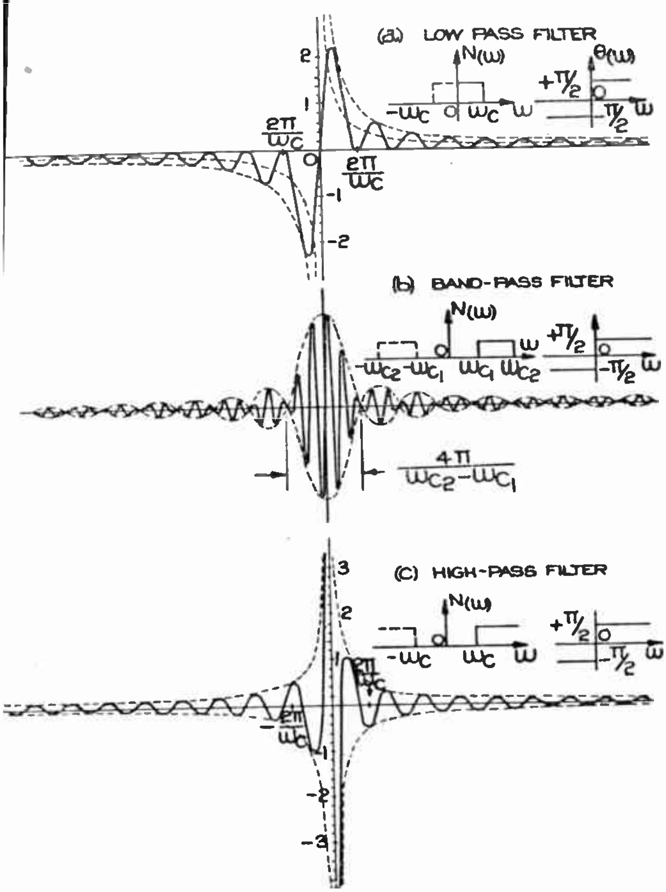

Fig. 7.—Impulse response of "90° *out of phase*" *ideal filter.*

2. Networks producing a 90° Phase-shift at all Frequencies

For this type of network $\theta(\omega)$ is given by equation (33)

$$\theta(\omega) = -\omega_0 t \pm \frac{\pi}{2} \pm 2k\pi \quad \ldots\ldots\ldots\ldots\ldots\ldots(33)$$

where if sign + is taken for $\omega > 0$, sign − must be taken for $\omega < 0$ and inversely, since $\theta(\omega)$ is an odd function (see section (2.1) and equation (9)).

Replacing $\theta(\omega)$ by its correct value in (36) leads to

$$I'(t) = \frac{-i}{2\pi}\int_{-\infty}^{0} N(\omega) e^{i\omega(t-t_0)}\,d\omega + \frac{i}{2\pi}\int_{0}^{+\infty} N(\omega)\, e^{i\omega(t-t_0)}\,d\omega \quad \ldots\ldots\ldots(42)$$

In this formula substitution of $N(\omega)$ by the expressions corresponding to the kind of filter under consideration yields its impulse response.

(a) *Ideal low-pass filter.*

Integration of equation (42) gives

$$I'_L(t) = \mp \frac{\omega_c}{\pi}\, \frac{-1 + \cos \omega_c (t - t_0)}{\omega_c (t - t_0)} \quad \ldots\ldots(43)$$

This curve is shown in (*a*) Fig. 7.

(b) *Ideal band-pass filter.*

By integration we obtain an equation

$$I'_B(t) = \mp \left[\frac{\omega_{c2}}{\pi}\, \frac{\cos \omega_{c2}(t - t_0)}{\omega_{c1}(t - t_0)} - \frac{\omega_{c1}}{\pi}\, \frac{\cos \omega_{c1}(t - t_0)}{\omega_{c1}(t - t_0)} \right] \quad \ldots\ldots\ldots\ldots(44)$$

which represents the difference between two low-pass or two high-pass filters (see equation (43) and equation (45) below).

Formula (44) can also be written

$$I'_B(t) = \mp \frac{\omega_{c2} - \omega_{c1}}{\pi}\, \frac{\sin \frac{1}{2}(\omega_{c2} - \omega_{c1})t}{\frac{1}{2}(\omega_{c2} - \omega_{c1})t}\, \sin \tfrac{1}{2}(\omega_{c2} + \omega_{c1})t \quad \ldots\ldots\ldots(45)$$

The shape of this curve is represented in (*b*) Fig. 7.

(c) *Ideal high-pass filter.*

If the impulse response of an ideal high-pass filter is added to that of an ideal low-pass filter having the same cut-off frequency, the impulse response obtained is not the unit impulse itself but the curve obtained in shifting the phase of each component by the value of $\theta(\omega)$ given by equation (33). Let $I'(t)$ be this response. Then

$$I'_H(t) = I'(t) - I'_L(t) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(46)$$

Now $I'(t)$ is the limit of $I'_L(t)$ when the cut-off frequency f_c tends to infinity[19]. Equation (43) shows this limit to be

$$I'(t) = \mp \frac{1}{\pi(t - t_0)}$$

Hence

$$I'_H(t) = \mp \frac{\omega_c}{\pi} \frac{\cos \omega_c (t - t_0)}{\omega_c (t - t_0)} \quad \ldots\ldots\ldots\ldots\ldots (47)$$

The shape of this curve is shown in (*c*) Fig. 7.

(3.2.1.2) Ideal Filters with Progressive Linear Cut-off

Filters with sharp cut-off produce impulse responses with long tails vanishing slowly. The use of progressive cut-off helps to secure shorter tails. A linear progressive cut-off is of interest because it lends itself to easy calculations and because it is important in the design of television transmission systems.

Assume for simplicity that the delay introduced by the filter is zero at all frequencies. A constant delay will simply shift the response parallel to the time axis.

The case of a low-pass filter will be studied as an example. Fig. 9 shows that this type of filter can be considered as the addition of a band-pass filter with linear attenuation starting at ω_1 and finishing at ω_2 to an ideal low-pass filter with sharp cut-off at ω_1. The equation of this slope is $\frac{\omega_2 - \omega}{\omega_2 - \omega_1}$. Let $I_1(t)$ be the impulse response of the first filter and $I_2(t)$ the response of the second. Then

$$I_1(t) = \frac{\omega_1}{\pi} \frac{\sin \omega_1 t}{\omega_1 t}$$

To obtain $I_2(t)$ it is simpler to use the trigonometric form of Fourier transform in order to integrate only between ω_1 and ω_2 and avoid the integration from $-\omega_2$ to $-\omega_1$. Thus

$$I_2(t) = \frac{1}{\pi} \int_{\omega_1}^{\omega_2} \frac{\omega_2 - \omega}{\omega_2 - \omega_1} \cos \omega t \, d\omega$$

$$= \frac{\omega_2}{\pi(\omega_2 - \omega_1)} \Big[\sin \omega t \Big]_{\omega_1}^{\omega_2}$$

$$- \frac{1}{\pi(\omega_2 - \omega_1)} \int_{\omega_1}^{\omega_2} \cos \omega t \, d\omega$$

$$= \frac{1}{\pi(\omega_2 - \omega_1)t} \Big[(\omega_2 - \omega_1) \sin \omega_1 t + \frac{1}{t}(\cos \omega_2 t - \cos \omega_1 t) \Big]$$

Hence

$$I(t) = \frac{2}{\pi(\omega_2 - \omega_1)t^2} \sin \frac{\omega_2 + \omega_1}{2} t \, \sin \frac{\omega_2 - \omega_1}{2} t$$

or

$$I(t) = \frac{\omega_2 + \omega_1}{2\pi} \frac{\sin \frac{\omega_2 - \omega_1}{2} t}{\frac{\omega_2 - \omega_1}{2} t} \frac{\sin \frac{\omega_2 + \omega_1}{2} t}{\frac{\omega_2 + \omega_1}{2} t} \quad \ldots (48)$$

In effect the impulse response is the product of the impulse response of a filter with sharp cut-off at $\frac{\omega_1 + \omega_2}{2}$ and another at $\frac{\omega_2 - \omega_1}{2}$. The two components and the resultant are shown in Fig. 8.

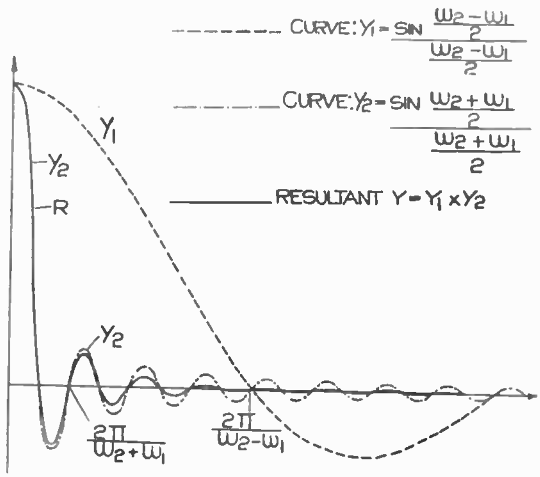

Fig. 8.—Showing how the impulse response of an ideal low-pass filter with sharp cut-off (curve Y_2) is modified when the cut-off becomes progressive and linear (resultant $R = Y_1 Y_2$).

Fig. 9 shows the impulse response for low-pass, band-pass and high-pass filters of this type. These curves should be compared with those of Fig. 6 which correspond to similar filters with sharp cut-off. Only a few secondary waves are visible in Fig. 9; all others have practically disappeared.

(3.2.1.3) Filters with Complicated Characteristics

When the shape of the frequency and phase characteristics are more complicated, the calculation of the impulse response requires that these functions be first expressed in an analytical form.

A powerful method which is particularly interesting from the theoretical point of view is to express the frequency and phase characteristics by means of Fourier series expansion. This method was used by the author in 1932 to study the frequency spectra of signals[15] and the results are summarised in sections (3.1.6) and (4.2). The present application is due to Wheeler[25, 26].

Consider as an example a low-pass filter having more or less complicated characteristics ((*a*) and (*b*) Fig. 10). Express $N(\omega)$ as a Fourier series. Since the curve is even

$$N(\omega) = \frac{C_0}{2} + \sum_{n=1}^{\infty} B_n \cos n\pi \frac{\omega}{\omega_0} \quad \text{..........(49)}$$

with $-\omega_0 < \omega < +\omega_0$, the fundamental period being $\frac{2\pi}{2\omega_0}$.

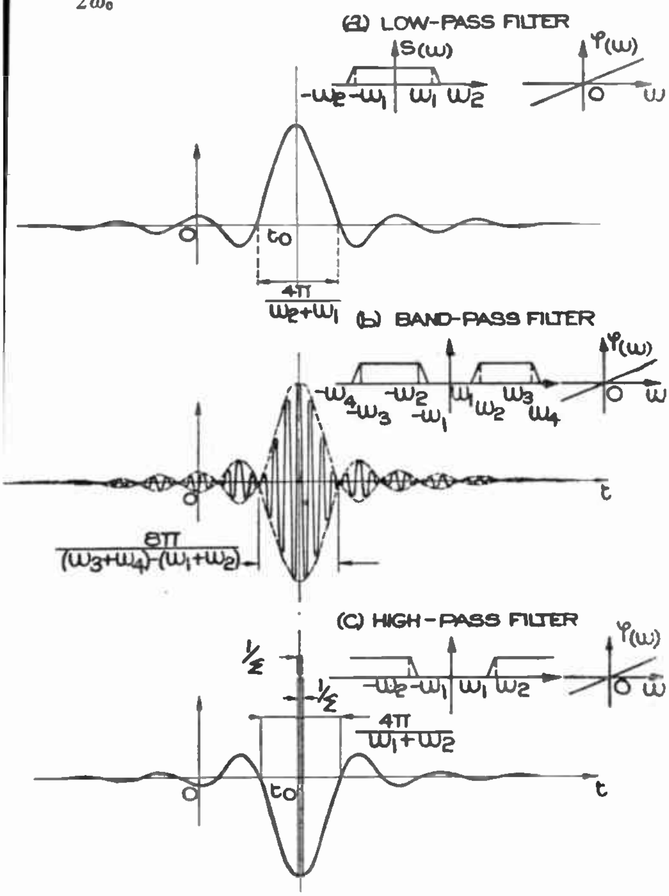

Fig. 9.—Ideal filters with progressive linear cut-off.

The impulse response is thus

$$I(t) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} N(\omega)\, e^{i\theta(\omega)}\, e^{i\omega t}\, d\omega \quad \text{............(50)}$$

$\theta(\omega)$ being the phase characteristic of the network. Replacing $N(\omega)$ by its value (49) gives

$$I(t) = \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} \frac{C_0}{2} e^{i(\theta\omega)}\, e^{i\omega t}\, d\omega$$

$$+ \sum_{n=1}^{\infty} \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} B_n\, e^{i\theta(\omega)} \cos n\pi \frac{\omega}{\omega_0}\, e^{i\omega t}\, d\omega$$

or

$$I(t) = \frac{1}{4\pi}\int_{-\omega_c}^{+\omega_c} C_0\, e^{i\theta(\omega)}\, e^{i\omega t}\, d\omega$$

$$+ \sum_{n=1}^{\infty} \frac{1}{4\pi}\int_{-\omega_c}^{+\omega_c} B_n\, e^{i\theta(\omega)}\, e^{i\omega\left(t+n\frac{\pi}{\omega_c}\right)}\, d\omega$$

$$+ \sum_{n=1}^{\infty} \frac{1}{4\pi}\int_{-\omega_c}^{+\omega_c} B_n\, e^{i\theta(\omega)}\, e^{i\omega\left(t-n\frac{\pi}{\omega_c}\right)}\, d\omega \quad \text{....(51)}$$

Let $I_0(t)$ be the impulse response of a low-pass filter having a sharp cut-off at ω_c, for which $N(\omega) = 1$ when $|\omega| < \omega_c$, and whose phase characteristic is $\theta(\omega)$.

$$I_0(t) = \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} e^{i\theta(\omega)}\, e^{i\omega t}\, d\omega \quad \text{...............(52)}$$

Substituting (52) into (51) and rearranging leads to the response

$$I(t) = \frac{C_0}{2} I_0(t) + \sum_{n=1}^{\infty} \frac{B_n}{2}\left[I_0\left(t + n\frac{\pi}{\omega_c}\right) + I_0\left(t - n\frac{\pi}{\omega_c}\right)\right] \quad \text{......(53)}$$

Thus, the impulse response is that which would be obtained from a low-pass filter with a constant amplitude and sharp cut-off, accompanied by a series of leading and lagging miniature replicas (echoes) of this impulse.

Consider now the phase distortion which can be found by the same method. The phase function is an odd function of ω; it may be considered as a straight line plus an odd function of ω which represents the deviation of $\theta(\omega)$ from the straight line. This deviation may be expressed as a Fourier series with respect to ω, containing sine terms only; the period need not be the same as that used for the amplitude function. Let it be $\frac{2\pi}{2\omega_0}$ [(*b*) Fig. (10)]. Then

$$-\theta(\omega) = \omega t_0 + \sum_{n=i}^{\infty} A_n \sin n\pi \frac{\omega}{\omega_0} \quad \ldots\ldots\ldots(54)$$

and

$$e^{i\theta(\omega)} = e^{-i\omega t_0} \prod_{n=i}^{\infty} e^{-iA_n \sin n\pi \frac{\omega}{\omega_0}} \quad \ldots\ldots\ldots\ldots(55)$$

Each term of the product can be expanded by the fundamental Bessel relation

$$e^{\pm iA \sin x} = \sum_{-\infty}^{+\infty} e^{\pm imx} J_m(A) \quad \ldots\ldots\ldots(56)$$

a single sine term is sufficient to represent the deviation of $\theta(\omega)$ from a straight line. Assume that it is $A_1 \sin \pi \frac{\omega}{\omega_0}$; then from (55) and (57) one obtains

$$e^{i\theta(\omega)} = J_0(A_1)\, e^{-i\omega t_0} + J_1(A_1)\left[e^{-i\omega\left(t_0 + \frac{\pi}{\omega_0}\right)} - e^{+i\omega\left(t_0 - \frac{\pi}{\omega_0}\right)}\right] + J_2(A_1)\left[e^{-i\omega\left(t_0 + 2\frac{\pi}{\omega_0}\right)} + e^{+i\omega\left(t_0 - 2\frac{\pi}{\omega_0}\right)}\right] + \ldots\ldots$$

Substitute in equation (52)

$$I_0(t) = J_0(A_1)\, I_1(t') + J_1(A_1)\left[I_1\left(t' - \frac{\pi}{\omega_0}\right) - I_1\left(t' + \frac{\pi}{\omega_0}\right)\right]$$

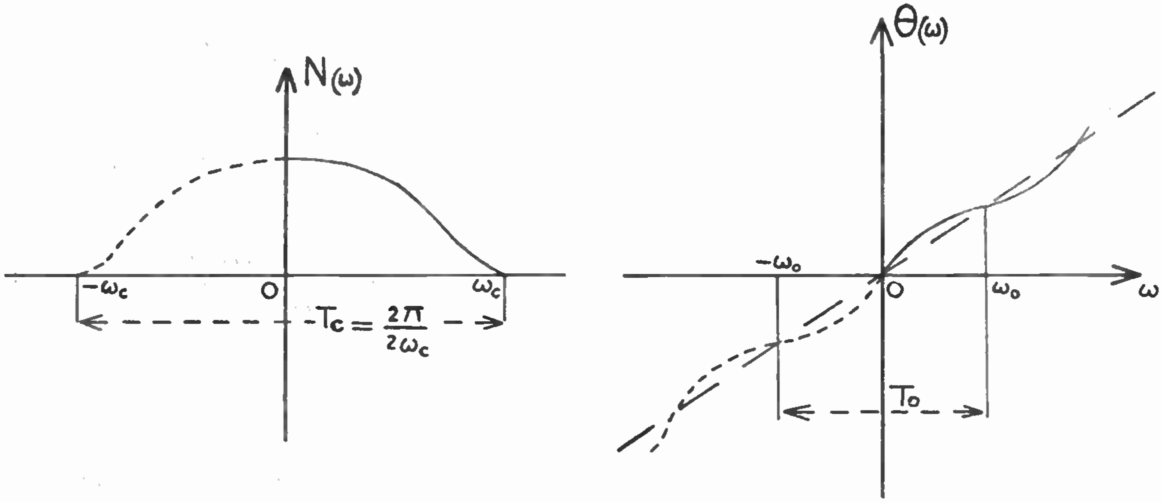

Fig. 10.—Frequency and phase characteristics of a low-pass filter.

where $J - m(A) = (-1)^n\, Jm(A)$, $Jm(A)$ being the Bessel function of the first kind of order m.

Thus

$$e^{-iA_n \sin n\pi \frac{\omega}{\omega_0}} = J_0(An) + J_1(An)\left[e^{-in\pi\frac{\omega}{\omega_0}} - e^{in\pi\frac{\omega}{\omega_0}}\right] + J_2(An)\left[e^{-i2n\pi\frac{\omega}{\omega_0}} + e^{i2n\pi\frac{\omega}{\omega_0}}\right] + \ldots\ldots\ldots\ldots(57)$$

Substituting this expression in (55) leads to an expression for $e^{i\theta(\omega)}$ in which every factor is of the type $\propto e^{\pm m\pi\frac{\omega}{\omega_0}}$. Substituting now in (52), the result is a series of terms of the type

$$\propto \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} e^{i\omega(t \pm t')}\, d\omega$$

which is the impulse response of an ideal low-pass filter changed in amplitude and shifted in time. Often

$$+ J_2(A_1)\left[I_1\left(t' - 2\frac{\pi}{\omega_0}\right) + I_1\left(t' - 2\frac{\pi}{\omega_0}\right)\right] + \ldots\ldots\ldots\ldots(58)$$

where $t' = t - t_0$ and

$$I_1(t') = \frac{1}{2\pi}\int_{-\omega_c}^{+\omega_c} e^{-i\omega t'}\, d\omega \quad (59)$$

$I_1(t')$ is obviously the impulse response of an ideal low-pass filter having the same cut-off frequency and the same average phase characteristic as the filter under consideration.

Thus $I_0(t)$, the response of the filter with an ideal amplitude characteristic and with a wavy phase curve, is the resultant of $J_0(A_1)$ times the impulse response of the same filter, but with a linear phase curve, and a series of echoes coming before and after this main response, just as in the case of distortions of the frequency characteristic.

The final expression for the response is found by substitution of equation (58) in equation (53)

$$\begin{aligned} I(t) = {} & \frac{C_0}{2} J_0(A_1)\, I_1(t') \\ & + \frac{C_0}{2} J_1(A_1) \Big[I_1(t'-\epsilon_0) - I_1(t'+\epsilon_0) \Big] \\ & + \ldots\ldots\ldots\ldots \\ & + \frac{B_1}{2} J_0(A_1) \Big[I_1(t'+\epsilon_c) + I_1(t'-\epsilon_c) \Big] \\ & + \frac{B_1}{2} J_1(A_1) \Big[I_1(t'-\epsilon_0+\epsilon_0) \\ & + I_1(t_1-\epsilon_0-\epsilon_c) - I_1(t'+\epsilon_0+\epsilon_c) - I_1(t'+\epsilon_0-\epsilon_c) \Big] \\ & + \ldots\ldots\ldots\ldots \end{aligned} \qquad \ldots\ldots(60)$$

Thus the impulse response of the filter is a function of the impulse response of an ideal low-pass filter having the average frequency and phase characteristics of the filter under consideration and of the departure of the characteristics from the ideal ones. These departures produce leading and lagging echoes.

Although these conclusions look very attractive, it must be observed that the response of an ideal filter has very long front and back tails so that at the moment when an echo appears, the preceding signals have not disappeared completely and their sum may be such that it cancels the echoes or even changes their signs. As an example, we have shown that a linear progressive cut-off reduces considerably the front and back tails of the ideal impulse response. In this case the echoes cancel nearly exactly the distant waves of the ideal impulse response and eliminate any sign of signal.

(3.2.2) Response of a Network to an Applied Signal

(3.2.2.1) Direct Method of Calculation

If a signal $e_1(t)$ is applied at the input of the network the shape of the signal $e_2(t)$ appearing at the output may be found as follows :

1. Determine the Fourier transform

$$\vec{\mathbf{e}}_1(\omega) = \vec{e}_1(\omega)\, e^{i\phi_1(\omega)}$$

of the signal.

2. Multiply this transform by the characteristic function $\mathbf{N}(\omega)$ of the network.

3. Obtain the output signal by the inverse Fourier transform formula

$$e_2(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \vec{\mathbf{e}}_1(\omega)\, \mathbf{N}(\omega)\, e^{i\omega t}\, d\omega \qquad \ldots\ldots(61$$

An impulse signal $e_1(t)$ is a particular case and a simple one since then $\vec{\mathbf{e}}_1(\omega) = 1$. All the foregoing conclusions concerning impulse response can be repeated by replacing the impulse response by the response to the signal $e_1(t)$. For instance, if the study of filters with complicated characteristics is repeated with a signal $e_1(t)$, the conclusions will be identified with those obtained with a unit impulse applied to the filter.

(3.2.2.2) Calculation with the Help of the Impulse Response of the Network

There is a close relationship between the response to a signal and the impulse response of a network. Since the impulse response defines completely the characteristics of the network it must be possible to express the response $e_2(t)$ to a signal $e_1(t)$ applied in function of the impulse response.

By definition of the impulse response an impulse $e_1(0)$ of infinitely short duration dt impressed on the network, at time $t = 0$ leads to an output voltage at time t

$$e_1(0)\, I(t - t_0)\, dt$$

Similarly an impulse $e_1(t_0)$ of duration dt impressed at time $t = t_0$ leads to an output voltage at time t

$$e_1(t_0)\, I(t - t_0)\, dt$$

Addition of all the output voltages at time t, which result from the signal $e_1(t)$ impressed on the network, gives the total response $e_2(t)$

$$e_2(t) = \int_{-\infty}^{+\infty} e_1(t_0)\, I(t - t_0)\, dt_0$$

To avoid confusion put $t_0 = \tau$

$$e_2(t) = \int_{-\infty}^{+\infty} e_1(\tau)\, I(t - \tau)\, d\tau \qquad \ldots\ldots\ldots(62)$$

This equation gives the response of the network for any input voltage as a function of its impulse response.

The physical interpretation of this equation leads directly to the fundamental property of selective transforms. Further details are given in section (4.2).

(4) More Advanced Applications

Advanced specialised applications require a great deal of care and are beyond the scope of this paper However, it is of interest to discuss briefly the results of studies on the propagation of waves through dispersive media, the theory of selective transforms and pulse modulation and demodulation.

(4.1) Propagation of Waves through Dispersive Media

In a medium where all frequencies have the same velocity of propagation, all types of signals will travel with the same velocity and without distortion. In a dispersive medium this is not the case and all propagation suffers distortion of the signal. Brillouin*[11] has carefully studied these distortions. He assumed that a sinusoidal signal (Fig. 11) travelled through the medium and he studied the distortion produced at a given distance from the sending point. To do this he represented the signal by a Fourier integral, i.e. by an infinite number of sinusoidal oscillations; for each component the velocity of propagation is known so that the phase of each component at the receiving point is known. The received signal is thus the integral of all received components, that is a Fourier transform which Brillouin succeeded in evaluating despite great mathematical difficulties. To avoid these difficulties Brillouin noted that the components whose frequencies were around the frequency of the oscillations of the signal had a predominant amplitude, and he studied first the propagation of these components. He found that this resulted in a signal of the same type as the original one but starting and ending progressively (central body of the received signal illustrated by Fig. 11). He then considered all other frequency components and observed that the integration of these components gave a negligible result if the phase π varied rapidly with the frequency ω; only those components whose frequencies were such that $\frac{\delta\pi}{\delta\omega}$ was zero, or nearly zero, gave an appreciable amplitude on summation. Brillouin showed that these appreciable signals appeared as echoes before and after the main body of the signal. The calculation was conducted with great skill and provided a very good example of the application of Fourier transforms to the study of physical phenomena.

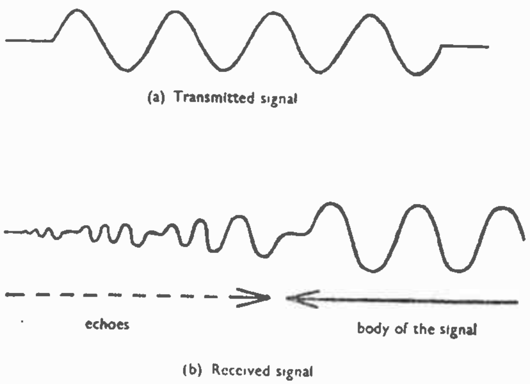

Fig. 11.—Propagation of a signal through dispersive media.

* A similar investigation was conducted at the same time by Sommerfield, but in a slightly different way. Sommerfield studied the propagation of a signal which starts at $t + 0$ and continues indefinitely as a harmonic oscillation. He solved the problem by means of Laplace transforms.

(4.2) Theory of Selective Transforms[15, 16, 17, 18].

(4.2.1) The main importance of this theory is that it gives to any integral of the product of two functions a visual and clear meaning; such an integral represents a selective transform, that is, in the integration some frequencies are increased in amplitude and others decreased, and the phase is also affected, just as in the case of transmission through a network.

To see clearly the meaning of "selective transform," consider a sine wave, cos ωt and the integral

$$T(t_0) = \int_{t_0 - \alpha}^{t_0 + \alpha} Y(t - t_0) \cos \omega t \, dt \quad \ldots\ldots\ldots (63)$$

where $Y(t - t_0)$ is a function, defined in the interval $t_0 - \alpha < t < t_0 + \alpha$, which we will call " transforming curve" Y. Put $t^1 = t - t_0$ and $t_0 = \tau$; then

$$T(\tau) = \int_{-\alpha}^{+\alpha} Y(t^1) \cos \omega(t' + \tau) \, dt'$$

Since $Y(t^1)$ is zero for $t^1 < -\alpha$ or $t^1 > -\alpha$

$$T(\tau) = \mathbf{R} \int_{-\infty}^{+\infty} Y(t') \, e^{i\omega(t' + \tau)} \, dt'$$

or

$$T((\tau) = \mathbf{R} e^{i\omega\tau} \int_{-\infty}^{+\infty} Y(t) \, e^{i\omega t'} \, dt'$$

The integral on the right hand side is a Fourier transform; put

$$\overline{Y}(\omega) = \int_{-\infty}^{+\infty} Y(t^1) \, e^{i\omega t'} \, dt'$$

$\overline{Y}(\omega)$ is the characteristic function of $Y(t')$. Call it the "selectivity function" of $Y(t')$. Thus

$$T(\tau) = \mathbf{R} \, e^{i\omega t} \, \overline{Y}(\omega)$$

Put $\quad \overline{Y}(\omega) = \overline{Y}(\omega) \, e^{i\phi(\omega)}$

Then $\quad T(\tau) = \mathbf{R} \, e^{i\omega\tau} \, \overline{Y}(\omega)$

$$T(\tau) = \overline{Y}(\omega) \cos [\omega\tau + \phi(\omega)]$$

This equation means that the preceding operation transforms a sine wave into another of the same frequency but with different amplitude and phase. This is exactly what an electrical network does so the above operation is equivalent to sending the sine wave through a network whose characteristic function is $\overline{Y}(\omega)$.

When a general function of time is used instead of a sine wave in equation (63), each frequency component of this function is changed in amplitude and phase by the selectivity function, since equation (63) is linear.

To find the selectivity function a very powerful method is to expand $Y(t')$ in a Fourier series in the interval $(-\infty, +\infty)$ and to add the selectivity functions of each component[15]. Since the selectivity function of a sinusoidal signal has a predominant maximum for its own frequency (Fig. 3), it is clear that components of predominant amplitude in $Y(t^1)$ correspond to a predominant maximum for the corresponding frequency in the selectivity function.

(4.2.2) The fact that every integral of the type

$$h(t_0) = \int_{-\infty}^{+\infty} f(t - t_0) g(t)\, dt \qquad \text{(64)}$$

can be considered as a selective transformation, and represents an operation identical to sending a signal $g(t)$ through a selective electrical network, gives to this type of integral a physical meaning from which many properties can be brought out, very often at a glance by those familiar with the theory.

Other applications can be deduced from the geometrical meaning of equation (64). For each value of t_0 (64) means that we take the product of the curves $f(t - t_0)$ and $g(t)$ and integrate from $-\infty$ to $+\infty$. When t_0 varies the curve $f(t - t_0)$ slides parallel to the abscissae axis. Such an operation represents for instance the scanning of a television picture by a spot of light ($f(t)$ representing the law of distribution of light of the spot along the moving axis), or the scanning of a sound track on a film by a light spot and its integration by a photo-cell. It is clear that these operations are selective. A uniform spot, represented by an ideal square law $f(t)$, will give a selectivity curve of the type $\frac{\sin \alpha\omega}{\alpha\omega}$ with a predominant maximum for $\omega = 0$. Such a curve (Fig. 1) is an imitation of a bad low-pass filter because the attenuation with frequency decreases very slowly; in sound film reproduction it would be responsible for a considerable amount of noise. Better laws are the triangular or parabolic laws (Fig. 1). The author calculated, with the help of Fourier transforms, the slop of the curve $f(t)$ which gives a low-pass filter with sharp cut-off. It is a curve with a predominant maximum and a series of leading and lagging progressively attenuated echoes. Such a law can be simulated very approximately by the diffraction replicas obtained when producing a small image of a filament. Thus, by using conveniently the diffraction phenomena—which are usually unwanted—one can obtain a good sound reproduction characteristic with sharp cut-off and zero reproduction of the frequencies above the cut-off. Since nearly all the noise comes from these frequencies the signal/noise ratio is considerably improved.

(4.2.3). Equation (64) has other interesting applications in network theory.[17,19]. For instance, equation (62)

$$e_2(t) = \int_{-\infty}^{+\infty} e_1(\tau)\, I(t - \tau)\, d\tau \qquad \text{(62)}$$

giving the response $e_2(t)$ of a network to an applied signal $e_1(t)$, is of the type (64). Thus, the response $e_2(t)$ is the function obtained by transforming the applied signal $e_1(\tau)$ by means of the impulse response $I(t)$. Electrical networks cause selective transformations just as if the transformations were effected by their impulse responses.

In the light of this theory the relations between the shape of the signals and their frequency characteristics can be interpreted straight away. Consider again equation (64)

$$h(t_0) = \int_{-\infty}^{+\infty} f(t - t_0)\, g(t)\, dt \qquad \text{(64)}$$

It is obvious that

$$\overline{h}(\omega) = \overline{f}(\omega)\, \overline{g}(\omega) \qquad \text{(65)}$$

Since the Fourier transform of a function is also its selectivity function, equation (65) shows that if we transform a curve f by a curve g, or inversely, the selectivity curve of the resultant is the product of the selectivity curves corresponding to f and g.

Examples.

(1) If a rectangle is transformed by an identical rectangle, the result is a triangle (Fig. 12). Thus, the selectivity function of a triangle is proportional to the square of the selectivity function of the rectangle (Fig. 1)

$$\left(\frac{\sin \omega\epsilon}{\omega\epsilon}\right)^2$$

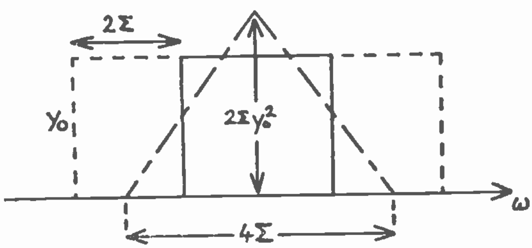

Fig. 12.

(2) If a triangle is tranformed by a rectangle, or inversely, the result is a curve formed by 4 arcs of parabolæ (Fig. 1) whose selectivity curve is

$$\left(\frac{\sin \omega\epsilon}{\omega\epsilon}\right)^3$$

This explains summarily how the curves of Fig. 1 were obtained.

(4.2.4). Another example, more mathematical, will now briefly be stated. Consider the Fourier series formulæ

$$f(t) = C_0 + \tfrac{1}{2}\sum_{n=1}^{\infty} C_n \cos(n\,\omega_0 t + \phi_n)$$

$$C_n = \sqrt{[A_n^2 + B_n^2]}$$

$$A_n = \frac{1}{\pi}\int_{-\frac{\pi}{\omega_0}}^{+\frac{\pi}{\omega_0}} f(t)\sin n\omega_0 t\,dt$$

$$B_n = \frac{1}{\pi}\int_{-\frac{\pi}{\omega_0}}^{+\frac{\pi}{\omega_0}} f(t)\cos n\omega_0 t\,dt$$

The right hand side of the expressions giving A_n and B_n are selective transforms where $t_0 = 0$. Consider now a non-periodic function, $f_{(t)}$, choose an arbitrary period $T_0 \propto = \frac{2\pi}{\omega_0}$, and calculate A_n and B_n for different positions of the section of width T_0

$$A_n = \frac{1}{\pi}\int_{t_0-\frac{\pi}{\omega_0}}^{t_0+\frac{\pi}{\omega_0}} f(t)\sin n\omega_0(t - t_0)\,dt$$

$$B_n = \frac{1}{\pi}\int_{t_0-\frac{\pi}{\omega_0}}^{t_0+\frac{\pi}{\omega_0}} f(t)\cos n\omega_0(t - t_0)\,dt$$

that is, for different values of t_0. We get two functions $A_n(t_0)$ and $B_n(t_0)$ representing $f(t)$ after transformation by the selective curves

$$\Big[\sin n\omega_0 t\Big]_{-\frac{\pi}{\omega_0}}^{+\frac{\pi}{\omega_0}} \text{ and } \Big[\cos n\omega_0 t\Big]_{-\frac{\pi}{\omega_0}}^{+\frac{\pi}{\omega_0}}$$

The amplitudes of A_n and B_n will be notable only if components $n\omega_0$ exist in $f(t)$[15]. Thus the mean value of $C_n = (\sqrt{A_n^2(t_0) + B_n^2(t_0)})$ will be notable only if $f(t)$ contains components around $n\omega_0$. Careful calculation shows that this is correct; the result is the same as that given by a spectrum analyser having a definite type of selectivity curve. It shows also that taking the mean value of A_n and B_n for 3 or 4 values of t_0 is generally sufficient. Thus the methods of harmonic anlysis can be extended to the analysis of non-periodic curves.

(4.3) Study of Pulse Modulation and Demodulation

In pulse modulation the intelligence or signals are not transmitted continuously but at equal intervals, very short compared with the highest frequency to be transmitted.

Fig. 13 shows the signal to be transmitted and the ordinates which are effectively transmitted.

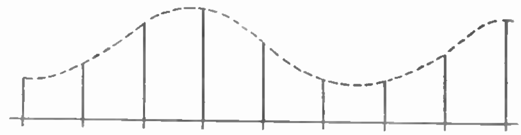

Fig. 13.—In "pulse modulation" the curve is chopped at equal intervals of time by sharp pulses.

The simplest method is to transmit periodically a very sharp pulse whose amplitude is proportional to the amplitude of the signal. This method requires a linear amplifier at the receiver just as in an amplitude modulation system. There is, however, a method of pulse modulation called "time pulse modulation" which gives the information required not by a variable amplitude but by shifting in time, proportionally to the amplitude of the signal, the moment at which the pulse ought to appear. Fig. 14 shows how this is done. In the absence of signal, pulse m appears at time $t_m = mT_0$, T_0 being the period of repetition. When the signal appears, the same pulse appears at time t

$$t = mT_0 + \triangle t$$

where $\triangle t$ is proportional to the amplitude of the signal.

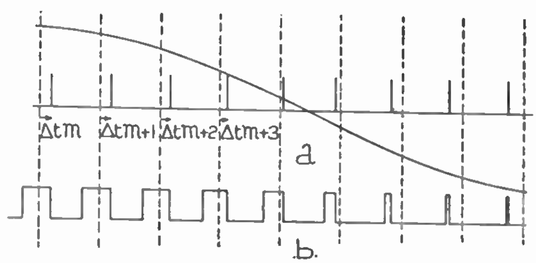

Fig. 14.—"Time pulse modulation" method: a pulse is shifted in time from its normal position proportionally to the amplitude of the signal.

At the receiver, this time modulation is changed to variable width modulation by the following process (Fig. 14*b*).

The leading edge of the periodic pulse train appears at time τ_m

$$\tau_m = mT_0 - \triangle T_0$$

$\triangle T_0$ being positive and small compared to T_0 but greater than the maximum value of $/\triangle t/$. The trailing edge appears with the pulse of the received train, that is, at time $\tau' = mT_0 + \triangle t$. Thus the width of the m^{th} pulse is

$$\triangle\tau = \triangle T_0 + \triangle t$$

On Fig. 15 the variable width pulse is reproduced with the transmitted signal on a convenient scale to explain the demodulation process. This process consists simply in integrating the variable width pulse. It is clear that if T_0 is very small compared to the period T_m of the highest frequency to be transmitted, the integration will reproduce the signal with a good degree of similarity. The question is to determine the amount of distortion obtained as a function of the ratio T_m/T_0, and this is best done with the aid of Fourier transforms. Since the time at which the m^{th} pulse appears is known as well as the time at which it disappears, the Fourier transform $\overline{P_m}(w)$ of the pulse can be calculated. Adding the transforms of all pulses leads to a function

$$\overline{P}(\omega) = \sum_{m=-\infty}^{+\infty} \overline{P_m}(\omega)$$

which represents the Fourier transform of the modulated train. Usually the integrating device is either capacitance shunted by resistance followed by a low-pass filter which suppresses the pulse repetition frequency and its harmonics, or simply a low-pass filter. If $N(\omega)$ is the characteristic function of the integrating device, the demodulated signal $S_2(t)$ will be such that its Fourier transform is

$$\overline{S_2}(\omega) = \overline{P}(\omega)\ N(\omega)$$

It is thus possible to choose a comvenient function, $N(\omega)$, in order that . $\overline{S_2}(\omega)$ is closely similar to $\overline{S_1}(\omega)$, the Fourier transform of the transmitted signal. The calculation is very delicate and requires great skill. The results are functions of a great number of parameters and it must suffice to state the most important conclusions to be drawn :

(1) The combined modulation and demodulation process produces no amplitude distortion except at sub-multiples of the recurrent frequency f_0. At these frequencies the amplitude distortion is function of the relative phase between the signal and the times mT_0 at which information on the signal is transmitted. The maximum distortion is $\pm$ 100 % at $f_2/_2$, and is usually negligible for lower sub-multiples.

(2) Harmonic distortion is produced by the modulation process but is balanced by an equal distortion and of opposite sign at the demodulation. The overall harmonic distortion is surely negligible, in fact of a smaller order than the approximations made. In practical multi-channel system they can be considered as inexistent.

(3) The integrating device must be a low-pass filter with a cut-off frequency slightly higher than the highest frequency to be transmitted.

(4) Demodulation of width-modulated pulses is best achieved by the use of a low-pass filter. If f_0 is the recurrent frequency, the cut-off frequency of the filter must be smaller than $f_0/2$.

(5) Another type of distortion appears in pulse modulation ; when the periodic train of pulses is modulated, the D.C. and harmonic components of the train are also modulated and each can be considered as a carrier modulated by the signal. In amplitude pulse modulation each carrier produces two side-bands and the D.C. component one side-band of same frequency as the signal. In time pulse modulation each carrier produces a great number of side bands, the lower ones being inside the transmitted band-width. At the demodulation these side-bands go through the L.P. filter and produce a special type of distortion. However, this distortion can be reduced to a negligible amount by reducing the modulation width to some per cent. of T_0. This is usually done in multi-channel systems.

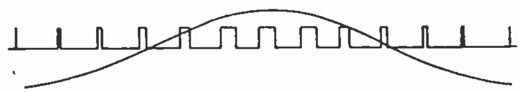

Fig. 15.—Signal and corresponding "variable width modulation." The variable width modulation is usually derived from the time modulation at the receiver.

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DISCUSSION ON THE DESIGN AND APPLICATION OF MODERN PERMANENT MAGNETS

by

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(Contributed to the London Section meeting held on the 17th October, 1946)

Mr. Tyrrell has, by publishing his paper, rendered a great service to members of the Institution, and my contribution is by way of expressing thanks to Mr. Tyrrell for his work.

There is a very close relationship between electric and magnetic circuits and I should like first to deal with the most fundamental relation, Ohm's Law. In electrical terms it takes the well-known form the current I being equal to the E.M.F. divided by the resistance R.

Let us consider the simple case of a conductor of uniform cross-section A and introduce the current density $i = I/A$ and write it on the left-hand side of the table. On its right-hand side we will put the magnetic equivalents which, in the case of Ohm's Law, is the simple relation that flux is equal to the magneto-motive force M.M.F. divided by the magnetic resistance or reluctance R_m. Again, considering a piece of iron of uniform cross-section A with the lines of force penetrating it perpendicularly we have the known relation that the total flux ϕ is equal to the flux density B times cross-sectional area A.

Whereas the units in the electrical case are doubtlessly Amperes, Volts and Ohms, they are Maxwells, Gilberts and Oersteds with a long shadow of a doubt, since there seems to prevail considerable confusion as to which magnetic quantity to assign to which venerable name of deceased scientists particularly if you add to the above last three names that of Gauss. If you refer to books on the subject you will find that those name allocations depend to a varying degree on the respective author's nationality and age. However, so long as one knows what one means all is well.

Regarding the resistance, analogous formulae apply in electrical and magnetic cases, and from the two analogies enumerated so far, and tabulated in the table we can see that electrical current corresponds to magnetic flux, current density to flux density, and conductivity κ to permeability μ.

Now let us form the product of squared current and resistance which gives the power P in Watts. By introducing the current density i and the resistance formula for a piece of conductor, we can split up the total power into a term i^2/κ which represents the power dissipated in one cubic centimetre, and another term, the volume V of the conductor.

Performing an analogous process with magnetic quantities, viz., multiplying the reluctance with the square of the flux and with a constant $1/8\pi$ we obtain an expression $B^2/8\pi\mu$ times the volume. In $B^2/8\pi\mu$ we recognise the energy of the magnetic field stored in one cubic centimetre of material expressed in Ergs.

This analogy is already very revealing for it shows that by the same process we obtain electrical power in the electrical case, which is energy dissipated in unit time, and in the magnetic case we obtain energy stored in the magnetic circuit, which seems clear now, for the magnetic circuit is static in its nature—" nothing really happens "—whereas the electrical circuit dissipates energy, producing heat. It also shows that a permanent magnet is a physical reality whilst a " permanent battery " would only prove the impossible, the perpetual motion.

However, let us proceed to complete circuits consisting of a source comprising an electromotive force E.M.F. and internal resistance R_i and a load resistance R. Let the terminal voltage be V, and the current flowing out of one terminal I. By varying the load from zero to infinity, I versus V can be calculated and plotted and from the linearity of the equations relating V and I it follows that we must obtain a straight line. For $V = O$ we have the short circuit current $I_{sc} = \frac{E.M.F.}{R_i}$ and for $I = O$ we obtain the open circuit voltage $V_{oc} = E.M.F.$ The straight line connecting V_{oc} with I_{sc} is called the characteristic or the regulation of the source, for it relates all possible terminal voltages and currents.

If we wish to find out the conditions for a particular load R we must draw the characteristic of R, i.e., the line relating all possible voltages across R and currents through R. Since $R = V/I$, this characteristic is a straight line through the origin.

Naturally since only one pair of V and I is possible at a time, the point of intersection of both characteristics is the solution for our query.

It is important to note, however, that the same operating point can be obtained by connecting to the terminals of the source an external E.M.F. of the value of the desired terminal voltage and in opposition to the source E.M.F. Provided now this external counter E.M.F. does not introduce any additional resistance—it could be realised by an external zero-impedance voltage source—we shall obtain exactly the same working conditions as with the load R. This is sometimes called the Compensation Theorem. In fact, by varying the counter E.M.F. the whole source characteristic can be explored, even beyond the boundaries of V_{oc} and I_{sc}.

† *Rediffusion Ltd.*

All this is, of course, well known, and I have only dealt with it here in order to be able to compare it concisely with the magnetic analogy.

Let us now consider a closed ring of permanent magnet material which is magnetised by a few ampere-turns around the ring. We reduce the magnetising current to zero and measure the flux ϕ_r which is called remanent flux. At this stage we can compare the closed permanent magnet with a short-circuited electrical source, whereby the remanent flux ϕ_r corresponds to the short-circuited current I_{sc}. In order to get the internal magneto motive force M.M.F. of the magnet which sustains ϕ_r we remember the Compensation Theorem, quoted for the electrical case. According to it we can measure the internal E.M.F. by applying an opposing E.M.F. of equal magnitude so that the current would vanish. This can easily be achieved with the magnet by reversing the magnetising current direction around the ring and increasing the current until the flux is zero. Then we know that the M.M.F. measured in terms of $0{\cdot}4\pi$ times ampere turns we have just applied, must equal the internal M.M.F. of the permanent magnet. This is called the coercive magnetomotive force $M.M.F._c$. Similar to the electrical case we have thus gone through the characteristic of the magnet source, as pictured in the table.

Now as a magnet is of a continuous structure and contains its M.M.F. and internal resistance in a uniformly distributed manner oriented along its axis, it is customary in " magnetotechnique " to refer all quantities to unit length and unit cross-section, i.e., to unit volume. It is in this form that we are familiar with magnet characteristics.

The significant quadrant of the previous figure is redrawn with all quantities referred to unit volume, so that, the remanence appears as B_r in lines per square centimetre, and the coercive force as $M.M.F_c$ per centimetre equal to H_c.

If we now cut a gap of width δ into the ring magnet, we are introducing external reluctance into the system ; we actually go from the short circuit to a load condition. Similarly to the electrical case, we can find the new operating point as the intersection of the characteristics of the magnet and the gap reluctance.

The gap reluctance, if introduced into the customary diagram, must, of course, be referred to unit length and unit cross-section too. As $\mu = 1$ for air, the gap reluctance becomes $R = \delta/\iota$ where ι is the total magnetic path length. Analogous to an electrical resistance the reluctance must also be the ratio of M.M.F. over the flux, or, if referred to unit volume, it will be the $M.M.F./\iota = H$, over flux density B. Hence $R_m = H/B$. Hence a gap of 1mm and a path length of 10 cm results in $R_m = \delta/\iota = 0{\cdot}1/10 = 0{\cdot}01 = H/B$. A line according to this ratio can easily be drawn through the origin, and its intersection with the characteristic gives the working point, whereby the flux density in the gap is usually the only interesting quantity.

It is customary to say that the air gap or the reluctance "de-magnetises" the permanent magnet. If we were to translate this into the electrical analogy, we would have to say : the load resistance inserted in a normally short-circuited source "de-currentises" the source.

You can see now that the problem of designing a permanent magnet to produce a certain flux density in a certain working gap, resembles very closely the problem of matching, viz., to choose for a given load a source such that the desired power is delivered from the source to the load at minimum effort. We must keep in mind that any physical source is only capable of delivering a certain amount of maximum power and the conditions under which it gives away that power are called matching conditions. Although in an electrical linear circuit the efficiency is only 50%, matching conditions, indeed, determine the physically smallest source to deliver the desired power to a given load.

This is the essence of permanent magnet design, viz., to find the smallest magnet to do the job. Substitute energy for power, and the above arguments hold for magnets.

There are, of course, certain provisos in applying these analogies.

The magnet characteristic is not only non-linear but it is also irreversible, contrary to the characteristic of a linear source. Increasing the load after magnetisation, and then reducing it, shifts the operating point along two different curves as was so clearly explained to-night.

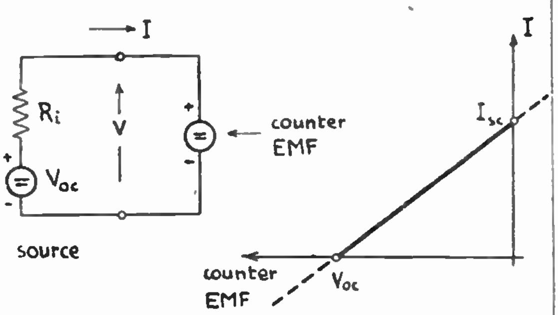
The other important proviso in our analogies is the fact that, whilst in an electrical circuit the leakage resistance of the air can be assumed to be infinity for normal operating conditions, this is not in the least the case with magnetic circuits. Instead of infinity, the ratio of air to iron reluctance is in the order of the permeability μ, and it is this fact which reduces magnetic calculations to more or less accurate estimations.

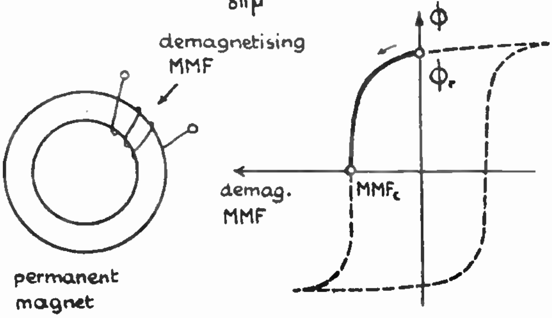
Nevertheless, the electrical analogies will always prove helpful if critically applied, bearing in mind the provisos just mentioned.

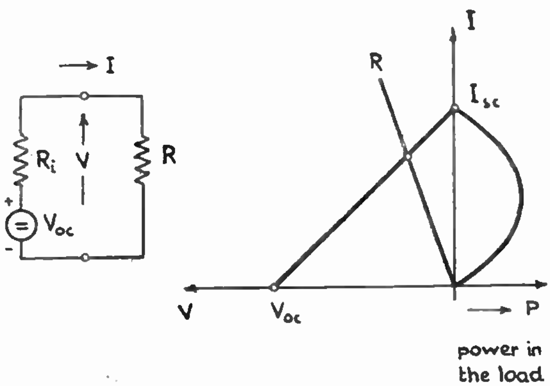
The paper on " Design and Application of Permanent Magnets " by A. J. Tyrrell was published in September/November 1946 Journal, pp. 178 to 213.

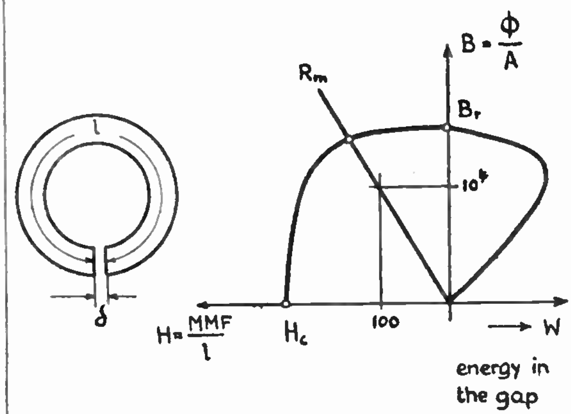
Analogies

Electrical	Magnetic
Ohm's Law	
$I = \frac{EMF}{R} = iA$, $[Amps] = \frac{[Volts]}{[Ohms]}$	$\phi = \frac{MMF}{R_m} = BA$, $[Maxwells] = \frac{[Gilberts]}{[Oersteds]}$
$R = \frac{l}{\kappa A}$ electrical resistance	$R_m = \frac{l}{\mu A}$ magnetic resistance or reluctance
l length; A crossection	
κ conductivity	μ permeability
$I^2 R = i^2 A^2 \frac{l}{\kappa A} = \frac{i^2}{\kappa} U = P$ power	$\frac{1}{8\pi}\phi^2 R_m = \frac{1}{8\pi} B^2 A^2 \frac{l}{\mu A} = \frac{B^2}{8\pi\mu} U = W$ energy
$\frac{i^2}{\kappa}$ power per cm^3	$\frac{B^2}{8\pi\mu}$ energy per cm^3
$U = Al$ volume	









Electrical	Magnetic
R load resistance	$R_m = \frac{H}{B} = \frac{\delta}{l}$ reluctance of the air gap referred to unit volume of the magnet
I_{sc} short circuit current	B_r remanence
V_{oc} open circuit voltage	H_c coercive force

A REVIEW OF RADIO AIDS IN AVIATION

by

Charles B. Bovill (Associate Member)*

A paper read before the North-Eastern Section of the Institution on December 11th, the Scottish Section on December 12th, 1946, the North-Western Section on January 29th, the London Section on February 20th, and the Midlands Section on March 27th, 1946.

SUMMARY

The object of this paper is to outline how radio is applied to assist aviation. The main technical problems peculiar to this branch of radio are dealt with in detail.

Some radio aids are analysed from the technical and economical aspects and it is shown that many of them are now outmoded by wartime developments.

Whilst the paper is essentially concerned with civil aviation, some reference to military technique is inevitable because many wartime aeronautical requirements are a guide to civil aircraft of the future.

Certain requirements are suggested, such as a radio collision warning device and electronic flight instruments.

* Decca Navigator Co. Ltd.

1. Introduction

Progress in modern aviation has been to a great extent dependent upon the development of radio devices for safety in flight; high speeds and great ranges of aircraft would never have been possible if radio apparatus had not been developed for the safe guidance of pilots.

To understand the basic problems which engineers have to face in applying radio to aeronautics various factors of a widely differing nature have to be considered.

Primarily, it must be realised that by comparison with other means of transport an aircraft is uneconomical as the ratio of the total weight to the useful load is seldom, in practice, in excess of five to one. To the radio engineer, this means that the airborne apparatus must be of the minimum possible weight.

Associated closely with the weight problem is the need for as complete a streamlining of the external structure of the aircraft as can be obtained without sacrifice of aerodynamic efficiency, it being the aim of aircraft designers to eliminate all protrusions from the fuselage which are not essential to the flight and propulsion of the aeroplane. To the designer of aircraft radio equipment this restricts aerial installations to masts and loops of small dimensions.

Perhaps not so readily recognised is the global aspect of air travel. An aeroplane leaving England may be in Australia within three days, having traversed areas of the world where wavelengths covering a wide range of the spectrum must be used to ensure constant communication and guidance to the pilot. Similarly, extremes of heat, cold and humidity may be met during the journey which must be provided for in the design of the radio apparatus.

Owing to the concentration of great power on a comparatively small structure in the shape of the engines of an aircraft, problems of vibration and high acoustic noise level are met which have to be allowed for by the radio designer. Static electricity effects and their consequent interference to radio reception, which are regarded as freak results on ground stations, are an everyday occurrence in aircraft and difficult suppression problems have to be dealt with.

Finally, the radio apparatus, although subject to these severe conditions of operation, has to be of a high degree of reliability, as its inefficient performance or failure may be of vital consequence at any stage of a flight.

While marine methods of navigation may be used for assisting in aircraft guidance, it will be appreciated that the faster rate of travel of an aircraft, when compared to that of a ship, can result in large errors in position estimation and that there are many occasions during flight when marine methods cannot be used successfully. It is therefore of primary importance to be able to provide the pilot of an aircraft with navigational assistance when it is needed. This requirement becomes increasingly important when civil aviation is considered and time tables have to be adhered to, and is a requirement which can only be provided for satisfactorily by radio, either from direction finding technique in its various forms, by the laying of beam tracks along which the aircraft can be flown or by hyperbolic navigation systems. Although navigational aid is without doubt the primary need of aircraft, they would be incompletely assisted unless two-way communication between air and ground was possible, this facility being required in order to pass meteorological information, landing instructions from the ground and for the aircraft to use for acknowledgment and emergency messages. In order to fulfil these needs radio apparatus has been extensively developed and the necessary facilities provided in various ways. Although normal flying instruments can be used to provide the pilot of an aircraft with guidance information with which he can fly an aircraft "blind" under conditions of reduced visibility, the compass and altimeter, upon which much would depend during a landing under similar conditions of visibility, have been proved to be inadequate for the purpose, being liable to errors which would make such an operation too hazardous for civil transport services. This has led to the development of radio devices for blind landing and indication of terrain clearance.

The independence of radio waves upon visibility has also been considered as a means of warning pilots of the danger of collision with other aircraft.

It will be seen that radio can be used not only for navigational aid and communication in aeronautics, but also for the supplementing of the information obtained from various flying instruments. It can also be applied for the solution of new problems peculiar to flying.

Radio applications to aeronautics may therefore be divided into four categories under the general headings of:—

(i) Navigational aids.
(ii) Communication.
(iii) Landing aids.
(iv) Flight aids.

2. The Radio Range System of Aircraft Guidance

2.1. *The Principle of the Radio Range System*

One of the chief requirements of civil aviation is to have the means of maintaining aircraft on the most direct route between the airport of departure and its destination. This enables time tables to be maintained, avoids petrol wastage and simplifies flying control.

In the United States of America the method of fulfilling this requirement is to provide beacons which lay down equisignal tracks between the main airports. These beacons, known as radio ranges, use transmitters of 50 to 200 watts aerial power rating and operate on the 200 to 400 kc/s band. The transmitters employ two pairs of aerials, each having a figure of eight polar diagram, which are in the majority of cases placed at 90 deg. to one another in order to produce areas of overlap of the field patterns. The aerials are both fed from a common source of radio frequency and are arranged, by special switching devices, to be modulated by different Morse characters. The timing of these characters, usually **A** (. —) and N (— ·), is interlocked so that when in the overlap zone a continuous note is heard in the receiver telephones. Thus, for a pilot to follow the track it is only necessary to guide the aircraft in such a manner as to maintain the continuous note, deviations from it being heard as a series of A's or N's. The important features of the radio range system are that the signals can be received on simple airborne equipment which can be of light weight, and that it can be used for the simultaneous guidance of a large number of aircraft from a single transmitter.

In the most generally used radio ranges an omnidirectional aerial is also included which at given periods transmits meteorological reports by telephony. The disadvantage of what is in other respects an almost ideal radio guide for aircraft is that it suffers from inaccuracies at night and during the periods of sunset and sunrise, due to interference from ionosphere reflections and that it is also liable to give false, or sometimes split courses, when the wave travels over terrain of varying conductivity. The former difficulty has been almost entirely overcome by using Adcock aerial technique, but there still remains the insuperable difficulty of changes of terrain conductivity, with its attendant course splitting phenomena and in some instances blind spots where reception ceases.

2.2. *The V.H.F. Radio Range*

Attention has therefore been turned to the uses and possibilities of V.H.F. for radio ranges. Apart from the large number of channels which can be accommodated in a given band at V.H.F., it has also the natural advantage that the waves at very high frequencies travel through space rather than over the ground and are less affected by changes of soil conductivity than medium frequencies. Sandretto[1] in a theoretical case shows that for a given soil conductivity a course error of 32 deg. at 300 kc/s will be reduced to 7 deg. at 100 Mc/s.

Frequencies of this order also have the very real advantage of being unaffected by atmospheric disturbances which make the installation of the radio range system a possibility in tropical countries where hitherto the medium frequency types have given only limited service.

These features combined with the simplicity of the ground plant and the ease with which the four beams emanating from the station can be pointed in the most useful directions for homing aircraft, make V.H.F. unquestionably the spectrum upon which radio ranges of the future will operate. According to published[2] details several V.H.F. ranges are already in operation in the United States of America.

2.3. *Markers*

For various reasons connected with the flight of the aircraft and also for economic reasons, it is not only necessary for the aircraft to be guided accurately from one airport to another, but it is also necessary for the pilot to have, from time to time, an indication of his progress along the beam. To enable this information to be given under conditions when visible sights of the ground cannot be taken, markers are installed along the range track at certain intervals which, operating on V.H.F. at 75 Mc/s, radiate a fan-shaped vertical polar diagram which is capable of being received in the aircraft with very simple apparatus. The breadth of the usable signal is arranged to overlap the continuous note area of the beam and can therefore be received by an aircraft which is flying slightly off the equisignal course, if required. Usually, the marker transmission is identified by the pilot by a distinctive tone in the telephones or indicated by a light in the cockpit which is operated through a relay by the received signal.

2.4. *Position Finding from Radio Range Signals*

A criticism sometimes made of the radio range method of guidance is that if the beam or continuous note area is lost the pilot cannot always find it. This is untrue, since by the very nature of the formation of the equisignal path there is either an A or an N signal in all quadrants round a range transmitter and by adopting a standard procedure entailing the use of the compass, aeronautical maps showing the bearings of the legs of the range stations, and by careful comparison of the strength of the A and N signals, a pilot can always find the equisignal path.

The procedure for finding beams is described in detail by Jordanoff[3], but does not seem to be known generally outside aviation circles where beam flying is in daily use.

2.5. *The Installation of Radio Range Receiving Equipment*

The installation in the aircraft for the use of the range system is, as already remarked, of extreme simplicity. This not only applies to the receiver but also to the aerial requirements, adequate reception at the limit of range of a beam being possible with an aerial of vertical construction, about 3 ft. high. As it is usual to use ranges for flying both to and from an airport, it is important to provide for a substantially omnidirectional polar diagram and a vertical aerial would appear to be the best choice. This kind of aerial may, however, at very short range from the transmitter, cause errors in course when the aircraft is being banked, due to picking up the horizontally-polarised component of the transmitted wave. Various methods are used to counter this undesirable effect, the most common being to use a short vertical aerial with a Vee form "roof." This construction not only gives a slightly increased effective height to the aerial but also, by careful adjustment of the length of the sides of the Vee, can be arranged to cause the horizontal components to cancel each other at the point of connection to the vertical part of the aerial. It would appear that these errors can occur at V.H.F., but there seems to be no reason why a similar aerial technique should not be employed. It should be noted, however, that at V.H.F. it will be more difficult to obtain an omnidirectional polar diagram on account of the screening of the wings, fuselage and tail unit of the aircraft. Since the aerials required for V.H.F. are small and therefore do not collect a dangerous amount of ice or seriously interfere with streamlining, it would seem that the best solution would lie in using separate aerials placed in suitable sites for flying towards and away from range transmitters.

2.6. *Radio Range Receivers*

The basic requirements of range receivers are that they should have high sensitivity and adjacent channel selectivity and that they should be capable of detecting small changes in input, in order to give the maximum aural discrimination between the A and N signals. The first two requirements are met without difficulty because it is possible to use a low value of I/F, typical receivers having a sensitivity of 50 mw output for an input of 5 microvolts, 30 per cent modulated, with a signal to noise ratio of 6 db and selectivity of the order of 40 db attenuation of 2 kc/s off tune. The aural discrimination is obtained by the use of a square law second detector. R/F gain is controlled manually and the output valve is arranged to load fully before any of the pre-detector amplifiers are overloaded, in order to oblige the pilot, for comfort of listening, to keep the gain control set at a safe value. This prevents course errors due to R/F overload and also ensures that the detector is operated under optimum conditions.

Continuously variable tuning is used with M/F radio range receivers and normal L/C circuits are incorporated in the R/F and oscillator stages. V.H.F. radio range receivers usually have crystal controlled oscillator circuits, owing to the difficulties of design of small stable variable circuits at these frequencies.

Although it is useful to be able to receive meteorological broadcasts on the range equipment without a change of tuning, there are occasions when the presence of voice frequencies is inconvenient to the pilot, who may, for example, be about to execute a difficult manœuvre and be in the need of clear guidance signals. Similarly, under weak signal conditions, the A-N modulation may render the telephony signals unintelligible. Filters are, therefore, incorporated in the A/F circuits of range receivers which enable either of the unwanted signals to be attenuated by about 40 db.

3. Navigational Aid from Airborne Direction Finding Apparatus

3.1. *The Uses of Aircraft Direction Finders*

Throughout the world there are many transmissions such as those originating from broadcast, commercial telegraphy and marine stations, of which the geographical position is known, that can be used for navigational assistance by the taking of bearings from them with loop direction finders.

Airborne apparatus for this purpose has therefore been developed and is nowadays in general use both in civil and military aircraft.

In the United States of America direction finders are the principal means of navigation when flying in areas not covered by radio range tracks, and for this reason the Civil Aeronautics Authorities enforce the installation of them in all transport aircraft.

3.2. *Aircraft Loop Installations*

Early aircraft direction finders used a normal pattern of loop aerial, but with the increase of speeds it has become necessary to reduce the drag caused by them, and on modern aircraft the winding is enclosed in a "teardrop" streamlined housing. As there is a practical limit to the dimensions of this housing, the diameter of the loop winding has had to be reduced to between 6 in. and 8 in. This results in a low effective height which is of the order of 15 cm. at 400 kc/s. In order to develop the maximum voltage across the loop it is usually constructed either of large cross section copper wire (with wide spacing between turns) or of litz.

The all metal construction of aircraft and their cruciform shape cause loops installed upon them to exhibit quadrantal errors which can be very large unless the loops are correctly positioned. The siting of loops has therefore been investigated and the technique is now fully understood. Various methods have also been developed for the reduction of quadrantal errors, such as the placing near the loop windings of copper bars which, by correct positioning, can be made to cause the loop scale reading to agree with its mechanical rotation.

While it is impossible to install a loop in such a manner as to eliminate quadrantal errors entirely, it is possible, by experiment, to reduce them to reasonable values and to cause the errors to be symmetrical. In practice the best all round position is usually found to be on top of the aircraft at the point of the intersection of the wings and the fuselage. Installed in this position the loop is not screened under conditions of level flight and has fairly symmetrically placed reflecting surfaces in all four quadrants. On some aircraft it is impossible to place the loop on the top of the fuselage, and it is placed beneath it, invariably causing a large quadrantal error, brought about by the screening of the engines and wing tips when at certain bearings to the source of signal. Even when receiving signals on the lower M/F band it is surprising to note that quadrantal errors are introduced by the presence of small fixed aerials, and it is important to connect such aerials to their respective transmitters and receivers when tests are being made for quadrantal error. Various curves of the quadrantal errors found on aircraft have been published, and that shown by Keen[4], which has a maximum value of 18 degrees, can be considered to be typical of the loop installations of the larger types of high wing aeroplanes.

It has been found that the extent of quadrantal error of an aircraft loop installation can only be determined with accuracy by measurements made while the aircraft is flying; for this to be carried out thoroughly it is usually necessary to fly for about two hours. During the peak production of military aircraft such flying time for loop calibration was not permissible and as a result of extensive trials it was found that a carefully-made master calibration of quadrantal error for a given type of aircraft could be applied to all production models of a similar type without degrading their loop accuracy, the only precaution necessary being to ascertain that the mechanical installation was carefully carried out. It will be realised that once a loop calibration has been made, its subsequent accuracy depends upon the mechanical stability of its drive mechanism and upon the freedom from backlash of the flexible drives associated with its rotation.

Aircraft loops are, in general, only intended for reception on frequencies below 1·5 Mc/s; it is, therefore, usual to construct them with several turns of wire in order to develop the maximum voltage across them, the limit of the inductance being set by the resonant frequency of the loop and its self-capacity and that of the leads which connect it to its associated receiver. This resonant frequency should be slightly higher than the highest frequency to which the receiver is designed to tune, as inaccuracies are found to occur on bearings which are taken on signals corresponding to the resonant frequency of the loop and associated circuits.

In order to eliminate 180 deg. ambiguity of bearings taken on the loop, it is necessary to provide means of determining "sense." With the simple loop circuits of the type used on aircraft installations this can best be obtained by combining the loop signals with a vertical component obtained from an omnidirectional aerial. For this purpose the rigid or fixed aerial is generally used, or in some instances a 6 ft. to 8 ft. flexible whip aerial is employed. The trailing aerial can also be used, but only if the installation is calibrated in conjunction with it, sense indication being the reverse of that found with aerials mounted on top of the fuselage.

3.3. *Visual Presentation of Loop Nulls*

The taking of bearings on signals received in an aircraft requires a higher degree of skill than is necessary on a ship or shore station owing to two factors; the high speed of the aircraft which makes rapid operation and calculation essential for the accurate interpretation of results, and the high acoustic noise level prevailing in the aircraft, the latter factor causing the loop zeros to appear to be broad, due to masking effects upon the ear. These difficulties have been overcome largely by visual presentation of the loop zeros in place of aural indications and by the development of mechanical devices which, by linking the loop scale with the repeater compass scale, eliminate much of the calculation necessary for conversion of the readings obtained on the loop into useful information to the pilot. In the latest form of airborne direction finder, mechanical arrangements are made which enable a continuous indication of bearings to be presented visually on a scale in the pilot's cockpit.

The visual presentation of loop zeros has the advantage over the aural method of not only enabling more accurate bearings to be taken, but also of providing the pilot with an instrument which can be used for homing guidance to any source of transmission to which the receiver may be tuned. The instrument used for indication was, in its original form, a differential type which indicated centrally when the loop was in the null position and to the left or right when the loop was receiving a signal. It was thus possible for an aircraft to be homed to a transmitter by setting the loop at right angles to the aircraft's head and flying in such a manner as to keep the meter indicating centrally. This type of indication had the disadvantage of giving the same reading for both the "on course" and no signal conditions, and it was possible for the transmitter being homed upon to cease operating without it being apparent to the pilot.

In order to overcome this difficulty the twin pointer visual indicator was developed. In this instrument, "on course" indication is obtained by the intersection of two pointers on a centre line on the dial face, the off course condition being shown by an intersection of the pointers to the left or right of the centre line. When homing, the height of the intersection on the centre line varies with the signal strength and will therefore show immediately the transmission ceases.

3.4. *Loop Ancillary Equipment*

In order to interpret the readings obtained on the loop scale as a useful navigational aid, it is necessary for them to be converted into true bearings so as to determine the position of the transmission being received. To make this conversion it is necessary to apply quadrantal correction, ascertain the course being flown and apply compass deviation correction for the locality in which the aircraft is being flown. As these operations and the associated calculations take an appreciable time to carry out, errors can be introduced due to the speed of the aircraft. A device has therefore been developed which eliminates all calculations and gives a direct reading of the true bearing of the transmission being received. This is accomplished by making the loop position indicator traverse a compass repeater scale and by placing adjustable cams in the loop drive mechanism which crowd or spread the readings in accordance with the quadrantal error. In this device[5] indication that the loop is in the null position is obtained by rotating a central zero visual indicator with the loop drive. In order to obtain a correct reading it is therefore only necessary for the operator to rotate the loop until the central zero instrument pointer is in alignment with the loop scale pointer. When taking bearings under conditions of unstable flight this instrument is of value as the operator only needs to maintain the alignment of the loop scale and central zero meter pointer from which an average true bearing can be obtained rapidly. A device of the kind described, although eliminating calculations and reducing the time needed for taking bearings, still requires manual operation of the loop.

The most recent development has therefore been to include means for the automatic rotation of the loop and for remote indication of the scale readings in such parts of the aircraft as may be required.

In order to obtain these facilities the basic visual indicator circuit is employed, but the voltages normally used for operating the meter are arranged, in this instance, to energise relays which control a motor for rotation of the loop; thus, when the loop is at the position of zero signal pickup the relays are not energised and the motor is stopped. As the aircraft progresses on its flight its position with respect to the transmission being received will change, resulting in a voltage being induced in the loop aerial and hence through the receiver to the motor controlling relay; this will in turn close the motor circuit and cause the loop to be rotated until the position of zero signal is found and the motor is again stopped. Receiving equipment of this type in its latest form uses two loops and receivers so as to enable a continuous fix to be obtained.

3.5. *Airborne Direction Finding Receivers*

For aerodynamic reasons there is little choice in the aerial systems which may be used in conjunction with aircraft direction finding receivers and most circuits are designed to work on the switched cardioid principle.

In order to maintain the correct phase relationship between the vertical and loop aerials it is important to avoid feedback to them from amplifying stages and it is necessary to operate the R/F and frequency changer stages under exceptionally stable conditions. In a widely used airborne direction finder[6] the vertical aerial is isolated from the loop circuit by an aperiodic amplifier in order to avoid phase shift. Owing to the small pickup of the aircraft loop aerial it is necessary to design receivers with a sensitivity of at least 10 microvolts input for full-scale deflection of the visual meter, the gain being obtained largely in the I/F stages. As any direction finder will need to receive signals which lie in the band used for the I/F in broadcast receivers, a low I/F is employed. The adjacent channel selectivity of the receiver must be high, as interfering signals would cause the visual indicator to deflect and lead to errors; in current designs the output of the receiver is attenuated by about 40 db at 3 kc/s off resonance. The effect of images upon the accuracy of the visual indicator is also equally important and rejection of the order of 70 db is usual. The choice of the intermediate frequency is limited, but endeavours are made to select a value which does not lie on any known regular transmission frequency, as breakthrough would render the indications on the visual meter useless. To reduce this risk wavetraps are placed in the input and output circuits of the R/F stage and an overall attenuation of about 90 db is obtained.

In all present-day direction finding receivers the vertical aerial or loop and the output to the visual indicator is switched electronically. In the motor-driven loop types thyratrons have been used latterly in place of relays for controlling rotation, and it is likely that all of the switching of the purely D/F circuits will continue to be accomplished electronically, as less maintenance is required than for mechanical devices.

While the sharpest possible loop null indication is needed for taking bearings, it is undesirable for the visual indicator to show large deflections for small changes in the heading of the aircraft when the pilot is using it for homing, owing to the tendency of aircraft to yaw. A control over the meter deflection sensitivity is therefore required, and in a current design of airborne direction finder, is met by a two-position switch having "bearing" and "homing" positions[7], the method of widening the null position used being to increase the amount of vertical component combined with the loop aerial. Since the loop is fixed when used for homing it therefore becomes necessary for the pilot to make a comparatively large change of direction of the aircraft before the visual indicator shows a deviation from course.

3.6. *Loop Reception of H/F*

Loop reception of H/F signals in aircraft does not appear to have been very extensively investigated for direction finding purposes, although it is used to counter certain conditions of static interference. Except for short-range operation, it would appear that simple loop direction finding must always be useless owing to reflections from the ionosphere interfering with the ground wave. Experiments have been carried out successfully with spaced loops on aircraft for homing on H/F, but such arrangements have the inherent disadvantage of requiring aerials to be mounted on the wings and have no apparent advantages over less complicated methods. If the need for H/F direction finding in aircraft should arise it would appear that its solution lies in pulsed transmissions from ground stations and cathode ray presentation of the information in the aircraft.

3.7. *V.H.F. Airborne Direction Finders*

Due to the difficulties of siting directional aerials for the reception of V.H.F. signals on aircraft, very little progress has been made in the development of airborne V.H.F.D/F, although various homing devices have been put into service for operation on frequencies as high as 400 Mc/s. Among those which have been most widely used is the 50 Mc/s homing device, used as standard equipment on Luftwaffe aircraft. This apparatus provides the pilot with a visual homing indication on a small central zero meter and uses conventional D/F circuit technique. A small loop is employed, installed for zero signal pickup in the direction of flight. The useful range of this equipment is stated to be about 200 miles at 20,000 ft.

An ultra high frequency homing device was used during the war by the R.A.F. in special airborne landing operations which operated in the 350 Mc/s band. In this instance, owing to the very short wavelength, it was possible to use a directional aerial array which gave satisfactory results, although it was necessary in all cases to make extensive tests before deciding upon the aerial site on the fuselage for a given type of aircraft, owing to the screening and distortion of the polar diagram which was found to take place from the engines, tail units and even pitot head tubes.

3.8. *Radar Homing Devices*

Various secondary radar[8] homing devices were developed during the war, which may be found to have applications for civil air transport work owing to their possessing the valuable facility of providing the navigator of the aircraft with a continuous indication of the distance between the aircraft and the beacon being homed upon.

The most fully developed of these devices is the system known as Rebecca-Eureka[9], which uses an airborne transmitter and receiver and a transponder type beacon radiating from an omnidirectional aerial.

The distance measurement is obtained by transmitting pulse signals from the aircraft which, when received by the receiver associated with the beacon trigger a pulsed transmitter ; signals from the beacon are received in the aircraft and the time taken for the two-way transmission is measured. This is indicated on a cathode ray tube in the aircraft which has a time base calibrated in distance.

"On course" indication is obtained in a simple manner. Directional dipoles are mounted to either side of the forward part of the aircraft fuselage and are sited to produce cardioid polar diagrams to either side of the line of flight. A high-speed motor driven switch alternately connects each aerial to the receiver, enabling the amplitude of the signals from each aerial to be compared by observation of the size of the traces to either side of the time base which is arranged vertically on the observation tube.

For homing, the navigator therefore instructs the pilot to steer the aircraft until the traces to either side of the time base line are of equal amplitude.

The range of the Rebecca-Eureka system is governed by the pulse repetition frequency and the altitude of the aircraft owing to the utilisation of frequencies in the 200 Mc/s band. In practice this is about 90 miles at 5,000 ft.

4. Hyperbolic Navigational Air Systems

4.1. *The Gee Secondary Radar System*

During the war there arose the need for a more precise method of determining the position of an aircraft than could be obtained from such devices as airborne direction finders. This requirement fostered development in what are now known as hyperbolic navigational aids of which the British Gee system was the first to be put into service. This system, by emitting pulse signals from synchronised transmitters, lays down a space pattern of intersecting position lines from which a fix of the position of the aircraft can be determined.

The lattice is produced by transmitting from a master station a pulse signal which triggers subsidiary or slave transmitters with predetermined and controlled time delays. Pulses from the master and two or three slave stations are received in the aircraft and are displayed on a cathode ray tube along a crystal controlled time base, and it is therefore possible to measure accurately the difference in time of arrival of the pulses from the slave stations with relation to the pulse signal from the master station. By careful synchronisation of the ground stations the time difference of arrival of the pulse signals can be determined for any position within range of the transmitters and maps can be prepared upon which lines of constant time difference can be plotted. These points, following well-known geometrical laws, will produce a straight line from a point midway between the master and slave stations and will be of hyperbolic shape to either side of this line.

For the greatest accuracy of fixing it is desirable for the position lines to intersect at an angle of 90 deg. To achieve this result over the maximum area three slave stations are sited in a star pattern round the master station and are spaced from it by about 100 miles.

Because the system depends upon the time difference of arrival of pulsed signals, it is important to avoid ionosphere reflections and the system is operated on the V.H.F. band between 40 and 80 Mc/s. This entails limitations to the system owing to the quasioptical behaviour of frequencies of this order, it becoming necessary to site the transmitters on high ground for maximum range and in order to secure the greatest possible length of base line between the master and slave transmitters. The necessity for cathode ray tube presentation in the aircraft places a limitation on the types of aircraft in which the receiving equipment can be installed because this not only is of substantial weight (80 lb.) but also must be observed by a crew member.

The accuracy of the Gee system must depend primarily upon the stability of the space pattern and, secondly, upon the measurement in the receiver of the time differences of arrival of the pulse signals. In practice the timing of the transmitters is maintained to within about ·66 microseconds. The receiving apparatus is of conventional type and employs interchangeable tuning units for different chains of transmitters. The signals are received on a 6-ft. whip aerial mounted in the position on the aircraft found to give a substantially omnidirectional polar diagram.

4.2. *The Loran Secondary Radar System*

The Loran system is of American origin and was developed later than the Gee system for the purpose of providing navigational aid to ships and aircraft over sea. In principle it is similar to Gee and depends upon the difference in the time of arrival of pulse signals from synchronised transmitters. In order to obtain ranges over sea up to 1,000 miles, frequencies of the order of 1·7 Mc/s are used which are reflected from the first E and abnormal E layers of the ionosphere during certain times over the 24-hour period. There is, therefore, a difference in the range obtainable during night and day, and there exist areas between the locality where the ground wave ceases to be received and the sky wave has not returned to earth where no signals are received. In addition to these disadvantages there is a considerable difference between the ranges obtainable over sea and land, due to absorption of energy by soil. The accuracy of timing of transmitters in the Loran system is to within one microsecond. These factors indicate that the Loran system is not wholly suitable for use as an aeronautical navigation aid.

4.3. *The Decca Navigational System*

Consideration of the shortcomings of secondary radar navigational aids would indicate that the solution for a large area coverage system would be to employ low frequencies.

To date, however, it has not been found possible to radiate pulse signals successfully on low frequencies because with existing coil design technique the steep fronted pulse which is needed, cannot be transmitted owing to the decrement of the inductances which must be associated with long wave transmitters.

There is also the inherent difficulty of the bandwidth which would be occupied by pulsed transmissions on low frequencies.

Owing to these difficulties the Decca navigational system has been developed which, although using a hyperbolic space pattern, does not employ pulse technique, but is based upon the principle of the comparison of the phases of signals radiated by synchronised unmodulated transmitters. This arrangement permits the use of dial presentation of information to the pilot and dispenses with the need for carrying a cathode ray tube in the aircraft. It also has the most important feature of providing continuous position information without attention. Long waves are used for transmission, making the signals receivable at all altitudes up to the limit of the cover of the system.

The space pattern of the Decca system is set up by transmitting C.W. signals from a master and phase synchronised slave stations. These transmissions are on harmonically related frequencies and phase comparison takes place on frequencies common to the master and each slave station. The position of the aircraft is determined by counting and recording the number of in-phase lines flown through and indicating the difference of phase between them for precision readings. In the existing British Decca chain frequencies of 85 kc/s, 113·3 kc/s, 127·5 kc/s and 70·8 kc/s are used. This permits phase comparison between the 85 kc/s master station and the 113·3 kc/s slave station at 340 kc/s. As the waves travelling from the master to the slave and vice versa will be in opposite directions the spacing between the in-phase positions along the base line will be $\frac{\lambda}{2}$ of the comparison frequency which corresponds to 440 metres. In practical form the phase meter can be made to read to 3·6 deg. of phase change or one-hundredth part; the system is, therefore, capable of reading position line to within 4·4 metres along the base line. In order to eliminate the possibility of disturbance of the space pattern by sky wave interference to the phasing signals, the stations are usually separated by a distance of about 100 miles and are set in a similar pattern around the master stations for the same reason as in the Gee system. There will, therefore, be about 250 in phase lines or " lanes " between the master and each slave station. This will cause the meter, in flying across the base line, to read 250 full changes of phase. To overcome the ambiguity which this would cause, the indicators include a gear train which logs and displays the number of lanes flown through. Thus, all that the pilot of an aircraft is required to do when using the system is to set the logging pointers of the indicators to the numbers on the hyperbolic map corresponding to the fix of the aerodrome of departure, after which the meters will give continuous readings throughout the journey from which a fix can always be obtained.

In any hyperbolic navigational system it is of the utmost importance to maintain a rigidly stable spare pattern as the slightest disturbance of it will lead to errors of navigation in the aircraft using the system. In the Decca system this is achieved by a novel synchronisation arrangement. The master station 85 kc/s signal is picked up by a receiver at the slave station, and after amplification and multiplication is used as the drive signal for the magnifier stages. A receiver at the slave station compares the phases of the signal from the master and the signal radiated by the slave aerial and maintains them at a predetermined value which depends upon the exact geographical position of the master, slave and slave receiver aerials. Any shift of phase is reflected through a reactor valve across one of the amplifier stages of the slave transmitter; this arrangement is found to maintain the space pattern stability to within 1 deg. of phase difference, amounting to a few yards only in position line accuracy at the limit of range.

The transmitting plant used in the Decca system can be designed for higher efficiency than is normally obtainable because the transmissions are unkeyed and unmodulated. This permits of the use of an aerial inductance of a value of Q of over 3,000. The aerial is of special design having a very high capacity and is in the form of a radiating tower with an umbrella top for the purpose of radiating vertically polarised waves only. The radiated power with this design is about 900 watts for an input of 2kW to the output circuit at 127·5 kc/s.

The receiving apparatus for the Decca system consists of cascaded amplifiers for each frequency followed by discriminator circuits feeding into the phase meters. The amplifiers are designed for high phase stability and can set up before use from signals from a built-in oscillator, to zero phase difference. The receiver is of the fixed tune type and has no external controls so that it can be installed in any part of the aircraft. The weight of this apparatus is 30 lb. and it will operate satisfactorily from a small fixed aerial.

The range of the Decca system is governed by the distance at which the space pattern will be displaced by more than one lane by the effect of downcoming signals reflected from the ionosphere. With the frequencies used this occurs at a distance from the base line of about 470 miles, allowing for a reflection coefficient of ·3 and a terrain conductivity of 10^{-13} E.M.U.

During the daytime the reflected signals are of negligible amplitude and the range is in excess of 1,000 miles.

Owing to the reduction of night effect on very low frequencies it would appear to be possible to use the Decca principle for the production of a stable space pattern to cover the North Atlantic by the use of transmissions on frequencies lying between 15 and 20 kc/s.

5. Two-way Communication and Direction Finding between Ground Stations and Aircraft

5.1. *The European Method of Communication and Direction Finding*

In order to exercise control over aircraft operating on air routes it is necessary to be able to communicate with them at any stage of a flight so as to pass instructions and meteorological information. By the provision of ground direction finders all communications between air and ground can be used as a means determining the position of aircraft. This method forms the basis upon which aeronautical radio services in Europe and throughout the Empire air routes have been organised.

Originally all two-way combined communications and direction finding were carried out on the 333 kc/s band and a range of about 200 miles only was required of the aircraft transmitter, Adcock stations being used for direction finding.

The increases of range of non-stop flights have since made it necessary to arrange for the system to be used on H/F also, and this is now the main navigational aid method for transoceanic crossings. For this kind of service the method approaches the ideal as on all such aerial journeys periodical reports from aircraft are essential in the interests of safety, and it is thus possible for the position of an aircraft to be progressively plotted from its normal report messages.

On the shorter air routes the method is inefficient and does not compare favourably with radio range or hyperbolic systems, as it is incapable of providing guidance to more than one aircraft at a time which leads to delays under conditions of large volumes of traffic.

5.2. *Two-way Communication and Direction Finding between Ground Stations and Aircraft on Medium Frequencies*

The reason for the choice of M/F for European aeronautical services seems to have been primarily because a number of D/F stations and associated transmitters were in existence after the 1914-1918 war, which were designed for this work and which could readily be put into operation. The original choice of the M/F band was evidently made after consideration of its behaviour during daylight hours and its comparative freedom from the effects of ionosphere reflections and interference.

Regrettably, very little thought seems to have been given to the difficulties which transmission from aircraft on M/F would entail, an oversight which has ever since been a tax on the ingenuity of airborne radio equipment designers. These difficulties arise because there is a practical limit to the size of the aerials which can be installed on an aircraft and on account of the insulation problems which are encountered when designing small M/F transmission equipment of the dimensions needed for aircraft. In order to obtain the maximum radiation, the trailing aerial is used, but this is restricted in length to about 200 ft. for aerodynamic reasons and, therefore, cannot be a very efficient radiator.

5.3. *The Aircraft Trailing Aerial at M/F.*

As the aerial, even on the slowest aircraft, does not hang directly below, but trails behind, the effective height is low and measurements made by Fassbender[10] on 90 m.p.h. aircraft show this to be of the order of 8 metres. On faster aircraft in the 200 m.p.h. category, the angle of trail is even more acute and recent measurements[11] show this to be of the order of only 3 metres at 333 kc/s. While communication range from the faster aircraft would not be affected, since under these conditions the radiation is predominantly in the horizontal plane of polarisation, the effect on the range over which

D/F bearings can be taken becomes very much smaller and it is necessary to increase the power of the aircraft transmitter in order to give the range required.

Even by operating valves at the highest possible efficiency, an anode efficiency of not more than 70 per cent. to 80 per cent. is possible in an aircraft transmitter; there is also to be considered the inefficiency of the H.T. converters used to transform the 12 or 24 volt D.C. supply and also the current drawn for heaters. These factors place a limit of power to the output circuit of M/F transmitters of about 150 to 200 watts in practical designs. The actual power output to the aerial is, however, very much less than this, as much of it is absorbed in the loss resistances of the aerial inductance and in the aerial/earth system of the aircraft. The loss resistance of the aerial inductance is directly proportional to the capacitance of the aerial, the average value of capacitance of a trailing type being between 300 and 400 pF. Although at first sight the trailing aerial with its metallic counterpoise formed by the fuselage and wings of the aircraft might appear to have a low loss resistance, in practice the resistance is of a rather high value, usually of the order of 10-15 ohms. This is found to be due to the eddy current loss, and is insuperable owing to the trailing aerial being in very close proximity to the bottom of the fuselage at which point the largest current is concentrated. Another source of loss has been found to be in the tube through which the aerial wire is led out of the aircraft[12]. In addition to these losses there is a dead loss in the aerial wire, as it is necessary for it to be constructed of stranded steel wire in order to withstand strains met in flight. It will therefore be realised that the design of the M/F aircraft transmitter output inductance is difficult, and every effort must be made to obtain a very high Q $\frac{\omega L}{r}$ to compensate for the dead losses in the aerial system, at the same time making it of sufficiently small dimensions and weight for it to be suitable for airborne use.

The polar diagram of the trailing aerial has not been subjected to very complete investigation, although the theoretical and probable directional effects are discussed by Fassbender[13] at some length. If it is assumed that the trailing aerial is similar to an inverted L type, it would seem reasonable to suppose that it would have the polar diagram of this type of aerial. At very short ranges from the receiving station it has been noted that the signal strength from the aircraft transmitter is greater when the aircraft is approaching than when it is receding from the receiving aerial, which tends to substantiate this theory. Although the wave transmitted from the aircraft can be considered to be travelling along the surface of the ground for the greater part of the distance between the aircraft and the receiving station, it has been shown[14] that the signal strength is, to an extent, dependent on the altitude of the aircraft. For approximate range calculations, however, the usual inverse distance formula with Austin Cohen correction can be used.

Apart from the electrical shortcomings of the trailing aerial it has never been regarded favourably by aircraft designers owing to it constituting a source of drag, nor has it been received favourably by airline operators, as it is known to be a source of danger during thunderstorms and a collector of ice under certain meteorological conditions.

5.4. *The Aircraft Fixed Aerial at M/F*

The frequent objections raised to the installation of trailing aerials have caused aeronautical radio engineers to consider the replacement of them by fixed and very much smaller aerials; these are rigged between a short mast and the tail unit.

The capacity of the shorter aerial is lower than that of the trailing type and a larger inductance is needed to tune the transmitter to M/F, therefore larger dead losses occur. The fixed aerial is also of very low effective height which seldom exceeds a value of one metre, this entailing for equal D/F range to the trailing type, a power increase in the transmitter of about ten times. With present day technique this cannot be achieved in airborne transmitter design and a maximum power rating of about 200 watts only can be obtained, with consequent reduction in range. At the present moment aircraft designers are reluctantly still obliged to install trailing aerials in their aircraft for useful M/F D/F ranges of transmission and instead of assisting the radio designer in developing fixed aerial M/F transmission equipment by incorporating aerial masts of increased height, designers are tending to eliminate the aerial mast altogether and are arranging for the aerials to be rigged direct from a deck insulator to the tail unit; such an aerial installation as this has, of course, negligible effective height.

5.5. *The Future of M/F for Aircraft Uses*

The provision of M/F transmission facilities from airaraft has always been regarded in the past as being essential on air routes which involve ocean crossings, owing to the ease with which communication can be established with ships in the event of an emergency. The reliability of communications on H/F nowadays would appear, however, to offer possibilities of more efficient emergency procedures, since upon receiving distress signals from aircraft, shore control stations could put into operation powerful transmitters which would be more likely to actuate the auto alarms on ships than the comparatively weak signals radiated on M/F by an aircraft. Consideration of this factor may result in the abandonment of medium frequency transmission from aircraft altogether.

If the use of these frequencies is discontinued it will relieve designers of radio equipment for aircraft of one of their major difficulties. It will also find favour with aircraft designers as it will avoid the necessity for the complicated trailing aerial arrangements such as would be required on pressurised types of aircraft.

5.6. *Two-way Communication and Direction Finding Between Ground Stations and Aircraft on H/F.*

The advantages of using H/F for aircraft communications were realised soon after the long distance properties of these frequencies were first discovered.

Their application to aeronautic uses was, however, delayed until about 1928 owing to the imperfections of the methods used for the suppression of ignition interference from aero engines, a difficulty which made reception of all but the strongest signals impossible. At about this time the whole technique of ignition interference suppression was improved by the introduction of engine screening harness, and it became possible to consider H/F reception in aircraft as being comparable to that obtained on M/F.

Based on theoretical considerations of propagation and with the knowledge of the ionosphere that existed at that time, independent investigators[15, 16] sought to find optimum frequencies upon which reliable communication could take place over fairly large distances between the ground and aircraft, it being realised that the ground wave from a transmitter would have a longer range to an aircraft at a normal operational altitude than it would have to another ground station. Similarly, it was supposed that the direct wave from the aircraft would have a correspondingly larger range of coverage. It was then thought that critical frequencies could be found which would extend the range of communication by the effect of the downcoming ionosphere wave, as this would provide a signal at the point at which that of the direct wave had ceased. As the result of investigations of a thorough nature in the United States and in Germany it was found possible to put these theories into practice and by the use of certain frequencies, ranges of constant contact between an aircraft and the ground of up to 600 miles were achieved consistently, often with very low power of transmission. Since these experiments were carried out a vast amount of work has been done in the investigation of the behaviour of H/F transmission and D/F with aircraft, and the whole technique is very fully understood.

5.7. *The Aircraft Aerial at H/F*

To an extent the problems of aerial systems on aircraft at H/F are similar to those met when using M/F, although even in its worst case the aircraft aerial is always a better radiator on H/F.

For some years the trailing aerial was used for H/F transmission and reception, it being reeled out to a length corresponding to a quarter-wave or half-wave of the frequency in use. While there is no doubt that this represents the most efficient radiator for an aircraft transmitter, the method has gone into disfavour nowadays with the requirement of operating on a number of widely differing frequencies, and present-day communication is all carried out on the fixed fore and aft type of aerial.

The characteristics of the fixed aerials of the average transport types of aircraft are now known, and the methods of determining them and typical resistance and reactance data have been shown by Kiernan[17] and Haller[18, 19]. In the usual aerial the loss resistance which appears at M/F is of a lower value on the band 2-20 Mc/s, and can for all practical purposes be considered to be negligible.

Over this band of frequencies, however, resonant and anti-resonant conditions are met and a very wide range of reactances is encountered, making it a requirement for transmitters to be capable of being matched to the aerial at certain frequencies as a very low impedance, while at other frequencies it must be capable of matching to very high impedances.

Examination of the characteristic curves of aircraft aerials on the band lying between 2 and 20 Mc/s points to the relationship between the physical length and the resonant condition as being quite normal, and it is thus safe to assume that an aerial of a given length will resonate at a frequency which is closely related to its physical size; therefore the aerials are, at some frequencies, a quarter wavelength long, while at other frequencies they are a multiple or submultiple of the wavelength. They are, in addition, rigged in very close proximity to the fuselage and tail units, and consequently it has been found, as would be expected, that the polar diagrams for different frequencies vary considerably.

The determination of the polar diagrams of aircraft is, of course, impossible with an aircraft on the ground owing to the reflection effects of objects in close proximity to the aerial. Even under flight conditions it is difficult to determine, as it will be affected by the height, direction of flight and altitude of the aircraft. The technique is therefore now to use scale models with the frequency of transmission from the model increased to appropriate value, this method having been proved to give accurate results.

To measure the polar diagram the model is mounted on a wooden tower and can be oriented to any position of flight by remote control. The introduction of this technique is of inestimable value when new aircraft are being designed and is now, according to a published report[20], in general use in the United States. A very interesting effect was recently discovered as the result of tests of this nature, that of the modification of the polar diagram on certain frequencies by the presence of dew and rain on the fuselage and wings of the aircraft.

On modern aircraft it is often necessary to erect two fixed aerials in order to enable simultaneous transmission and reception to take place at different frequencies. Under these conditions, being able to determine the effect o the one aerial upon the other is valuable and the scale model technique may be used to advantage.

A form of aerial which has made its appearance during the war is the whip type consisting of a vertical flexible rod about 6 ft. to 8 ft. long. This aerial is useful for such purposes as short range transmission, and has the advantage over other types of being mechanically somewhat unstable while in flight which prevents it from becoming coated with ice, thereby eliminating the danger of being broken off. On the H/F band from 3 Mc/s upwards this aerial has a high impedance, low capacity and a low loss resistance; it can be considered to be a reasonably good radiator on the higher frequencies and to have, if correctly sited, a symmetrical polar diagram.

The most recent development of aircraft aerials for H/F working is to eliminate the wire entirely and to use the wings of the aircraft as a shunt fed aerial. The basic requirement for radiation is for the total span of the wings to be at least 40 per cent. of the working wavelength, a readily fulfilled requirement on most twin-engined aircraft with the frequencies in general use. With this type of radiator the wing is fed by a wire from the transmitter to a point on it found by experiment to be that which gives optimum results.

The characteristics of the wing radiator are similar to those of a normal fixed aerial, the resistance over the H/F band being of the same order. The reactance over the useful transmission band of a normal sized aircraft is, however, inductive only. The range of transmission of such an arrangement is found to compare favourably with that of a fixed aerial, according to Haller[21], and it would appear that further investigation might be made with advantage.

The disadvantage of the shunt fed wing from the aerodynamic viewpoint is that the feeder wire must be led from the fuselage across the line of flight to the point of attachment to the wing, in which position it is liable to collect ice.

There is now under review the project of building aerials into the tail units of the larger aircraft, such tail units being constructed from insulating material. Should this project materialise the aerials will have the advantage of being well sited and should have symmetrical polar diagrams and also be impervious to ice accretion.

The plane of polarisation of transmission from aircraft fixed aerials must vary over the H/F band from vertical, at the lower frequencies, to horizontal at the higher frequencies; that of the whip type must be almost entirely in the vertical plane of polarisation.

No information is obtainable relating to the type of polarisation which is radiated from the shunt fed wing, but it would appear that this is almost all in the horizontal plane.

The fixed aircraft aerial when working on H/F radiates waves in different planes of polarisation for different frequencies and it will be seen that both D/F and communication systems for aircraft require very great care in planning, as in the choice of frequencies this factor has to be considered in addition to the normal factors of ionosphere reflection and resultant range of transmission. If, for instance, a range of communication on a certain part of an air route is required to be 800 miles and it is found that a frequency must be used for this coverage which is radiated in a predominantly horizontal plane from the aircraft using the route, consideration must be given to the erection of a D/F receiving station which will respond to waves of this type.

Up to the present time extensive study has not been given to this aspect of H/F direction finding, but with the increasing distances over which aircraft can now fly without refuelling there seems no doubt that it will eventually be necessary.

5.8. *H/F Direction Finding Methods*

Under present-day conditions and ranges of flight the majority of H/F direction finding from aircraft signals is carried out on the 3 to 9 Mc/s band, Adcock D/F being in general use at the ground stations. On these frequencies the radiation from the aerial of a transport type aircraft is predominantly in the vertical plane of polarisation. With such frequencies ranges of up to about 1,000 miles are possible as evidenced by Hodgson's[22] illustration of the D/F position plots obtained on an Atlantic flight in 1937. Since the compilation of these data improvements have been made in the technique of cathode ray direction finders and H/F D/F has become a more exact science. Pulse technique has also been introduced which has the fundamental advantage of indicating the signal which has taken the shortest path to the D/F station. It is interesting to note that pulse transmission from aircraft was generally adopted by the Luftwaffe to obtain a high accuracy of bearings observed, as is shown by Edwards[23].

A development of importance to direction finding from aircraft signals is the spaced loop direction finder which has the property, unlike the Adcock type, of being capable of obtaining an accurate bearing on signal of which the wave is either vertically or horizontally polarised. In this lesser known direction finder two loops are arranged so that they are capable of being rotated together and when receiving a vertically polarised wave show four nulls, two from the position which makes the loop pickup zero and two from the position which make the phase difference due to spacing zero. When receiving a wave from a downcoming path from the ionosphere at a sharp angle, such as would occur on a first skip at certain frequencies, only two nulls appear which are due to the opposition of phase of the voltages induced in the loops by the downcoming wave.

Owing to the aerial arrangements of modern aircraft and the different planes of polarisation of waves radiated from them, it seems probable that the majority of development must be carried out on spaced loop ground stations designed to be capable of obtaining bearings from any H/F signals transmitted from aircraft.

5.9. *H/F Telephony Systems for Aeronautical Communications*

Although stress has been laid on the use of H/F for the "European method" of direction finding and guidance of aircraft, the uses to which it has been put in the United States for radio telephonic communication should not be overlooked. In this country, while the main channel of guidance is from the radio range it still remains essential to have communication to and from aircraft in order to be able to give landing instructions and to have some measure of control in the vicinity of crowded airports. To obtain this facility a system of H/F radio telephony has been established and has reached a high state of efficiency. It will be realised that the development of telephony in the United States airways is likely to remain a unique feature with them as in no other part of the world would such an arrangement be possible owing to linguistic difficulties. While the general technical problems are identical with those encountered on the C.W. transmission systems, the ranges to be covered are considerably less and do not usually exceed 100 miles. In order to obtain this range consistently and at widely varying altitudes of flight it was necessary to select a frequency which fulfilled this requirement.

After a considerable amount of experimental work had been carried out it was not found possible to use a single frequency band for both day and night communication, and the system was standardised to operate on the 6 Mc/s band during the daylight hours and the 3 Mc/s band during the hours of darkness. Under these conditions the communication over the required range is accomplished by working on the direct wave for part of the distance after which the downcoming wave from the first skip is used, the practical effect being for the signals to reach a point where they weaken, at the limit of range of the direct wave, after which they increase in strength when the aircraft enters the zone where the strength of the reflected wave is at its maximum. The whole basis of the American system of aircraft guidance being to reduce the weight of the aircraft radio equipment, a wireless operator is not carried and designs are centred around remotely controlled receivers and transmitters. In the most up-to-date airborne apparatus L/C oscillator circuits are avoided and crystals are used for the control of master oscillators and also for the control of the local oscillators of the receivers. The aerial tuning circuits are all of the preset type and remote switching used to adjust taps on the tuning inductances of the transmitters and to place into circuit the necessary capacitance in the transmitter and receiver tuning circuits. This is invariably accomplished by the manipulation of a single switch which may be arranged to select as many as ten separate frequencies. The radio apparatus being for pilot operation, the ideal of the designers is to provide a facility which resembles as nearly as possible a normal telephone, and circuits must be of extreme stability and reliability to achieve this.

Between the local and distant ranges of communication it will be realised that great differences in signal strength applied to the receiver input occur. It therefore becomes necessary to provide an exceptionally good A.V.C. circuit, as following the telephone ideal, it is undesirable for the pilot to have to adjust a gain control at different stages of the flight. Supplementary A.V.C. circuits are therefore included in the more advanced types of receiver which limit the signal in the telephones to a comfortable level and which are usually associated with a quiescent type of A.V.C. to avoid an excessive background noise during the condition of maximum receiver sensitivity.

5.10. *Two-way Communication and Direction Finding between Ground Stations and Aircraft on V.H.F.*

The recent development of aircraft communication and D/F operating on V.H.F. is of very great value as it has provided a system which is almost entirely free from atmospheric disturbances, has a definite relationship between altitude and range, enabling common channels to be used and provides a large number of channels in a small band and which is particularly acceptable to aircraft designers owing to the simplicity and smallness of the aerials necessary on the aircraft. By virtue of the very short wavelength it also simplifies the installation of the complementary ground equipment, both for transmission and for D/F. Economically the use of V.H.F. is advantageous as the waves travel through space rather than over the ground and their attenuation with distance is not large, thus enabling small orders of power to be used both in the aircraft and ground transmitters.

The main application to which V.H.F. has been put for aircraft use is for radio telephony, and it was used universally by the R.A.F. during the war for the control of fighter aircraft.

It would seem that its application to civilian airways must be for all telephonic communication in parts of the world where atmospheric interference prevents H/F and M/F from being consistently used.

5.11. *Aircraft Aerials at V.H.F.*

Unlike the aerials of aircraft on H/F and M/F those used on V.H.F. can be made to be of high efficiency over the whole band. They can be fitted without causing serious interference to the airflow, it being possible to instal a full quarter wave aerial for 100 Mc/s which has a length of about 2 ft. only. There are, however, certain phenomena encountered in the installation of aerials for these frequencies in aircraft which do not occur in any other circumstances, the most marked one being the effect of the propellers upon signals received and transmitted. The effect is for signals being received from a direction which passes through the arc of a revolving propeller to be modulated at a frequency which is the product of the number of blades and the number of revolutions of the propeller. Similarly, at certain distances from an aircraft, its transmissions will be found to have this modulation superimposed upon them. The effect of this propeller modulation is particularly bad when an oscillating circuit is connected directly to the aerial, and precludes the use of self-driven transmitters for aircraft communications.

This fundamental difficulty can best be overcome by placing the aerial as far from the propellers as conditions permit, but this may be at the expense of a symmetrical polar diagram and is not acceptable in all circumstances. In many instances the effect can be almost entirely eliminated by placing the aerials at a position which is an odd number of quarter wavelengths from the propellers.

On most aircraft it is difficult to site an aerial to give freedom from the propeller modulation and at the same time to obtain an omnidirectional polar diagram, the latter difficulty being due to the presence of the metallic reflecting surfaces such as the wings, fuselage and tail units. On most aircraft the best all-round position seems to be when the aerial is mounted on top of the fuselage and usually at a short distance behind the trailing edge of the main plane. Aerials mounted on the bottom of the fuselage appear to be extensively screened by the engine nacelles and are found to give non-symmetrical polar diagrams. It is not known whether the scale model technique has been applied to V.H.F., but there would seem to be no difficulty in its application. A great many experiments have been carried out in an endeavour to improve the symmetry of the polar diagrams of V.H.F. aerials on aircraft and in some cases several aerials have been installed in various parts of the fuselage and connected to a common receiver in an attempt to overcome screening effects. Owing to the relatively small size of the average aircraft with relation to wavelengths of the V.H.F. band, these experiments have not produced good results owing to phase differences between the aerials and the resulting overall polar diagrams are poor.

The major part of V.H.F. technique has been developed round the use of waves in the vertical plan of polarisation, the reason being that the installation of aerials of vertical type is simpler on aircraft, also from considerations of the polar diagrams which would result from practical installations of horizontally polarised aerials.

5.12. *The Range of V.H.F. Communications between Air and Ground*

Experience has shown that ranges of, at least, the optical path distance can be expected consistently on a frequency of 100 Mc/s indicating that distances of the order of several hundred miles can be obtained in communication with aircraft flying at substratospheric levels. The fact that the aircraft must fly at a specified height to be within the area at which reception of a given transmitter is possible is of very great importance for aeronautical use, permitting, as has already been stated, an economy of channels and it becomes possible by suitable positioning of ground stations to use common transmission channels without risk of interference. The investigation of Kramar and Hahnemann[24] has provided sufficient data upon the relationship between altitude and range for air maps of the future to be annotated with the altitude to be flown to communicate with given ground stations on V.H.F., although more recent data yet to be published may provide more accurate information. The great value of the zonal effect due to the range/altitude relationship has been recognised in the United States as a solution to many of the difficulties experienced with the H/F system used at present, and according to recently published information[25] steps are being taken to change the whole telephony system from H/F to V.H.F.

5.13. *Ignition Interference to Reception of V.H.F. Signals*

While the V.H.F. band is almost entirely free from interference due to atmospheric disturbances, it is very susceptible to ignition interference from poorly screened aero engines and from inefficient bonding of metal parts on an aircraft. In some aircraft which are free from ignition interference at H/F, reception at V.H.F. is found to be impossible as the ignition noise is of such magnitude that it masks signals completely. Similarly, a poorly bonded or loose engine cowling has been found to cause considerable interference to reception on very short wavelengths. This factor may be found to impede the use of V.H.F. on the smaller aircraft, which, due to considerations of cost, are less efficiently screened and bonded.

5.14. *Airborne V.H.F. Equipment*

The airborne equipment used for V.H.F. communication during the war was of conventional design and used crystal control for the drive valves followed by harmonic generators and crystal control for local oscillators in receivers. The equipments were designed for about six predetermined frequencies and the harmonic generators and output circuits were tuned by motor-driven variable condensers. Frequency selection was by press-button control. Efficient volume control and limiter circuits were included which eliminated the necessity for manual volume controls. Practical results showed that a receiver sensitivity of 10 microvolts for 50 mw. output met all operational needs, while an 80 per cent modulated 5 watt signal gave adequate range from the aircraft. In order to allow for temperature variations with changes of altitude and climate which affected the fundamental frequency of the crystals, a bandwidth per channel of 180 kc/s was adopted as standard.

Although the efficiency and performance of these equipments is completely satisfactory it is evident that they cannot be constructed without intricate mechanical switching devices for frequency changing, which results in the equipment being heavy, and their total weight is about 60 lb. The latest technique is, therefore, to eliminate the adjustable tuning of the harmonic amplifiers and output circuits and to utilise broadband amplifiers both in receivers and transmitters, permitting of a change of crystal only for frequency selection.

5.15. *V.H.F. Direction Finding Methods*

The simplicity of the aerial arrangements required to obtain a quite useful bearing from aircraft signals on V.H.F. is remarkable, it being possible to determine the direction of the origin of a signal with a simple Yagi aerial and an elementary type of receiver. By the application of Adcock technique, bearings of a very high degree of accuracy can be obtained which are, of course, free from ionosphere reflection errors. It is, however, of importance to site V.H.F. D/F stations in positions which are clear of any obstructions which might cause reflections such as those from buildings, trees and wire fences, which are strong at V.H.F. and can cause errors of large magnitude.

5.16. *Two-way Communication and Direction Finding Between Ground Stations and Aircraft on U.H.F.*

U.H.F. communication between ground and air and position finding appears to have been a somewhat neglected field of development, principally, it is assumed, on account of the value of this band of frequencies for Radar and for instrument landing devices.

The work which has been carried out rather indicates that U.H.F. equipment on aircraft involves great difficulties in the siting of aerials having an omnidirectional polar diagram. In addition, some of the propeller modulation problems become exaggerated and difficult to control. There is also the problem of frequency stability in the aircraft transmitters and receivers which is not easy to obtain using conventional circuits ; if crystal technique is used it becomes necessary to multiply existing crystal frequencies by over forty times for use on U.H.F. which must increase the size of the airborne equipment substantially. It is therefore thought that except for specialised requirements of a military nature, such as communication between aircraft in flight and for collision prevention devices in civilian aircraft, this band of frequencies will not be pressed into service until ether congestion becomes so acute that communication is forced to take place on wavelengths which will accommodate more channels.

6. Landing Aids

6.1. *The Difficulties of Landing Aircraft under Conditions of Reduced Visibility*

If air transport is to compete seriously with other forms of conveyance of goods and passengers it must be capable of adhering to strict time tables. This means that flights and landings must be possible under all weather conditions.

Such a requirement cannot be met by the use of flying instruments alone, although they are adequate for navigation when used in conjunction with radio aid during the stages of the flight in which the aircraft is operating at normal altitude and cruising speed. The reason for this is that the discrimination of both the compass and the altimeter is not of sufficient fineness to provide the information to the pilot which he requires during a landing. Under conditions of normal visibility this does not present any difficulty to a pilot of an aircraft as he is able to make visual observations of the ground to enable him to guide the aircraft to the runway with accuracy, and relies upon his judgment gained from experience, for the determination of his height during the final stages of the landing. If, however, conditions of low visibility or thick fog are encountered at the airport, the pilot, having no opportunity of taking ground observations, cannot rely on the aneroid type altimeter nor upon the compass to steer the aircraft in to a safe landing, and may be obliged to fly to another airport many miles distant before visibility is good enough for a landing to be made.

Owing to the shortcomings of flight instruments during landings in poor visibility, radio aids have been investigated since they can be of such form as to provide an accurate approach path with " milestones " along it which indicate the position where the landing should be commenced and can also provide a guiding track at an angle to the surface of the ground which can be of the required inclination for safe descent.

6.2. *The Lorenz Blind Approach System*

The first apparatus made available commercially, that due to the German Lorenz A.G., appeared in about 1933, and by the use of directional transmitting aerials radiating on a frequency of 33 Mc/s, provided an equisignal course for guidance to the runway which was radiated in such a manner as to lie at a small angle to the surface of the ground, the intention being to provide, on a single frequency, both course guidance and a glide path. The "milestones" or markers were provided by two transmitters operating on the 30 Mc/s band situated at the point at which the descent should be commenced and at the boundary of the aerodrome. In this system visual presentation of all the information required by the pilot was given from a single instrument in which was placed an indicator for course guidance, an indicator for glide path guidance and two lights which were switched on from signals received from the markers. While no special techinque was needed in the course guidance or marker transmitters as they were modelled on radio range practice, the arrangement for obtaining glide path guidance deserves mention. The method was, in this instance, to fly the aircraft into the equisignal track and to maintain a predetermined altitude until the first marker signal was received. The pilot was then required to keep the aircraft in the equisignal zone and, at the same time, manœuvre it until the glide path indicator gave a certain reading which had to be maintained throughout the descent, this reading corresponding to the signal strength at the lower edge of the inclined lobe radiated from the transmitter aerials. Although this operation may appear to be rather hazardous it must be remembered that in addition to the information provided by the indicators, the pilot also used his experience of the aircraft's landing characteristics and was aware of its approximate descent rate with a given set of control adjustments and was therefore likely to make a reasonably good approach.

From this brief description of the principles involved in using the Lorenz system it might appear that it provides the pilot with all the additional aid which he requires during a landing operation under conditions of low visibility or even fog. There are, however, certain difficulties which prevent it from doing so, foremost among them being the discrimination of the glide path indicator which could not, in its practical form, be of such accuracy or fineness as to indicate very small signal strength changes which during the final stages of the descent are convertible into changes in terrain clearance. It was therefore possible, if attempting a truly blind landing, for the pilot to interpret the glide path indication as meaning that the aircraft was within only a few feet of the ground when, in fact, it was still sufficiently high for a stall to cause an accident. Similarly the pilot could also be led to believe from the glide path indicator that the aircraft was still above ground and touch down at too steep an angle, or even before the runway had been reached.

Associated with this defect was also the effect of alteration of the glide path angle of inclination which was found to occur when the surface of the ground over which the transmitted wave passed in its early stages was covered with rain or snow, alterations of as much as 3 deg. not being uncommon.

In some cases the siting of the transmitter presented difficulties due to the reflections from local obstacles causing interfering lobes, the practical effect of which was to split the guidance beams and to give false courses. Kramar and Hahnemann describe the difficulties experienced in the siting of the Lorenz aerials at the airports of Paris and Munich, due to multiple courses caused by the presence of gasometers and hangars near to the airfields.[26]

In spite of the defects of the Lorenz landing aid it should be mentioned that at the outbreak of the war forty installations were in operation at airports in Europe and that some were used in England. It should be noted, however, that there is evidence that British airlines did not base their time-tables upon the certainty of being able to land at a given airport under any conditions of visibility, although most of their aircraft carried suitable receiving equipment.

6.3. *Recent Landing Aid Developments.*

The improvements which have been made to landing aids since the introduction of the Lorenz system have been effected in order to render the approach courses more stable and to provide a more satisfactory glide path.

The advances in V.H.F. technique have made it possible to fulfil the requirements of approach courses without difficulty, but the method of obtaining glide path guidance from constant signal strength indications has been discarded in favour of an equisignal path in the vertical plane. This has the advantage of being stable and also of laying a path which permits of a linear rate of descent. The latter is a requirement of modern aircraft which must be flown under power until the wheels touch the ground; with the Lorenz system it will be realised that the glide path is of parabolic shape and does not permit this form of landing.

The improved landing aid system requires a total of four transmitters, consisting of two markers radiating on 75 Mc/s, a course guidance or approach transmitter operating on the 100 Mc/s band and a glide path transmitter consisting of an R/F source, operating at 330 Mc/s, which is fed to the aerials producing the equisignal path. The separate glide path transmitter makes it possible to site the aerials to the side of the commencement of the landing runway and to guide the aircraft to a touch down point which gives it the full length of the runway in which to come to a standstill. The method of producing the overlapping signals is to place the two radiating systems above each other, but as this requires a mast which can cause an obstruction to an aircraft which is slightly off the approach course, experiments are being carried out with glide path transmitters operating on 700 Mc/s, with which small parabolic reflectors can be used for the production of the equisignal track.[27] (See 10—References.)

The required accuracy of guidance of landing aids is for the approach course to be laid out to within an accuracy of ½ deg. relative to the far end of the runway and for the glide path to be within ¼ deg. of a predetermined angle, the inclination of which should be between 2½ deg. and 3 deg. to the horizontal. This angle permits of a rate of descent of 460 ft. per minute at 120 m.p.h.[28] (See 10—References.)

6.4. *Equipment and Installation Requirements of Landing Aids*

The design of airborne equipment for the reception of signals from landing aid transmitters does not have as a requirement a need for high sensitivity as the ranges of operation are not great. An exceptionally high degree of stability and reliability is, however, essential because a failure of a unit or abnormal operation might not become apparent in time to avoid the disastrous results of false guidance indications while attempting a landing in conditions of reduced visibility.

The installation of aerials on an aircraft for the reception of landing aid signals is not difficult to accomplish satisfactorily, because an omnidirectional polar diagram is not needed, it being sufficient to provide an unobstructed signal path in the direction of flight of the aircraft. For this reason it is general practice to instal them in the forward part of the aircraft. The marker aerials, only being needed to receive from beneath the aircraft, are installed on the bottom of the fuselage and consist of dipoles, stood off from the metal fuselage by small insulators, and no attempt is made to obtain a high performance from them.

6.5. *Future Development of Landing Aid Devices*

While it would seem that the V.H.F. landing aid system must have considerable merit by virtue of its widespread use, it must be realised that what is required by pilots is a device which enables them to have displayed before them in the cockpit of the aircraft a picture of what lies in the path of the descent to a sufficient distance ahead for them to manœuvre to a safe landing. This does not present insuperable difficulties if radar technique is used, and it is logical to suppose that it is in this direction that future development will be concentrated.

7. Flight Aids

7.1. *The Shortcomings of Flight Instruments*

The normal means of indicating the altitude of an aircraft is to show the height above sea level through the medium of a simple aneroid type instrument. Attention has already been drawn to the shortcomings of this type of indicator when wishing to read small changes in altitude, it being dependent upon atmospheric pressure for its operation. It should also be pointed out that it is affected to an extent by temperature variations. With the requirements of modern flying these defects cause it to be inadequate for the many different manœuvres which a pilot is called upon to perform. The most simple example of this inadequacy may be taken as in the circumstances when a pilot wishes to descend through cloud which is obscuring the ground, and does not know his exact whereabouts. In this case the cloud may be very near the ground and unless provided with an indicator of terrain clearance or absolute altitude, the pilot may, in the process of attempting to break cloud fly the aircraft into the ground.

7.2. *Radio Terrain Clearance Indicators*

The shortcomings of the aneroid instrument have therefore made it necessary to provide terrain clearance indicating devices which can only be realised through the medium of radio.

To achieve a practical design, use has been made of the reflecting properties of very short waves, these being transmitted from the aircraft and reflected back from the ground immediately below the aircraft. Although a very simple arrangement can be made to operate by the use of pulses and cathode ray presentation, there are practical difficulties which prevent the installation of even a small tube on the pilot's instrument panel, and a system which enables the indicator to be of standard flying instrument size has, therefore, been developed. In the best known of these devices, the basic principle which seems first to have been proved and made known by Matsuo[29], the apparatus consists of an U.H.F. transmitter and aerial on the aircraft which is frequency modulated. Associated with this is a receiver, the aerial of which is placed in such a position that it permits direct reception of the radiation from the transmitter and also of reception of waves which have been reflected from the ground and returned to the aircraft. Since the transmitter is frequency modulated there will always be a frequency difference between the wave which is received directly from the transmitter and the wave which is received after reflection from the ground immediately below the aircraft, this frequency difference being directly proportional to the height of the aircraft above the ground. Thus, the altitude indicator must take the form of a frequency indicator in order to provide the necessary information. In the early models of terrain clearance indicator a moving iron voltmeter was used for this purpose in which the discrimination was of a high order at small ground clearance, and of a low order when the clearance was of a safe value, by virtue of the frequency discrimination of this type of instrument. This was later replaced by a more accurate indicating instrument in which an electronic frequency counter circuit was employed, such an arrangement forming the basis of apparatus now used. This improvement is, however, not obtained without an increase in complication in the equipment, as it entails the use of a stabilised voltage supply and additional valves associated with the counter circuit. The all-up weight of such a device is about 30 lb., but as the accuracy is of the order of 10 per cent. at all heights, the additional weight is well justified. In the instrument, which is almost universally used for indication, the scale covers 270 deg. in order to obtain the maximum discrimination. To increase further the accuracy of the instrument, the circuit includes a range switch which enables the full scale reading to be divided or multiplied as required.

It will be appreciated that the need for a terrain clearance indicator is only great when at comparatively low heights above the ground, such as the condition already described, or when making an approach to land. A lesser known type of indicator which does not indicate very great ground clearances should, therefore, also be mentioned, the capacity type. In this device the height above the ground is measured by determination of the very small capacity which exists between an aircraft and the ground below. In its practical form the apparatus comprises two plates mounted on insulators below the aircraft which have a small capacity between them and the fuselage, and also between the two plates remote from the fuselage. There also exists a capacity between each plate and the ground which can be considered as a variable quantity with changes of height and which can be considered as a capacity in parallel with the fixed capacity between the two plates below the aircraft. While this capacity is of small magnitude, and must also vary by an infinitesimal amount with height changes, it has nevertheless been found possible to measure it with accuracy, and without apparatus which is too delicate for inclusion in an aircraft, practical instruments having been produced and used with success.

Another use for the terrain clearance indicator which has been suggested is to employ it as a rough position indicator when flying along a radio range. In this application it is used in conjunction with the aneroid altimeter, and by flying at a constant height shown on the aneroid instrument, the undulations of the ground below can be followed with reference to contour maps, thereby indicating the position along the range.

7.3. *Radio Collision Warning Devices*

Although not at present available in commercially made form, a requirement of aviation is a simple device for the prevention of collision with other aircraft. This is a constant danger when flying along radio ranges, under which conditions many aircraft are concentrated within narrow limits of space in the sky. In the United States the procedure adopted to avoid this is for aircraft flying on ranges in different directions to operate at different altitudes ; owing to the conditions of weather and ice formation levels, this is obviously not an infallible procedure. There is also the additional danger of a faster aircraft overtaking and colliding with slower aircraft travelling in the same direction.

The best method of providing anti-collision warning is still undecided. If the convention is adopted that the smaller types of aircraft must give way to the larger types by virtue of their more rapid manœuvrability, it means that small apparatus must be devised ; owing to the payload of the smaller aircraft being restricted it is not possible to carry heavy apparatus. While the obvious solution to the problem seems to lie in radar, it must be borne in mind that cathode ray presentation will be involved, and that the associated apparatus is of appreciable weight ; in its present state of development this seems to preclude the use of radar, although it will, without doubt, be used ultimately.

A solution to the problem might be to adopt the principles described in an American patent in which aircraft are equipped with transmitters of which the frequency is determined by the altitude of the aircraft through a mechanical control of tuned circuits by suitable gearing to the altimeter. This device also arranges for the receiver tuning to vary with altitude, and therefore any aircraft travelling between certain limits of height will transmit warnings and will be capable of receiving them. While this would in all probability give a degree of collision warning while flying radio ranges, it would not be capable of giving sufficient warning when off range courses. The inventor has therefore included a further facility of indicating the direction in azimuth of the transmitting aircraft which emits a distinctive modulation for each course by an arrangement of a circuit associated with the compass.[30]

How far progress has been made in the development of a practical collision warning device is not known, but it should be stated that in the author's opinion such apparatus is one of the most urgent needs of aviation, and must become eventually a standard item of safety equipment in all aircraft.

8. General Problems of Aeronautical Radio Engineering

8.1. *The Noise Level in Aircraft*

As would be expected, a very high noise level prevails within the fuselage of an aircraft, this being caused by the revolving propellers, the rotation of the engines, the exhausts and the effects of the slipstream on the thin walls of the aeroplane. Owing to the different nature of the sources of the noise it covers the whole audible frequency spectrum. It is therefore difficult to exclude from the ears of the users of the radio equipment and from microphones used for telephony transmission, necessitating special design of equipment to render both received and transmitted signals intelligible.

To understand the basic problem, the behaviour of the ear under various conditions of sound level and external noise interference should be considered. Primarily the effect known as "masking" takes place, which is that if a low frequency sound of large volume is impressed upon the ear it renders it less sensitive to sounds of higher frequencies. In the practical case of an aircraft this may be interpreted as meaning that the ear is de-sensitised to speech frequencies to some extent, by masking due to the large volume of sound from the exhaust, which is of a low frequency lying between 50 and 250 c.p.s. It therefore becomes necessary to augment the volume of sound in the telephones to a higher level than normal at speech frequencies, in order to overcome the masking and to make the speech of sufficient volume to be understood.

The exhaust is, however, not the only sound of large amplitude which causes masking in an aircraft. The higher frequency sounds from the propeller tips and blades also have to be considered, with their attendant masking effects and the necessity for a further increase in the volume of the wanted sound in the telephones for it to be understood. This brings the point of operation of the ear near to the condition known as the "threshold of feeling" which, if reached, can cause some pain to the listener and considerable fatigue after a short period of listening. When the "threshold of feeling" condition is being approached the characteristic of the ear undergoes a change, and it responds more readily to the lower and higher frequencies of the audible spectrum than to the middle frequencies, giving rise to an overload condition at a lower level for the higher and lower frequencies, while being capable of standing its maximum volume of sound at the middle frequencies. This makes it necessary to design the "listening" equipment comprising A/F circuits and telephones to eliminate the higher and lower frequencies of the signals received so as to avoid masking from them when applied to the ear from the telephones at the large volume necessary. In addition, efforts must be made to eliminate so far as is possible the externally generated sounds, but as the mean volume of these is sometimes of the order of 120 phons it is difficult to accomplish with an ear pad or helmet of a size which is comfortable to the wearer.

The characteristic of frequency response of the telephone output may at first sight appear to be poor if the method described is followed, but the human ear is found by test to be accommodating, and it has been noted that complete elimination of all frequencies below 700 c.p.s. and above 2,500 c.p.s. only decreases speech intelligibility by about 15 per cent., and the method of restricted response is generally adopted for aircraft work. Under the conditions of flight with the highest possible external noise, the quality and intelligibility of speech from audio frequency amplifiers and telephones of these characteristics is remarkably good. The actual power applied to the telephones for intelligible listening appears to be a question which has never been agreed upon, and it is noteworthy that in the specifications of a number of receivers for airborne use described by Morgan[31] the maximum A/F output is found to vary between 10 and 700 milliwatts. Although in many cases the low value of output may be found to be adequate, it is the author's opinion that, at least, 100 milliwatts should be available, owing to the progressive de-sensitising of the ear which occurs in flight due to the continual high level of noise applied to it. The maximum degree of de-sensitising seems to be about 35 per cent. to 40 per cent. according to C. B. Mirick[32] who made a series of measurements on a number of aviators. Mirick's paper gives an interesting example of the danger of providing inadequate output to the telephones of an aircraft receiver and states that it is generally considered that it was this which caused an early Atlantic flight to fail, the operator being unable to hear any signals after many hours of flying and therefore being unable to provide navigational assistance to the pilot.

As the telephones need only respond to a restricted frequency range, no difficulty is found in adapting simple types of earpiece for airborne use, and most types will be found to peak at about 1,000 c.p.s.

Microphones of the carbon type are considered by the Air Ministry to be unsuitable for airborne work, being subject to vibration, but they are still used in the United States. An electromagnetic type is used throughout the R.A.F. While this microphone is less sensitive than the carbon type, and requires more amplification to develop a useful voltage for modulation purposes, it has an inherent lack of response to the lower frequencies, and simplifies the problems of eliminating external noise from speech transmission from aircraft.

The throat microphone or laryngaphone was at one time thought to be a suitable solution to the problem of the finding of a satisfactory speech transmitter for airborne use, but according to Hecht[33] is considered by the Air Ministry to constitute a danger to the wearer when flying under conditions of reduced pressure, such as would be met at high altitudes, and has, therefore, been discarded.

8.2. *Static Electricity Interference to Radio Reception*

Although reception of radio signals in aircraft is subject to interference from static electricity disturbances and "man-made" static, the most serious interruption is caused by an effect amost exclusive to flying which was formerly known as rain static, but is now known as precipitation static on account of the conditions under which it is met in practice.

Interference originating from this source does not cause the crackling sounds usually associated with static disturbances, but takes the form of an uninterrupted tone, the mean frequency and amplitude of which vary while the conditions last, and it can be likened to the sound of M.C.W.

The cause of this kind of interference was uncertain for some years, and was thought to be due to charged drops of rain or snow striking the aerial of the aircraft and discharging to the airframe through the receiver input circuits. This theory was substantiated by its being noted that the sounds were only heard when the aircraft was flying in cloud, that reception was always better when the loop aerial was used, and that the amplitude of the interference could be reduced by flying at a slower speed. These methods of reducing interference were, however, not always successful, and led to an investigation being made in order to ascertain its real cause, and to find a more effective method of reducing it.

This investigation showed that an aircraft assumed a charge equal to the potential of the area through which it was flying, no interference being audible during the process of charging, as the voltage gradient of the air is gradual under normal conditions. If, however, the aircraft, having assumed the normal potential of the air at the height at which it was flying, flies into a raincloud of which the potential is different, such as occurs under the meteorological condition before a thunderstorm, its normal charge will be unequal to that of the cloud and it will adjust itself to the new conditions ; as there may be a very large difference in potential, the charging or discharging of the aircraft will be accompanied by corona, in itself the chief cause of the interference to radio reception.[34]

In order to reduce the effects of corona it is usual to fit devices to the wing tips and tail units of aircraft, which are designed to dissipate the discharges and reduce their effects. These devices consist of a resistance fitted to the structure of the aircraft to the end of which is connected a number of fine discharging wires. The theory of operation of this discharger is to reduce corona by slowly dissipating the charge of the aircraft fuselage through the resistance, also to localise the discharge at parts of the aircraft remote from the aerials.

Due to the varying potential of some clouds met in flight it has been found possible for one part of an aircraft to be in a positively charged part of it and another in a negatively charged part, causing large currents to flow through the airframe and making it of importance to ensure that the electrical bonding of all metal parts is capable of meeting these abnormal conditions.

8.3. *Vibration*

As a result of installing engines of great power on the comparatively small structure of aircraft, considerable vibration is set up throughout the airframe; this may be in the latitudinal, longitudinal and vertical modes, and of varying amplitudes in different parts of the fuselage. Sound waves of great strength are also generated by the engines which can cause sympathetic vibration in various parts of the aircraft, and in such items as the components of radio equipment. It is therefore necessary to instal all radio equipment for airborne use on mountings which can absorb the vibrations and to construct certain components to be unaffected by vibration from either mechanical or acoustical sources.

Closely allied to vibration problems are those relating to the severe stresses which anti-vibration proof mountings must be capable of withstanding during the landing, take-off and taxi-ing of an aircraft, a requirement which make it necessary in practice to effect a compromise between strength and efficient vibration absorption.

For many years all airborne radio equipment was suspended by elastic cords which were attached to the airframe, and which allowed the instrument cases to float with large clearances between them and adjacent parts of the aircraft. This method, although giving satisfactory freedom from vibration transmitted directly through the aircraft, takes up excessive space, and has now been superseded by mountings which are designed to absorb vibrations in specially processed fixings in which rubber of the correct cross section is attached to metal, which is capable of withstanding the severest shocks of landing and take-off. The positioning of the attachments is arranged to effect some cancellation of vibrations, and the effective absorption is based upon this correctness of positioning. The combined absorbing effect of the rubber isolating feet and positioning can be made sufficiently effective for it to be possible to mount most components directly to a chassis suspended in this manner with the exception of variable condensers on H/F equipment. The design of cases for radio equipment for use in aircraft must allow for them to be substantially unaffected by sound waves striking them if undesirable microphony is to be avoided. Basically, this necessitates their being constructed of heavy gauge material, but owing to weight considerations this cannot usually be fulfilled. The technique is, therefore, to strengthen them by using "aircraft" methods of strengthening sides and panels by ribbing them or to place vibration absorbing cork mats inside them.

Consideration of vibration problems may in some cases restrict the efficiency of design of certain components such as inductances, it being necessary to support the windings, which tends to increase dielectric losses. It is also necessary to secure the winding to the supports very firmly as any looseness of turns may give rise to undesirable modulation effects from vibration sources. Similarly variable condensers and fixed condensers of the air dielectric type must in many cases be constructed with abnormally wide plate spacing, and of rather more robust design than is met in other types of radio apparatus.

The restrictions imposed upon components of these types by vibration have tended to cause designers in many cases to use crystal control for local oscillators in receivers, and for master oscillators in transmitters, and where possible to use iron dust cored inductances.

8.4. *Aircraft Electrical Power Supplies*

The nature and size of electrical power systems in aircraft must always be closely linked with the installation of radio equipment, and in many instances this is the factor which limits the basic design of transmitters.

During the early era of civil aviation the electrical supply of an aircraft of a constant speed windmill-driven generator mounted on the wing which provided, while in flight, a low voltage output for charging an accumulator and also supplied high tension for the radio transmitter and receiver. In the interests of aerodynamic efficiency this was abandoned when faster types of aircraft were introduced and was replaced by low voltage direct current generators which were driven from the engines and provided for loads of the order of 500 watts.

Owing to the wide variations of engine speed met in practice, constant voltage generators have come into general use which enable several generators to be connected in parallel as would be required on multi-engined aircraft. The method of obtaining the constant voltage is almost universally to use the well-known carbon pile regulator. The D.C. voltage is standardised at a nominal value of 24 volts, but apparatus is nowadays designed to operate at maximum efficiency at a voltage of 29, this being the usual value across the accumulator terminals under conditions of charge when airborne.

The weights of the engine-driven generators are remarkably low, a typical 3-kW. generator having a weight of 32 lb. only. The weight of the aircraft accumulators is high, however, the standard 24-volt aircraft type weighing about 100 lb.; this is due to the requirements of airworthiness which necessitates their being unspillable, and therefore rather bulky.

The H.T. supply for transmitters is obtained from rotary converters driven from the low voltage aircraft system. These types of power supply are also used for H.T. for most types of receiving equipment, although vibrators are sometimes used. The efficiency of both the rotary converters and the vibrators seldom exceeds 50 per cent., and if the weight of the average smoothing components is included, the total weight of the power supply apparatus for airborne radio transmitters and receivers will be found in most cases to be high.

The variation in supply voltage between the condition met in flight when the accumulator is being charged and the condition on the ground, when the engines are stopped, presents a difficult problem to designers of radio apparatus for aeroplanes; this is of the order of a 15 per cent. to 16 per cent. change, which occurs directly to the valve heaters and indirectly to the high tension circuits. Since a number of items of the airborne apparatus are remotely controlled and must be set up on the ground, it will be appreciated that precautions have to be taken to ensure that the setting up is carried out under the conditions of input voltage which are met in flight.

The immediate solution of this problem is to provide means for external connection of accumulators which have an output voltage equal to that obtained from the power supply when airborne. This solution is only partial, however, as occasions can arise when the power supply voltage is too low and cannot be increased, such as would occur when a flying boat is forced to alight upon the water, in which circumstances the pre-set adjustments would probably be found to be incorrect for efficient operation of the equipment.

In order to solve this problem in a more satisfactory manner attention has of recent years been turned to the provision of a small generating plant with its own petrol engine housed within the aircraft fuselage, and a 28-volt generator of 5 kW capacity has been made available with a weight of 140 lb. This represents a substantial loss in payload when compared to the generator driven by one of the aircraft engines, and would not appear to be an economical project except in the largest types of aircraft. In addition, it must be realised that an independently driven generator does not give a constant power output at all altitudes unless it includes a supercharger which, of course, involves additional weight. When comparing the respective merits of the two types of primary power supply it must be appreciated that in the event of failure of the generating plant the whole electrical system fails, while with the engine-driven generators the load can, in the event of stoppage of an engine, be distributed among the generators driven by the remaining engines.

The ultimate solution to the problems of aircraft electrical supplies may be to use alternating current in place of D.C., but before it can entirely supplant the older method many difficulties will have to be overcome, involving not only radio apparatus but also flying instruments and the various services in which direct current motors are used.

The main advantages of alternating current supplies in aircraft are that they will enable the accumulator to be dispensed with, and that by transformation, voltages over wide ranges will be available at any part of the aircraft. If high periodicities are employed the necessary transformers can be of light weight, this also applying to such smoothing equipment as may be needed. A real, though not readily apparent, advantage of alternating current lies in the simplification of maintenance of electric motors working from this type of supply when compared to D.C., and the fact that the power supply apparatus for the radio equipment will not require so much attention.

In applying alternating current to aircraft a difficulty is at once met when considering the method of providing the primary power to the generators. If they are to be driven from the aircraft engines a speed variation ratio of about two to one will have to be allowed for in order to meet the engine revolution conditions between take off and cruising; such differences in the speed of the generators will result in wide variations in the periodicity of supply, all of which will have to be allowed for in the design of associated apparatus. If this condition is met in a satisfactory manner there will be the further problem of operating several generators in parallel from the different engines and the difficulties of synchronisation of their frequencies.

It would therefore appear that if alternating current is to be used it will entail the use of a separate engine within the aircraft fuselage as a prime mover, and that this will have to be duplicated to allow for continuation of electrical supply if the one generating plant fails.

At the present stage of development of aircraft it is not possible to dispense entirely with D.C., as this is required for various instruments connected with flight and engine performance indication. In order to satisfy the requirements for both types of supply, an installation which is of interest has been made in the Short Shetland type flying boat, comprising duplicated 60 h.p. generating plants, each delivering three-phase alternating current at 110 volts, 250 c.p.s., and each with total output of 20 kW, also D.C. at 29 volts, with a total output of 3 kW. In this installation it is not intended to run both generators with their outputs in parallel, the duplication being primarily to provide for the event of breakdown, although it is stated in a published description[35] that under operating conditions the plant not under load is arranged to idle and can be switched into circuit immediately it is needed. The total weight of the electrical power plant on this aircraft must be of the order of 1,000 lb., including the accumulators, and amounts to between 1 and 2 per cent. of the total weight of the aircraft. While this weight may appear to be large, it is not possible to assess the economics of the electrical system as a whole without a complete specification of the aircraft, as much may be saved not only in the electrically operated services but by the replacement of some hydraulically operated services by small electrical motors, fed by very small conductors in place of the heavier hydraulic pipelines, all of which may result in a considerable overall saving in weight.

9. Conclusion

The paper has endeavoured to provide an introduction to the applications of the radio art to aeronautics, and to describe some of the technical and practical problems which have to be considered by those responsible for this important work.

Stress has been laid throughout upon the imperfections of aeronautical radio equipment and installations and upon the unsoundness of some of the systems used. It will, therefore, be clear that there is a necessity for development in the future for the improvement of equipment, and that there is a need for a more scientific approach to some of the problems encountered, not only in the design of apparatus, but also in the planning of systems for radio aid to aircraft.

In formulating an opinion of the future trends of development of aeronautical radio, the primary consideration should be the forms which air transport will take, the nature of the regular flights which will be made, the trends of future aircraft design, and the requirements of airline operators, particularly from the economic viewpoint. The basis upon which air transport will operate appears to be that there will be a large volume of traffic between the main towns in most countries and that there will be a less dense volume of traffic between continents, involving flight over oceans and over long distances.

Owing to the likely introduction of gas turbine engines in the near future, higher speeds can be expected on all types of aircraft, and in consequence the requirements of streamlining will be more exacting, entailing a reduction of aircraft aerial sizes to the minimum dimensions possible.

The ideal of the airline operators will doubtless be to operate aircraft to time-tables in all possible weather conditions and with the maximum safety, necessitating the use of all types of radio aid. In spite of this requirement the weight of radio apparatus will be under close scrutiny, as it will represent to the owners of the aircraft a reduction in payload, and the demand for lighter apparatus will continually be made.

In order to meet the needs of the airline operators it would seem desirable to consider designs which would save weight by combining the four distinct services which radio can provide in equipments in which common power supplies, audio frequency amplifiers, and in some cases intermediate frequency amplifiers are included, instead of having separate self-contained equipments such as are included in present-day designs of airborne apparatus. The objection sometimes raised to this scheme is that it reduces the safety factor of the installation, for if a component fails the whole of the radio service ceases to function. If this objection is accepted it shows a weakness in radio technical knowledge as a whole, admitting a lack of understanding of the causes of failures and their prevention. In this field it is considered that knowledge is lacking, and that it is a phase of radio engineering that has an important bearing on the future design of airborne apparatus. At the present moment a universal radio guidance system does not exist which will enable the pilot of an aircraft to fly to any destination knowing that the radio facilities at the point of departure are of the same type as those at the destination. An example may be taken from the case of an aircraft flying from Europe to the United States of America.

In this instance M/F two-way communication and D/F are used while in the area of European control, H/F is used whilst over the Atlantic, and upon approaching and flying over the American continent radio ranges and H/F telephony are used.

In addition, the landing aids used in Europe differ in principle and frequency to those used in the U.S.A.

In view of the amount of radio apparatus which is needed to utilise the facilities at different stages of a flight a standardisation of systems is clearly necessary, present conditions calling for unduly complicated installations and being very uneconomical. This unsatisfactory state is now recognised officially, and is among the reasons for the various international conferences which have recently taken place. The task before these conferences is immense. Ground organisations for aeronautical use already exist in most civilised countries which must be modified or dismantled before a unification of systems can be achieved. It is therefore difficult to forecast whether the ideal will ever be achieved, or how much time must pass before its realisation.

Among the essential changes which must take place it would appear that V.H.F. communication must supersede all other methods of local control owing to its many advantages. Similarly, hyperbolic navigation is essential to modern flying when time-tables must be adhered to and large volumes of traffic are concentrated in small areas.

In the field of technical development radio engineers have yet to produce a landing aid which can be installed in all types of aircraft, and which will permit of landing under all conditions of poor visibility. When this is accomplished air travel will doubtless supplant all other means of travel over distances in excess of two to three hundred miles.

The aeronautical industry and air lines will also await a collision warning device which is suitable for installation in all types of aircraft, and which will give useful and timely warning of obstructions in the path of flight.

Finally, a new application for electronics in aviation is foreseen when aircraft are developed to fly at supersonic speeds as under these conditions certain vital flying instruments of the type at present used do not work satisfactorily. The time may come, therefore, when radar and radio will not only indicate where an aircraft is flying, but will also indicate the manner in which it is flying.

Acknowledgments

In conclusion the author wishes to thank for their assistance in providing photographs and technical information: Marconi's Wireless Telegraph Co., the Decca Navigator Co., the Weston Sangamo Co., the Sperry Gyroscope Co., La Société Française Radio Electrique, and the General Electric Co. Ltd.

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NOTE.—Frequency classifications are in accordance with British Standards Glossary of Terms used in Telecommunication. B.S. 204 : 1943.

STUDENTSHIP REGISTRATIONS

Since April 1st, 1946 (the beginning of the Institution's year), a total of 177 proposals have been received up to the end of 1946.

The following were registered as Student members of the Institution at meetings of the Membership Committee held on November 26th and December 17th, 1946. A total of 46 proposals for Studentship were considered at these meetings and the General Council has now confirmed the following registrations.

ADAMSON, Thomas Fearnley	Southport
AYRE, Thomas	Hetton-le-Hole
BARTON, Francis Allan	Stockton-on-Tees
BERRY, Ker	London
BERTOYA, Hastings Charles	Hornchurch
BURNELL, James Douglas	Cape Town
BURNETT, Reginald George, M.B.E.	Croydon
COOKE, Arthur	Sheffield
COWLIN, Michael Laidlaw	Rickmansworth
CROW, Stanley George	London
CULLINGTON, Sidney Albert John	Llandudno
DAVISON, Clifton John Frederick	Whitley Bay
DEAN, John Granville	Woodhouse, Notts
FAULKNER, Derek Charles	London
GEORGIOU, Christos Nikitas	Limassol, Cyprus
HIGGINS, Frank	Manchester
HOBERT, Matthew Alexander	Jerusalem
HULME, James	Lanarkshire
HUMPHREYS, Edward Kenneth	Torpoint, Cornwall
HUSTON, Alexander Edward	Manchester
JOHNSON, John	Badnera, India
KERSHAW, Harry	Felixstowe
LEHANE, Donal	Co. Cork
LIGHT, Thomas	Rochdale
MANNIX, Timothy Patrick	Lancaster
MAY, Bernard Calverley	Chatham
McDONNELL, Patrick Joseph	Tipperary
McLENNAN, Douglas George, B.Sc.(Eng.)	Grieff, Perthshire
MILLER, William Aikman	Edinburgh
NOONAN, William Edward	Liverpool
POOLE, Lloyd William	London
PRABHAKAR, Vedula	Chakardharpur, India
PURDON, Reginald David James	London
REIDY, Kevin John	London
RIESEL, Herbert	Tel-Aviv
ROSE, Frank Edwin	Baldock
RUBENSTEIN, Gerald	London
SEK, Stanislaw	Ipswich
TALBOT, George Kenneth	Blackburn
THOMAS, William Derrick	Rutherglen
THOMPSON, Michael Raymond	Douglas, Isle of Man
TURSKI, Stefan	Fife, Glasgow
TWISS, Jeffrey Gordon	Victoria, Australia
VINCENT, John	Huddersfield
WADDELL, William Angus, B.Sc.(Hons.)	Glasgow
WILKINSON, Stanley Henry	Hounslow

N.B.—One of the present regulations governing registration of Student members provides that the candidate shall satisfy the General Council as to his general education. In general, this has necessitated the candidate having passed an examination equivalent to the Matriculation examination of any approved University, with science subjects.

In considering possible revisions to various Articles, the Council of the Institution, at their meeting on November 29th, 1946, resolved that later this year, there should be an Extraordinary General Meeting for the purpose of passing, if approved, further alterations to the Articles. These alterations will include provision that instead of reintroducing the old Preliminary Examination for those wishing to become Registered Students, future applicants for Studentship *must* have passed the Common Preliminary Examination of the Engineering Joint Examination Board, or one of the examinations recognised by the Board for the purpose of obtaining exemption from the Board's Examination.

The Engineering Joint Examination Board was established in 1938, and is supported by nearly all the leading engineering Institutions of the country. Further details regarding this examination may be obtained from the Secretary of the Institution, or from the Honorary Secretary of the Engineering Joint Examination Board, Great George Street, Westminster, London, S.W.1.

NOTICES

Brit.I.R.E. Journal Volume VI (New Series)

This issue of the Journal completes Volume VI (new series). A Subject and Author Index will be circulated within the next six weeks to all members who normally receive the Journal.

In response to many requests, a Subject and Author Index is also being published to cover Journal Volumes 2 to 5, inclusive—1941 to 1945. A copy of this index will be sent to members on request, but it is important to note that Volumes 2 and 3 (new series) are now entirely out of print. The only copies available to members are those which may be borrowed from the Institution's Library.

A few copies of Volume 1 (new series) (1939/40) are still available, price 10s. 6d., post free, and copies of Volumes 4, 5 and 6 are also available, in bound form, at 12s. 6d., post free. Requests for all or any of these volumes must be accompanied by the appropriate remittance.

1947 Component Exhibition

The Radio Component Manufacturers Federation are holding their 1947 Exhibition at the Royal Horticultural Hall, Greycoat and Elverton Streets, Westminster, S.W.1, during the period March 10th to 13th, 1947.

The exhibition, which is private, will be opened to visitors, by invitation only, from 10 a.m. to 6 p.m. daily, during the four days Monday to Thursday, inclusive. Tickets may only be obtained from the Radio Component Manufacturers Federation, 22 Surrey Street, W.C.2.

Physical Society—Acoustic Group

A meeting will be held in the Jarvis Hall of the Royal Institute of British Architects, 66 Portland Place, London, at 3 p.m., Wednesday, February 19th, 1947, to discuss the formation of an Acoustics Group of the Physical Society.

Membership of the groups is available at a nominal sum to members of other societies, and there is provision for Group Membership by firms.

All those wishing to attend the meeting should send their names to the Acting Secretaries, Mr. A. T. Pickles and Mr. W. A. Allen, the Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7.

1947 Radio Exhibition

The Radio Industry Council announces that Radiolympia—the National Radio Exhibition—will be held from October 1st to October 11th, 1947. Present plans are that there will be a pre-view on September 30th.

Radio Industry Council

Soon after the Radio Industry Council was formed in 1944, it was decided that a Technical Directive Board should be formed representing the four constituent associations to act in an advisory capacity to the Council. A Technical Executive Committee was also set up to carry out the day-to-day technical activities of the radio industry.

Meetings were instituted between Industry and the Inter-Service Components Technical Committee, which later became the Radio Components Standardisation Committee, with Mr. Hecht as Chairman and Mr. Whitehead as Secretary. Much work was also done relative to the standardisation of screw threads, valves and to matters affecting the users of radio apparatus.

In the important field of ship-borne radar the Technical Directive Board has been able to resolve the question of the official view regarding the most suitable wavelength for general purpose navigation and to eliminate doubts about the efficiency of the 3 cm. system.

North-Western Section Committee

Messrs. C. W. Miller and H. Whalley (Associate Members) have found it impossible to continue as joint Secretaries to the North-Western Section Committee and in their place, Council has now appointed Mr. George C. Turner, B.Sc. (Associate).

Communications for Mr. Turner should be addressed to 1 Coleridge Road, Manchester, 16. Mr. Turner's private telephone number is Chorlton-cum-Hardy 4520; during normal business hours, he may be obtained at Failsworth 2000, Extension 200.

Members of the Section have responded well to the questionnaire circularised by the Committee as a result of which, it is now proposed that a sub-centre be formed for the Liverpool and Merseyside district; first meetings in Liverpool are to be arranged for the 1947/8 session and offers of papers from members in the area will be particularly welcomed by the North-Western Section Committee.

The next meeting of the North-Western Section will take place on February 5th, 1947, at the College of Technology (Reynolds Hall), Manchester, 1, at 6.45 p.m. Mr. R. A. Lampitt (Associate Member) will then give his paper on " D.C. Amplifiers."

GRADUATESHIP EXAMINATION

SUPPLEMENTARY PASS LIST—MAY, 1946 (Final List)

Passed Entire Examination

HODGKINSON, John Thomas	Mombasa
MIDDLETON, Eric John	Johannesburg
MILLER, George Bertram	Johannesburg
SARIN, Jagdish Chandra	Bombay
SEHPOSSIAN, Haig	Cairo
WOODS, Alfred Walter Ray	Cape Town
WULKAN, Alfred	Jerusalem
WATT-BRIGHT, John Robert	Deniliquin, N.S.W.

Passed Parts I, II & III

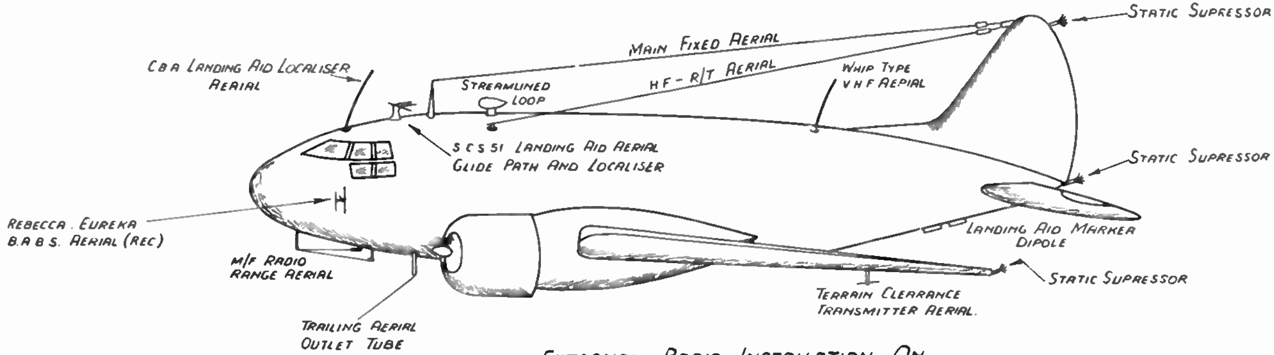
LATIF, Moiz Ebrahim	Bombay

Passed Part III only

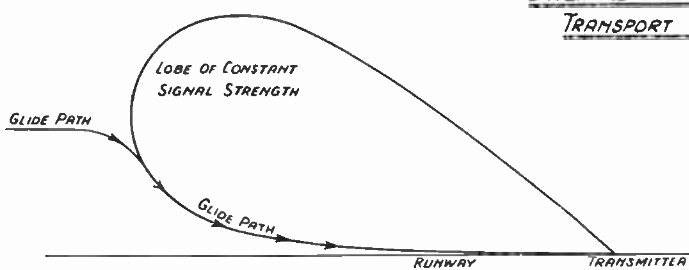
BEAUCHAMP, Kenneth George	Calcutta
DICKMAN, Matthew Colin	Johannesburg

Passed Part I only

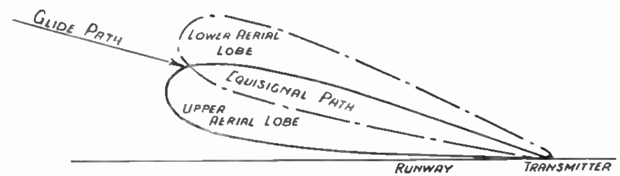
ABOBA, Joseph Julian	Cairo



External Radio Installation On Transport Type Aircraft.

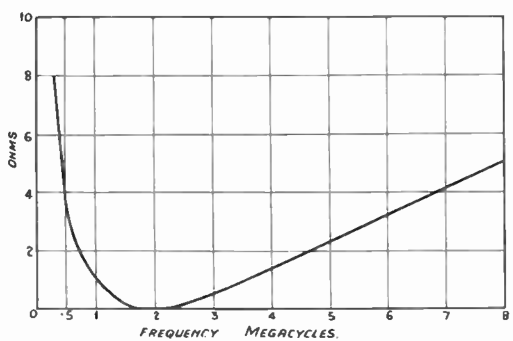


Lorenz System.

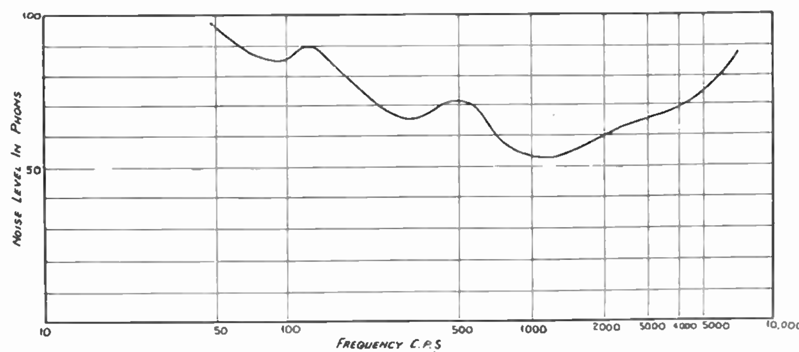


S C S 51. System

Methods Of Obtaining Glide Paths.

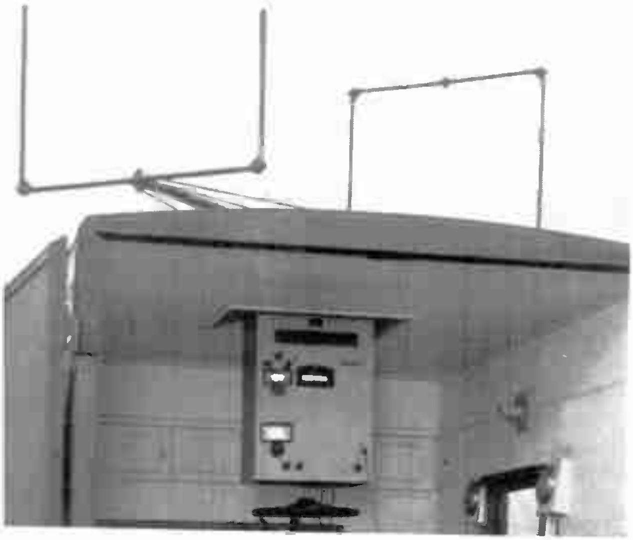


Aerial Resistance. Typical Fixed Aerial.

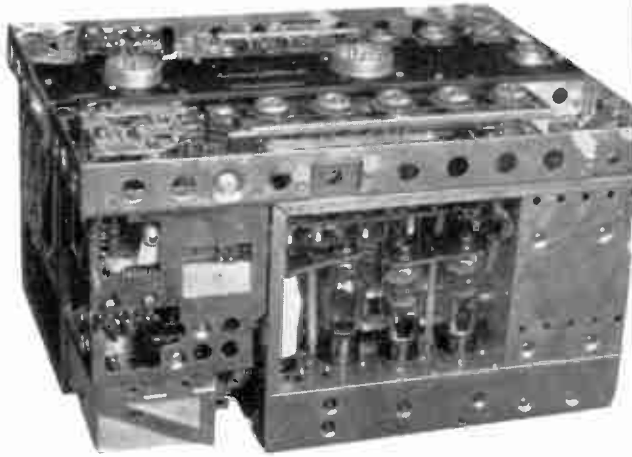


Noise Level In Aircraft.

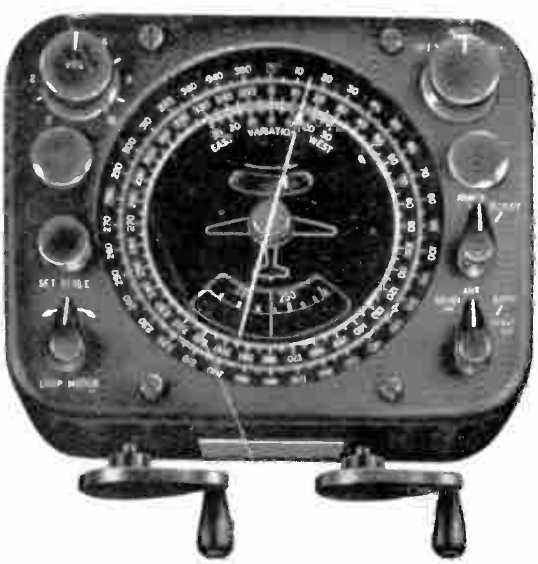
World Radio History



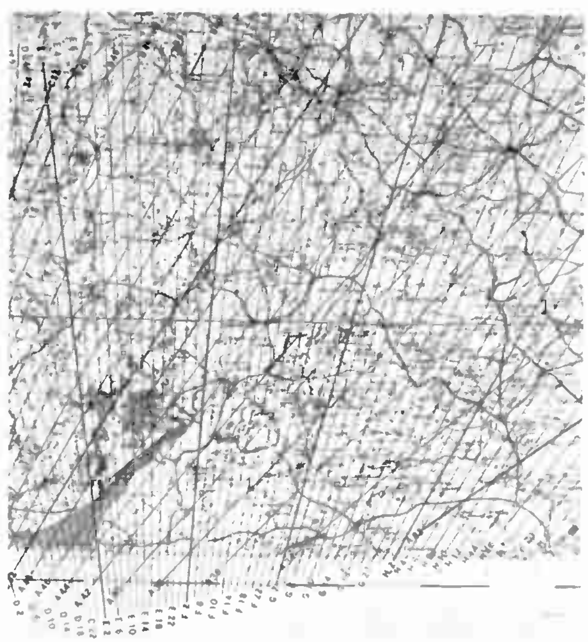
Mobile Spaced Loop Direction Finder to H F.



Airborne V.H.F. telephony transmitter and receiver unit. (G.E. Co. photograph.)



Automatic radio compass presentation and remote control unit. (Sperry gyroscope photograph.)



A section of a Decca hyperbolic map.