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"To promote the advancement of radio, electronics and kindred subjects by the exchange of information in these branches of engineering."

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THIRTY YEARS ON

The first 30 years of the average man's life span his most formative years; the experience and knowledge gained in that period greatly influences his subsequent career and ability to contribute to the well-being of his profession.

During the first 30 years of its life, the Institution has benefited both from youth and experience, for it must never be forgotten that it required many men of considerable experience to bring into being the Institution as we know it to-day. All of those founder members were already qualified and in responsible positions, when, in the summer of 1925, they met to discuss the formation of a British "Institute" of Radio Engineers.

Earlier attempts to form an independent body for the professional radio engineer in Great Britain had been unsuccessful; nevertheless the founders of the Brit.I.R.E. were undoubtedly inspired by the success which had attended the formation of the American Institute of Radio Engineers just before World War I—only 16 years after Marconi had sent out from South Wales the first radio message ever to be broadcast. On the other side of the world, the present Australian Institution of Radio Engineers became established in 1924. This body initiated, in 1936, Radio Foundation Day, which is observed every year to commemorate the successful transmission across the Atlantic of the morse letter "S" by Marconi on December 12th, 1901.*

The Institution inaugurated a scheme of examination in November, 1929. Only a small number of candidates sat on that first occasion, but there has always been a constant increase in entries each year, resulting in the present total of over 1,000 per annum. The syllabus has, of course, been frequently revised to meet changing needs and the scheme is closely followed by the Australian Institution of Radio Engineers in their membership requirements.

By 1932 the founders of the Brit.I.R.E. were sufficiently confident of the Institution's future to seek official incorporation. The Institution, as indeed the radio industry, found its beginnings in new means of communication. In more recent years the principles of radio have been extended into the comparatively new field of electronics, and although corresponding changes have been made in the Institution's Memorandum and Articles of Association, its function as the professional body of the radio and electronic engineer has remained unaltered.

In 1943 the growth of the Institution's membership and staff necessitated the acquisition of larger premises and the present building was leased; now, after 12 years, these headquarters are quite inadequate and the Council's objective is to purchase the freehold of suitable premises complete with lecture theatre, etc. This achievement will be a major step toward the permanent stability of the Institution. Members and industry have already responded well to the appeal recently made for financial help towards the cost of a new building.

The first 30 years of the Institution's life have laid sound foundations; future progress will lie in the three principal aspects of its work: the encouragement of training in radio engineering, the promotion of the status of the radio engineer, and the advancement of radio science and engineering. In all these objects the support of members and industry is needed. The record of the past 30 years is encouraging.

* The first radio message ever to be broadcast was sent by Marconi from the island of Flat Holm, off the South Wales coast, on May 18th, 1897. This date has been commemorated since 1922 by a "Goodwill Day" radio broadcast, now transmitted all over the world from the B.B.C. studios in Cardiff.

NOTICES

"Scientific Research at Aldermaston"

A recent publication by the United Kingdom Atomic Energy Authority with the above title has been produced with the object of giving university science students some idea of the work carried out by the Atomic Weapons Research Establishment.

Following a brief foreword by the Director, Sir William G. Penney, and an historical introduction, chapters deal with work on mathematical physics, experimental physics, explosives and radio chemistry, metallurgy, electronic and other special instruments, and trials of atomic weapons. In the chapter on electronic instruments, problems dealt with are ultra high-speed oscillography, u.h.f. radio telemetry, and radiation detection instruments.

It is stressed throughout that in spite of the necessity for much of the work to remain secret, a large portion of it can be discussed and published, since it consists of basic fundamental investigation. In any case, the considerable scientific strength of the Authority itself enables scientists within it to discuss their work very freely with fellow workers.

Dr. Rudolf Kompfner

Members will be interested to learn that the 1955 recipient of the Duddell Medal of the Physical Society will be Dr. Rudolf Kompfner. It will be recalled that his paper "On the Operation of the Travelling-wave Tube at Low Level," which was read before the London Section of the Institution in 1950, gained him the Heinrich Hertz Premium.

Dr. Kompfner was, of course, largely responsible for the invention of the travelling-wave tube, and since 1951 he has been carrying out research on microwave vacuum tubes of various types at the Bell Telephone Laboratories in the United States.

Reed's Schools

Members of the Institution who contribute to the Benevolent Fund will be interested to know that the Governors of Reed's School have appointed Mr. R. Q. Drayson, D.Sc., M.A., as headmaster, and he will commence his duties in September, 1955. Mr. Drayson was educated at St. Lawrence School, Ramsgate, and read History at Cambridge.

It was with regret that the Governors of Reed's School announced recently their decision to close the girls' school at Basingstoke. Continued shortage of funds has forced this decision, although the boys' school at Cobham will continue and is, in fact, to be extended.

Whitworth Foundation Awards

For a considerable number of years the awards from the Whitworth Foundation have consisted of:—

(*a*) Whitworth Senior Scholarships open to holders of degrees or Higher National Certificates or Diplomas in engineering;

(*b*) Whitworth Scholarships open to engineering apprentices of at least two years standing;

(*c*) Whitworth Prizes awarded to unsuccessful candidates for scholarships whose work deserves recognition.

In recent years there has been a great increase in the number of maintenance allowances and scholarships from public funds given to enable suitable students to obtain university degrees or to undertake other forms of full-time further education. There has been, however, a smaller number of students seeking Whitworth Scholarships and to meet the changed conditions the Minister of Education, as Trustee of the Sir Joseph Whitworth Foundation, has decided to increase the maximum number of Senior Scholarships from two to three and to increase their value from £325 to £500 per annum. These awards will be available for post-graduate work and will, in future, be known as Whitworth Fellowships.

The first Fellowships will be offered in 1956 and will be tenable normally for two years; submission of a thesis forms part of the condition of the award. In addition, a number of Whitworth Prizes of greater value than previously will be awarded to unsuccessful, but meritorious, candidates for Fellowships. The award of ordinary Whitworth Scholarships will be discontinued.

British Instrument Industries' Exhibition

As has already been announced in the *Journal*, the 1955 British Instrument Industries' Exhibition will be held at Earls Court, London, from June 28th to July 9th.

Over 150 firms and organizations are exhibiting and in addition there are to be a number of papers read at the associated Conference. These will cover a variety of subjects and will include papers on instrumentation for various industrial applications such as nuclear energy, fuel efficiency and the prevention of "smog." A paper will also be read on future applications of digital computers.

MAINTAINABILITY OF SERVICES EQUIPMENT

A Discussion Meeting in London on March 30th, 1955
In the Chair: The President

Part I* submitted by

G. W. A. Dummer, M.B.E. (Ministry of Supply representative)†

1. Introduction

The paper summarizes the position on faults occurring in electronic equipments as far as is known at present. It must first be emphasized that there is difficulty in obtaining accurate information on failures in equipments. There is always a long delay between the production of an equipment and the date when it is brought into service. The components used in it may have been made many years ago—it may have been stored under adverse climatic conditions, or subjected to much rough handling. Many other factors, some unknown, affect any analyses which might be made, so that no fault analysis can be considered scientifically accurate. In spite of this, in order to clear some of the fog of ignorance and guesswork which surrounds this subject, some form of analysis is essential, but it must be used sensibly and regarded only as a useful guide.

2. Fault Analysis

Some years ago the Radar Research Establishment began accumulating information on faults occurring in electronic equipments and a report published in 1952 summarized the position as it was then. A further analysis has been completed and Tables 1 and 2 give a brief summary of information taken from a number of different sources and presents a comprehensive view of all electronic equipment faults. It shows the main causes of faults—in fact, the reasons why maintainability is a problem.

In addition to the faults recorded, many others occur in practice—changes in performance require re-alignment and re-tuning, unskilled repair causes damage, and there are many other factors impossible to estimate.

It is emphasized once again that failure rates for individual equipments will vary considerably and that the position is always changing. These figures do, however, form a background to the problem.

Table 3 lists the components and valves which give trouble and have to be replaced. It will be seen that, generally speaking, valves are the largest single source of failure, the order being:

Table 3

Valves
Resistors
Capacitors
Transformers
Switches
Relays
Meters
Cables and Connectors
Chokes and Inductors
Valve Holders
Plugs and Sockets

It is interesting that a large-scale analysis by the Bell Telephone Laboratories in the U.S.A. gave an identical order of failure for the first five mentioned.

When analysed as a percentage of the total of each type of component, the order of failure is as shown in Table 4, which shows the worst types of components, irrespective of the quantities used.

Table 4

Meters
Valves
Relays
Cables and Connectors
Transformers
Switches
Chokes and Inductors
Plugs and Sockets
Capacitors
Resistors
Valve Holders

It is possible to estimate the effect of Service conditions on fault rates. Table 5 shows an analysis divided into three conditions of operation:

(1) Service conditions; (2) laboratory conditions; (3) ideal conditions.

*Manuscript received February 24th, 1955. (Paper No. 315.)
†Ministry of Supply, Radar Research Establishment, Malvern, Worcs.
U.D.C. No. 621.37/9.004.6 : 623.

Table 1

Analysis of Faults Due to Components During Period 1950-51-52 in Descending Order

Pre-service Testing K.114		R.A.F. Failure Reports Forms 1022		Typical Laboratory Conditions, Harwell*		Ideal Conditions, Computer	
Component	%	Component	%	Component	%	Component	%
Resistors	34·3	Valves	36	Valves	54	Valves	88
Valves	24·3	Capacitors	24·9	Resistors	22·8	Resistors	4·2
Capacitors	11·9	Transformers	13·5	Capacitors	9·9	Capacitors	4·2
Transformers	8·6	Plugs, Sockets	9·7	Transformers	7·3	Relays	0·8
Switches	7·2	Resistors	7·8	Relays	2·0	Valve Holders	0·6
Plugs, Sockets	4·8	Switches	3·6	Switches	1·9	Transformers	0·2
Relays	2·9	Relays	2·8	Meters	0·9	Chokes, Inductors	0·12
Valve Holders	2·8	Valve Holders	2·6	Chokes, Inductors	0·5		
Chokes, Inductors	1·4	Chokes, Inductors	1·5				
Cables, Connectors	0·95						

Table 2

Analysis of Faults Due to Components During 1953 in Descending Order

Royal Naval Reports		R.A.F. Failure Reports Forms 1022		Typical Laboratory Conditions, Harwell*		Civil Aviation B.O.A.C.	
Component	%	Component	%	Component	%	Component	%
Valves	53·6	Valves	44·8	Valves	52·8	Valves	55·6
Cables, Connectors	14·7	Capacitors	34	Resistors	23·5	Capacitors	21·5
Plugs, Sockets	8·7	Resistors	4·32	Capacitors	3·8	Resistors	13·5
Resistors	7·7	Cables, Connectors	2·3	Transformers	2·3	Transformers	2·6
Relays	5·7	Relays	2·0	Relays	1·5	Switches	1·8
Switches	5·0	Plugs, Sockets	1·7	Plugs, Sockets	1·5	Chokes, Inductors	1·8
Capacitors	2·1	Switches	1·2	Switches	1·4	Relays	1·6
Chokes, Inductors	1·5	Transformers	0·9	Meters	0·9	Cables, Connectors	1·3
Transformers	0·92	Valve Holders	0·4	Valve Holders	0·5	Plugs, Sockets	0·3
		Chokes, Inductors	0·4				

It will be seen that about 13 times as many faults occur on Services equipments as in computer equipments using basically the same components. It has also been found that 10 times as many faults occur in airborne radar equipments as in ground equipments. How does one therefore tackle this problem of maintainability? Whilst accessibility is essential with present failure rates, the obvious answer is to improve reliability and reduce the necessity for maintenance. From a design angle there are many things which can be done:

1. Thorough pan-climatic, vibration and shock testing with full Service Trials of all equipments.
2. Improved reliability of valves and components.
3. Use of simple circuits wherever possible and de-rating of valves and components suitably.
4. Use of new constructional techniques, such as wired-in valves, unit systems of construction, sealed or potted units, printed circuits, etc.
5. Replace known suspect items by new designs fundamentally more reliable, for example, magnetic modulator to replace hydrogen thyratron; magnetic amplifiers to replace valve servo amplifiers; gyrator ferrite cores to replace T.R. and T.B. cells.

3. Design Methods of Improving Maintainability

3.1. *Pan-climatic, Vibration and Shock Tests*

Test schedules exist which simulate actual Service conditions of vibration, shock, high and low temperature, high humidity and high altitude. It is mandatory that all Service equipments be subjected to these tests, during which many faults will arise, particularly in vibration and humidity. These faults can be remedied in the laboratory and modifications made to the equipment so that the production models will not suffer from the defects. Service Trials also confirm faults which occur under the simulated climatic tests. The Ministry of Supply regards this as one of the most valuable aids in improved reliability of equipments and one example can be cited to illustrate the value of this pre-testing. A certain airborne equipment was designed to be used in the Canberra. The scanner assembly of the equipment was found on vibration test to have a pronounced resonance at 29 c/s. Measurements in the Canberra showed a small airframe resonance in the region of 24 c/s. If the equipment had been fitted without structural modifications, there is no doubt that every single one of the scanner assemblies would have been broken.

It is estimated that at one establishment alone 450 major faults have been obviated in the last few years by tests such as those which have been described.

Table 5

Effect of Service Conditions on Fault Rates

Sources of Information	SERVICES K.114 Tests at R.R.E. 1946-1952	LABORATORY Harwell 1949-1952*	IDEAL Manchester University Computer
Estimated working hours	600	1,000	7,420
Total components (including valves) ..	8,024	587,394	20,892
Total failures	210	4,535	527
Hours per fault per 100 components	230 hr	1,430 hr	2,968 hr

Under Ideal Conditions: 1 in every 100 components fails during first 3,000 hours.
Under Laboratory Conditions: 1 in every 100 components fails during first 1,400 hours.
Under Service Conditions: 1 in every 100 components is estimated to fail during first 230 hours.

* See also, for instance, D. Taylor, "The reliability of nucleonic instruments," *J.Brit.I.R.E.*, 14, pp. 570-580, November 1954.

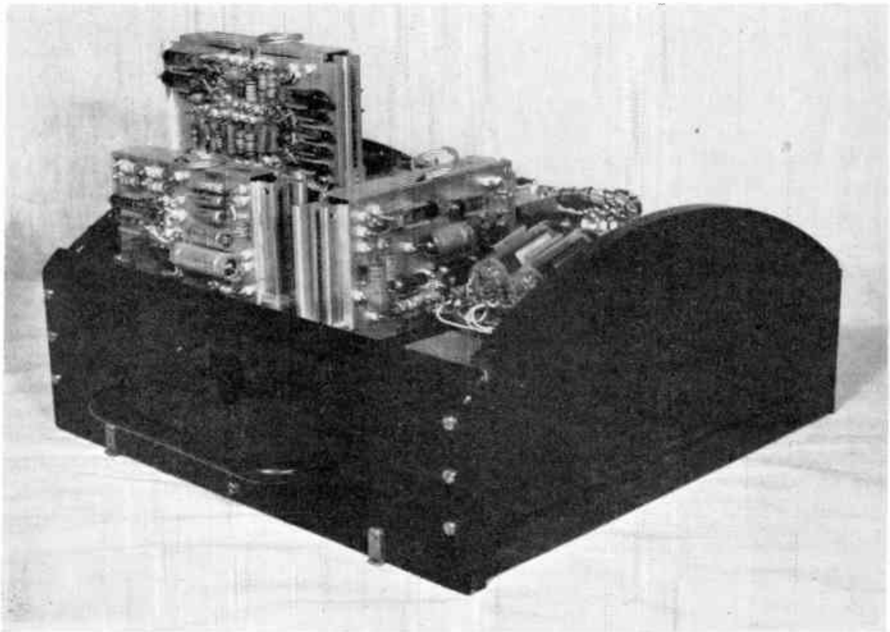

Fig. 1.—Example of "pull-out" sub-unit.

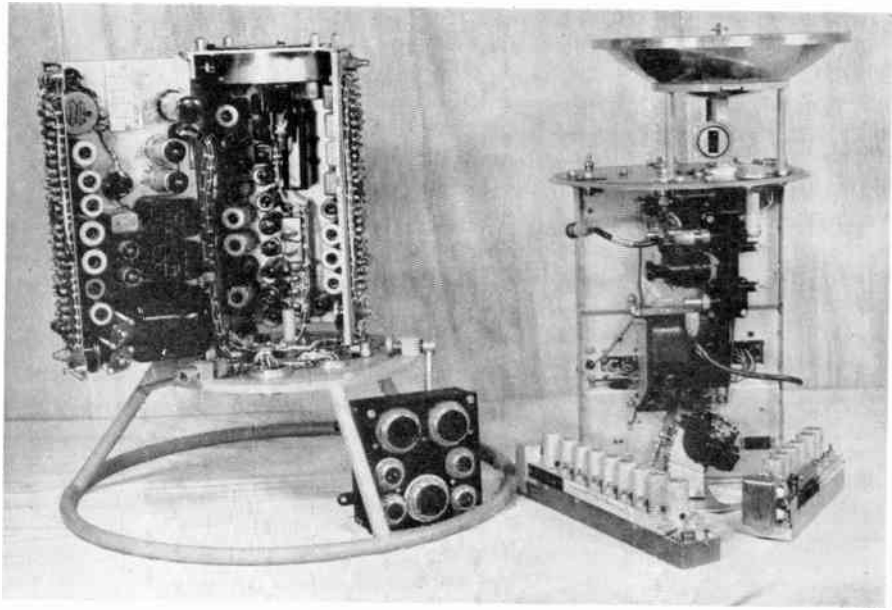

Fig. 2.—Accessible sealed and pressurized construction.

3.2. *The Improvement of the Reliability of Valves and Components*

Future equipments are likely to be more complex and the number of valves and components is likely to increase. Already ground equipments are being designed and operated containing 1,200 valves or more. The average ratio of components to valves in radar equipments is 9 to 1 so there are 10,800 components (12,000 including valves) which may go wrong in a single installation. A modern bomber may carry 400 valves or a total of 4,000 components. It has already been shown that in airborne equipments the failure rate of equipments is 10 times higher than in ground equipments, so that the design and production of reliable components to meet these arduous conditions is a considerable problem. A great deal has already been done through the Radio Components Research and Development Committees but there is a long time-lag between the development of a new component and its introduction into the Service. This time-lag involves many stages—initial research, the production of preliminary samples, tests, development contract, design approval, more tests, type approval, production contract—before the component can be introduced into equipments at the manufacturers.

The vast amount of work which is being done on the improvement of valves and components cannot be detailed here. There is no doubt that the "ruggedized" valve now being produced is many times more reliable than its predecessor and it must be remembered that reliability improves with quantity of manufacture. The largest market for valves produced in this country has been, and still is, domestic radio and television sets, and until a few years ago, the type of valve used in domestic equipment was also used in Service equipments. However, the increasing need for improved reliability under Service conditions of shock and vibration led to a series of stringent tests being initiated by the Services and the valve manufacturers in order to discover the cause of early catastrophic failures. Since then many lessons have been learnt and heater cathode structure, electrode assembly, welding methods, etc., have been improved. Test methods have been studied and specifications prepared by the Services in conjunction with the valve manufacturers. There is, however, room for still further improvement in valve construction.

In the component field, cracked carbon resistors, particularly in values over 100,000 ohms, are subject to open circuits. Wirewound resistors have recently become a source of trouble because crazing of the enamel allowed penetration of moisture, resulting in fracture of the wire. Capacitors show many different types of faults depending on the dielectric and construction, generally resulting in open circuits. Penetration of moisture in high humidity and high temperature also lowers the insulation resistance. Variable resistors are subject to

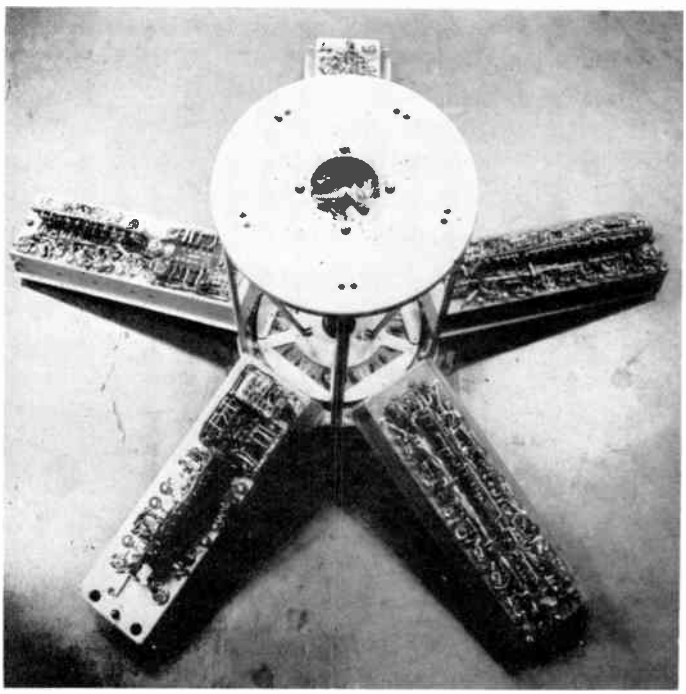

Fig. 3.—Accessible construction of airborne radar equipment.

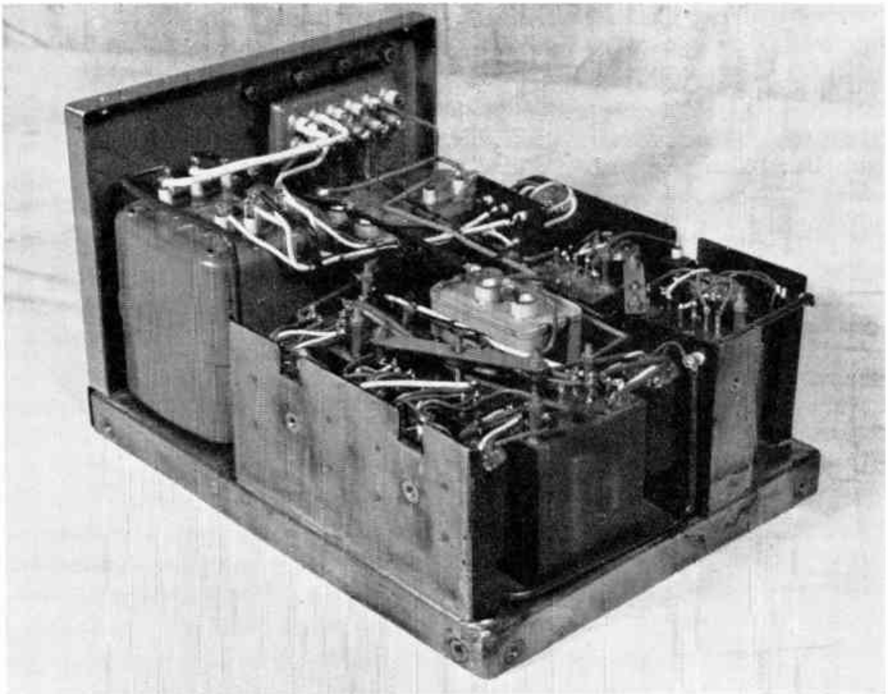

Fig. 4.—Reliable radar—construction of synchronizer unit.

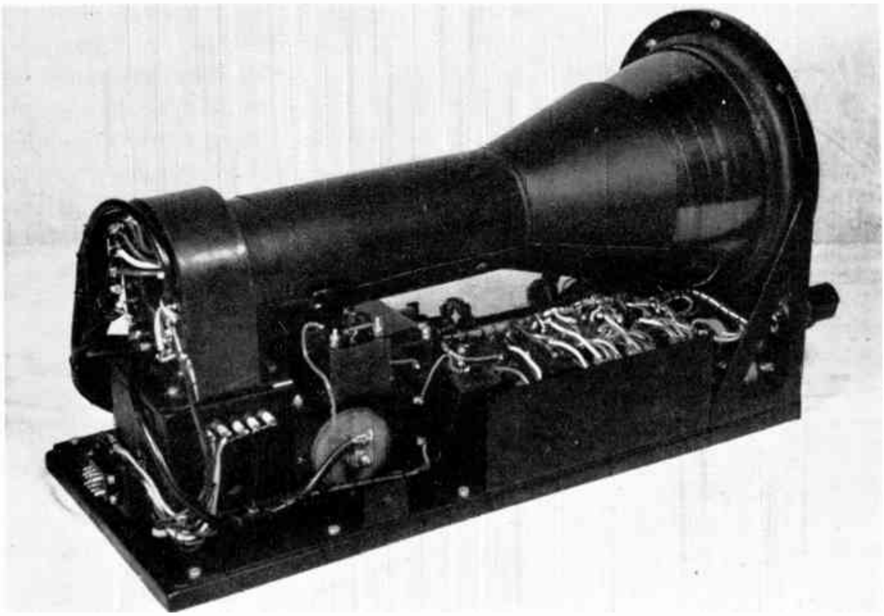

Fig. 5.—Reliable radar—construction of indicator unit.

contact troubles and corrosion, and a range of sealed Service-type variable resistors is being developed.

New components such as the tantalum electrolytic capacitor are being designed which have a theoretical shelf life of 10 years and can operate over a temperature range of $-50°C$ to $+125°C$ with negligible change in capacitance under the worst Service conditions. Their leakage current is measured in microamps rather than milliamps. In fact, a great deal of effort is being devoted in this country, and co-ordinated by the Radio Components Research and Development Committee, to improving the reliability of components used in equipments.

3.3. *Simple Circuits*

It is obviously advisable to reduce the number of valves and components in any equipment by simplified design, but this is not always possible in practice. Sufficient time is not usually available to the designer as target dates have to be met and equipments must pass rapidly from development into production. It might be worth while, if more time were available to the designer, to simplify his circuits wherever possible in an attempt to improve overall reliability. The rating of components should also be very carefully checked; for instance, it is known that the life of a paper capacitor is inversely proportional to the fifth power of the voltage across it, up to 85°C, and the life of a Grade 2 resistor is adversely affected by serious overloads of any kind. It is essential, therefore, to make certain that all components are suitably de-rated.

3.4. *The Use of New Constructional Techniques*

Experimental tests have confirmed that the use of wired-in valves is advantageous as far as reliability is concerned, but accessibility may suffer through their use. Again, a compromise is reached where the ability to change a valve may be offset by the avoidance of contact troubles through valve holders. It has been found in practice that i.f. strips using wired-in valves are much more stable and give increased gains over plug-in valve types.

Techniques such as potted and printed circuits are of interest in improving reliability, as experience has shown that potting components gives a gain in reliability of at least 3 to 1 over open constructions. Sealing or potting of the components protects them from the adverse effects of humidity, vibration, etc.; from the design point of view, sealing is essential if long lives and good reliability are required. The printed circuits are free from vibration defects and are remarkably stable provided they are used in sealed equipments. They are reproducible with great accuracy so that performance changes due to, for example, displaced wires in high gain amplifiers, do not occur.

The unit system of construction is being adopted by most manufacturers of Service equipments to-day. Accessibility of components should be easy if components fail, and the unit system results in easier servicing. Interconnection between units raises problems, as each plug and socket is a possible cause of unreliability. Some typical examples of equipment design for ease of maintenance are shown in the illustrations.

Figure 1 shows a design for ease of maintenance in which the sub-units are lifted from the main chassis by collapsible rings. Maximum accessibility is thus provided for servicing whilst the equipment is still operating. The units slip back into place when repairs are completed.

Figure 2 shows a sealed and pressurized radar equipment in which accessibility to the components is provided by swinging back the lid of a rectangular chassis. The lid also carries components which are then accessible for maintenance.

Figure 3 shows a construction in which any or all of five sub-chassis can be swung out for maintenance whilst the equipment is operating. Each sub-chassis can also be unplugged for rapid replacement.

3.5. *The Use of New Design Techniques*

In high-power transmitters and modulators, hydrogen thyratron valves have lives which may be quite limited. It is possible to replace the modulators by magnetic modulators to produce comparable pulses; being based on transformer techniques the magnetic modulators are inherently more reliable. Magnetic amplifiers using similar transformer techniques can be used to replace valve amplifiers and, again, they are inherently reliable in design. Gyrator ferrite cores may soon be used in waveguides to replace T.R. and T.B. cells, valves being replaced by a block of ferrite material which is inherently less prone to faults. Other techniques are being developed which will in time improve the reliability of designs as we now know them.

4. Reliable Radar

As an experiment in design techniques, work has been done in the last two years at the Radar Research Establishment on a typical airborne search radar system to achieve maximum reliability. All the design points mentioned earlier are being incorporated in this equipment and it is intended that, apart from gaining useful experience in reliability design, a standard of reliability performance of a typical complex airborne radar system can be established. Much time has been spent in simplifying the circuits, and in obtaining the best possible components which are suitably de-rated. Potted circuits are being used to give protection to components, and magnetic modulators, magnetic amplifiers, etc., are used to replace valve amplifiers. The mechanical design of the scanners has been investigated and metals and materials used are being thoroughly inspected. Solid block waveguide techniques are being used instead of section waveguides and an improved system of rotating waveguide joints has been designed and incorporated. Wired-in valves and cathode-ray tubes are used throughout.

All the experience gained in pre-testing equipments is being incorporated in this experimental radar system which, it is hoped, will give some standard of performance to be expected by special design for reliability.

Figure 4 shows the construction of the synchronizer unit and Fig. 5 the indicator.

5. Conclusion

It has been shown that much work is being done on design for improved reliability, but it must be emphasized that every individual component and technique, and even workmanship, are links in a chain, and any weak link will render all this work of little value. Painstaking attention to detail is essential and the co-operation of manufacturers of equipments and of valves and components is essential if equipment is to operate without undue maintenance.

6. Acknowledgments

The author wishes to express his thanks to the Chief Scientist, Ministry of Supply, for permission to publish this paper.

Part II* submitted by

Major R. B. Brenchley, R.E.M.E. (Army representative)†

1. Introduction

Before giving the Army's views on the maintainability aspect of electronic equipment it is important to have a general picture of the existing organization and the conditions under which repair is carried out in the field. These factors, which are themselves dictated by operational, technical and strategic considerations, influence to a considerable extent the design policy of the War Office.

Briefly, there are three categories of repair called Unit, Field and Base. Unit repairs are those which can be carried out by the user or by technicians held on his strength and in the main are concerned with getting the most out of the equipment by preventive servicing, re-adjustment and rectification of minor faults, such as valve failures, fuses, faulty inter-connecting cables, etc. The range of repairs in this category can be judged from the repair facilities available to the technician. These generally amount to a kit of hand tools, a multi-range meter, and possibly a special test set to indicate the overall functioning of the equipment.

Repairs which cannot be dealt with by the unit but which do not involve an extensive rebuild are called Field repairs, this category embracing the great bulk of the workload. Repair is carried out by mechanics under the direction of an Armament Artificer or Officer, and takes place in special 3-ton vehicles equipped with a comparatively wide range of test gear, the operational performance of the equipment being substantially restored to its original specification. This work may either be done at

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the workshop location or in unit lines, depending on such factors as the portability of equipment and the urgency of the repair. Repairs are usually carried out by an electronic element of a R.E.M.E. workshop, but in certain cases repair to telecommunications equipment is carried out by Royal Signals. Field workshops also inspect equipment in the hands of troops and where this is below a certain standard, the Field Condemnation Standard, it is taken back to the workshops for repair.

The fact that field workshops are mobile means that facilities and test gear must be adequate and must be kept as simple, robust and easy to operate as possible. Moreover, since mass repair methods are not possible, repair personnel must be highly trained and very versatile.

Base repair, as the name implies, is work carried out at the operational base of the theatre of war. Here, repairs are undertaken which are beyond the technical capacity of field workshops; examples are equipment extensively damaged or needing special tools and test gear, and test equipment in need of adjustment and re-calibration. Equipment which has become unreliable as a result of repeated handling during field repair will be stripped and rebuilt to its original specification both electrically and mechanically. A fully static organization is acceptable at the base and conditions approach more nearly to those of factories in this country. The labour force is often predominantly civilian, working under military direction.

Summarizing, repair is mainly carried out well forward in mobile workshops or at the unit itself, with the object of maintaining the maximum of equipment in action with the minimum of dependence on the lines of communication.

2. The Effect of Design on Maintainability

In most of its applications electronic equipment plays a role so vital that repair time must be kept to an absolute minimum. A small equipment could probably be replaced in its entirety and repaired at relative leisure but problems of supply make it impossible to follow such a policy for larger equipments. However, if these equipments are designed as a number of inter-connected, quickly replaceable units, with inbuilt monitoring facilities, the faulty unit can be quickly located and replaced by a spare.

These small equipments or faulty units must themselves be repaired rapidly, otherwise an unacceptably large pool of spares would have to be carried. To this end the design should be centred around a number of sub-assemblies of functionally inter-connected components so arranged that they can be removed and replaced with comparative ease. Plug-in sub-assemblies are extremely convenient. However, soldered-in units are to be preferred from the point of view of equipment reliability and can still be made replaceable with comparative speed. The designer should incorporate monitoring points to ease the task of locating a faulty assembly and this monitoring system must be designed with the full knowledge of the range of test equipment and tools available to mobile workshops in the field.

There are many detailed points of design which can greatly assist the task of maintaining electronic equipment and these are briefly summarized in the Appendix.

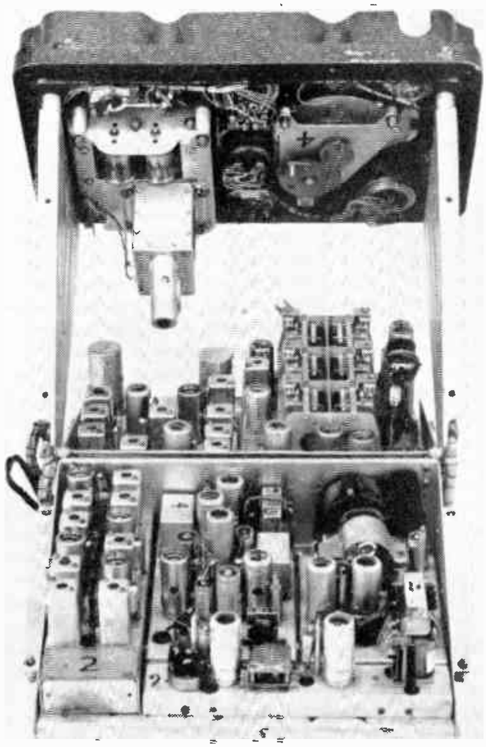
Unfortunately, it is not always possible to design equipments to fit in with the ideals of the maintenance staff; many of these ideals conflict with the user's requirements for size, weight and shape, so that in the end a compromise has to be made. To ensure that whilst primarily meeting user requirements the maintainability aspect is not overlooked, the design is watched throughout its development by R.E.M.E. detachments called Maintenance Advisory Groups which form part of our Maintenance Technique Development Establishment. These MAG's are staffed by military personnel who have had extensive experience in the field and they work at the designer's elbow to make certain that at all stages the ease of repair aspect is considered.

When the equipment has advanced to the prototype stage it is given a trial by the user and immediately afterwards it is passed to the Maintenance Technique Development Establishment R.E.M.E. for an ease of repair trial. At this latter trial various repairs and adjustments are carried out to ensure that the work of the MAG has resulted in an equipment which is easily maintainable. Recommendations are made for design changes to give improved ease of maintenance. These, together with design changes required by the user arm, are embodied in a revised prototype, which after further trials and modifications becomes the accepted model on which production is based.

3. The Conflict of Design Requirements

In the Army, the requirements of portable field equipment are extreme robustness, coupled with reliability, simplicity of operation and portability. These requirements are largely conflicting but by good design a fair compromise can be worked out. At first sight it would appear that the use of miniature components would provide an answer to the size and weight problem, but this solution would also bring in its train problems of its own. The main problem is the difficulty of fault tracing by conventional point-to-point methods since miniaturization would result in functionally grouped components being lumped physically close together. This problem could be overcome, however, by building a miniaturized equipment in such a manner that functionally grouped components formed an easily monitored, readily removable sub-assembly. Provision would, of course, be needed for inbuilt monitoring facilities or sufficient test points for the connection of external test equipment. By this means faulty sub-assemblies could be readily traced, rapidly replaced and a very short "out-of-action" time achieved, the faulty units being repaired at the most convenient place. An essential of such a system would be that to achieve the short "out-of-action" time any sub-assemblies must be capable of adjustment or alignment at the time of manufacture or repair and should need no extensive or intricate adjustment after being fitted. Ideally the sub-assemblies would also not require elaborate test jigs for alignment during repair. By adopting the soldered as opposed to the plugged-in type of sub-assembly, a high degree of reliability can be attained consistent with comparatively rapid sub-assembly replacement.

Reliability of electronic equipment depends to a large extent on the ability of components to work under all atmospheric conditions; because of this it is frequently necessary to use components capable of operation under wide variations of temperature and humidity. In general these components are larger than their counterparts for use under more comfortable conditions. If this method is adopted as a means of achieving reliability, the size is likely to increase and as a result there is a conflict between the design requirements of minimum size and weight and maximum reliability. An attractive solution might be in the use of



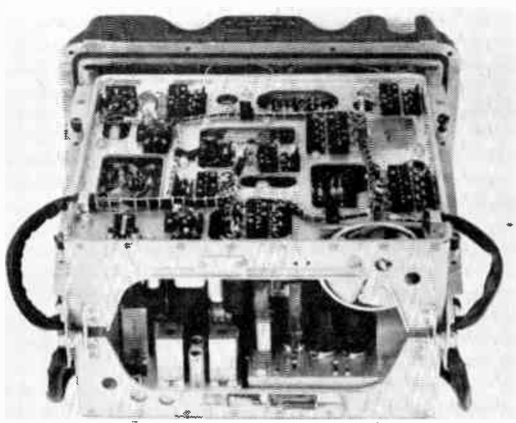


Fig. 1.—Illustrating hinged book-form construction. The top view shows the easy access to all components, including front panel items.

The lower view shows the set closed up. Terminal blocks for sub-unit inter-connections can be seen. These are also useful test points.

miniature components, not in themselves pan-climatic but protected from atmospheric conditions by sealing the complete equipment. More detailed examination, however, of this possible solution will reveal that it has certain disadvantages, particularly the problem of keeping the equipment sealed and the components dry. Since fairly elaborate equipment would be required to dry out and seal test it is obvious that unit repairs would be somewhat limited in scope.

Another conflict arises from the tendency of the user to demand a maximum of facilities to be incorporated in his equipment. This greatly increases complexity, and there is an attendant increase of the workload on the maintenance and repair organization. With the vast flexibility of technique to-day, almost any requirement of the user can be met, but often only to the detriment of reliability or size and thus it is imperative that the designer should represent to the user the cost of providing these technical refinements in terms of any decrease in reliability and increase in workload. Simplicity of operation can only be gained at the expense of technical simplicity and here again a compromise must be made between the advantages accruing from simpler operation on the one hand and an increase in complexity and work which attends it on the other.

In general, a final design must always be a compromise worked out by the designer, the user, and the maintainer, both at the inception of the requirement and throughout the succeeding development and trials.

4. The Effect of the Increased Quantity of Equipment

The introduction of radar early in the last war marked the commencement of an expansion in the employment of electronic techniques which has since rocketed to formidable proportions. Generally speaking, there is a benefit from this in that the increase in automaticity which follows the adoption of electronic techniques gives rise either to increased weapon efficiency and a more economical utilization of the user manpower, or an actual saving in the number of men needed to operate a weapon.

Unfortunately, from the manpower point of view, this reduction in requirement for relatively unskilled men is at the expense of an increase in demand for technicians, and the shortage of this class is one of the major problems which faces the Army in common with the electronics industry. Training is constantly going on at the highest pressure but finally there is the limiting factor of the number of men entering the Services with the right intelligence level and educational background. This largely reflects our general standard as a nation and cannot be altered materially by the Services. The suggestion of decreasing standards so as to accept a larger proportion of the intake immediately presents itself, but this has proved to be no solution; a certain minimum of knowledge of basic principles, equipment techniques, and equipment practice is essential, and any reduction below this, although increasing the availability of manpower numerically, brings about an overall loss because of their individual decrease in effectiveness.

The electronic circuit is still comparatively unreliable by comparison with its mechanical counterparts and a failure either immobilizes a weapon or at best greatly reduces its effectiveness. Although preventive maintenance can do much to anticipate failure, there remains the inevitable breakdown which must be remedied with a minimum of delay. A great deal of help can be derived from inbuilt monitoring facilities which enable the user to locate and exchange faulty units, but there is a limit to the number of spare units which can be carried in modern mobile warfare; this imposes the need for quite extensive repair facilities well forward, since the alternative of depending on a sure supply of repaired units from base via the lines of communication is limited by various factors which are outside the scope of this paper. The vulnerability of both equipment and supply lines justifies the, at first sight, uneconomical system of carrying out the greatest volume of repair work well forward in field workshops.

5. The Calibre of the Men Employed in the Workshops, and their Training

Electronic equipment has so wide a range of application in the Army that it is not practicable to train a mechanic who is competent in the whole field. Further, since National Servicemen form a large proportion of the material available for training, it is necessary to keep the length of courses as short as possible and, to this end, specialization has been adopted to the extent that we now have many different types of mechanic.

The responsibility for servicing and repair of telecommunications equipment is shared between Royal Signals and R.E.M.E., whilst R.E.M.E. are solely responsible for servicing and repair of radar and associated equipment.

In R.E.M.E. there are three classes of skill. Class III, the lowest, is a man with a fair knowledge of electronic theory and with a superficial understanding of the principles underlying the equipment with which he has to deal. In general, he is not competent to take the initiative for repairing an equipment but he can do useful work under supervision. Class II mechanics have a thorough understanding of basic theory and a detailed knowledge of the equipments in which they specialize. They are competent to locate and repair all but the most obscure faults. Class I mechanics are upgraded from Class II on the basis of experience and ability; they are capable of some supervisory duties and carry out more skilled operations, such as alignment and calibration, under supervision.

Royal Signals are responsible for operation, servicing, unit repair and installation work on telecommunications equipment. This work is carried out by three trades, radio mechanic, line mechanic, and telecommunication mechanic. These trades are also divided into three classes of skill and, in general, the dividing line between the classes is the same as outlined above. These trades differ however from R.E.M.E. trades, which are primarily concerned with workshop repair, in that more attention is paid to servicing, unit repairs, installation and circuit engineering.

The backbone of the Army repair system is the R.E.M.E. Armament Artificer. These technicians, holding the rank of Staff Sergeant or above, cover a far wider field than any mechanic and are recruited from regular soldier Class I mechanics of proved ability. They are given extensive training in basic and equipment principles, the standard approximating to that of the Higher National Certificates. Armament Artificers are capable of diagnosing and carrying out all types of repairs and adjustments to their equipments and can be entrusted with the organization and control of small repair groups.

Similarly the Foreman of Signals is the Royal Signals' telecommunications expert on installation, servicing, repair and circuit engineering. His training is in four parts. He first gains experience in a working unit, usually in one of the three mechanic trades; after passing an entrance examination he then attends the Part I of the Foreman of Signals course, he is then sent back to a unit to gain further experience, finally returning to the School of Signals for Part II of his course.

In addition, there are officers who are professional engineers and who have a broad-based understanding of the whole range of electronic equipment used in the Army. These officers carry out the technical organization, training, staff work, and system engineering in the Army at all levels and also assist the Ministry of Supply in the design of a new equipment.

6. The Servicing Information Available

Each equipment is covered by a series of servicing handbooks which give:—

(*a*) A general "thumb-nail" outline of the equipment, giving its function, range, power requirements, size and weight.

(*b*) Instructions to the operator on how to set up and operate the equipment (items of test equipment only).

(*c*) A general description of the equipment giving a technical explanation of its operation together with detailed circuit and layout diagrams and other servicing information.

(*d*) Repairs and adjustments which may be carried out by the user or his attached technicians.

(*e*) Repairs and adjustments to be carried out in field and base workshops.

In addition there are more general publications which cover such subjects as: technique of soldering and repair; unfamiliar technical principles; the current range of test gear issued to field units in the Services; details of standard frequency broadcasts, etc.

User handbooks are also produced for all items of communications equipment. These give an outline of the principles of operation, operating routine and operator's servicing.

7. Conclusions

The outstanding lesson which must be learned is that maintainability must be considered at all stages in design. It is not sufficient to complete the prototype and submit it for criticism; there must be stage-by-stage consulation to ensure that the equipment will be capable of being dealt with by the man in the field, equipped with his existing tools, test gear and facilities. If a new technique should demand new test gear, this must be developed concurrently with the main equipment and should be designed with a view to future extensions of the technique.

There are two outstanding benefits which arise from having equipment designed so that it is easy to repair. Firstly, the out-of-action time of equipment is reduced by rapid diagnosis and repair. Secondly, the more maintainable the equipment the smaller the number of technicians needed to support a given force; this can go far to prevent the technical manpower shortages which promise to develop in the age of guided missiles.

8. Appendix: Design Features Recommended by the Army

Constructional Details

1. *Weight Limitation and Handling Requirements*

(*a*) Panels, units or chassis should normally not exceed 60 lb in weight excluding the transit/protective case.

(*b*) Cabinets, panels, units or chassis must be provided with suitable handling devices.

(*c*) Cabinet-mounted panels should be provided with cradles and runners or other approved devices to permit easy withdrawal for servicing, preferably without interfering with the operation of the equipment.

(*d*) The design of panels, etc., should enable equipment to be rested on any side without damage to the components.

2. *Disposition of Components, etc.*

(*a*) Components should be grouped on panels, chassis or in units according to circuit functions.

(*b*) Assemblies or components, which need frequent setting up or which are liable to require attention due to low reliability or for other reasons, should be placed in an accessible position. Methods of mounting these assemblies or components must be secure, but should allow for rapid removal.

(*c*) Fragile components mounted on panels, etc., should not be positioned in exposed places but should be shielded as far as practicable, guard rails being used where necessary.

(*d*) Pre-set controls required for the initial setting up of units should be located to the front of the panel. Positioning should be so arranged that, when adjustments are made, the indicating devices can be easily read. Controls which are solely the concern of the maintenance staff should not be readily accessible to the operators. They should be labelled clearly to indicate that they are for use by maintenance staff only.

(*e*) Small portable equipments should be constructed on the sub-assembly system, each sub-assembly containing a valve stage or valve stages and being replaceable without realignment. Sub-assemblies requiring infrequent replacement should be soldered in, the soldered connections being grouped and easily accessible. Sub-assembly fixing devices should be easily identifiable.

(*f*) Panels and units of static, mobile and transportable cabin equipments should be rack- or cabinet-mounted.

(*g*) Certain equipments, particularly on mounted gun-carriage and fighting vehicle equipments, should be divided into a number of easily detachable units (as far as circuit conditions allow such sub-division), to enable repairs on site to be effected by replacement of faulty units.

3. *Accessibility*

(*a*) Access to any single component for identification, testing or replacement is desirable without completely removing its parent chassis. The conventional "inverted tray" chassis is not always the most suitable form and other methods, such as "stepped construction," should be considered. Valves should always be easily visible.

(*b*) The disposition of the racks should allow free access for maintenance and for the removal of panels and dust covers.

(*c*) Plugs and sockets should be fitted in such a way that panels can be removed without unsoldering connections.

4. *Miniaturization*

In order to avoid unnecessarily difficult repair techniques, miniaturization should not be pursued for its own sake.

5. *Safety Requirements*

Automatic locking of cabinet-mounted panels must be provided both in the normal and withdrawn positions. Where points of dangerously high potential are exposed release devices must be interlocked with safety switches. Neutralizing devices requiring a special key must be provided to enable power supplies to be maintained for test purposes.

6. *Duplication of Components and Units*

Where a component or assembly has a short life and where it is important that the equipment should be repaired rapidly, consideration should be given to the fitting of stand-by components or assemblies which can be put into the circuit by a switch or link.

7. *Sealing, Storage and Drying*

(*a*) Equipments should be designed so that a minimum of work is required when placing into, or taking out of, long-term storage.

(*b*) Mobile cabins and vehicle bodies containing unsealed equipments should be provided with access points to allow the circulation of dry air from an external plant during storage. Standard couplings will be required at each point.

(*c*) Where equipments are hermetically sealed, external indication of the humidity within the equipment must be provided.

(*d*) Two coupling points of standard sizes should be provided in accessible positions on any sealed equipment, suitably spaced to allow the circulation of hot dry air and for seal testing.

(*e*) Leads from sealed equipments must be capable of being repaired or replaced without breaking the hermetic sealing.

(*f*) Components such as desiccators, known to require frequent renewal, should if possible be replaceable without breaking the main seal of the equipment.

Design Requirements for Components

8. *General*

(*a*) Components and assemblies should be standardized wherever possible with corresponding items in other equipments.

(*b*) Replacement components and assemblies should be electrically and mechanically interchangeable without modification or adjustment to the main body of the equipment.

(*c*) All plug-in components must be fitted with retaining devices.

(*d*) Circuit designs permitting the use of wide tolerance components are preferred; nevertheless a closer tolerance should be specified than is indicated by the design to allow for drifting of component values. An anticipation of the direction of drift will reduce maintenance.

(*e*) The shelf life of components should be at least five years. The necessity for special storage arrangements must be avoided.

(*f*) Components requiring special tools for removal should be avoided.

(*g*) Oil-immersed components must be adequately sealed to prevent weeping in any position in which they may be mounted, and must be capable, where necessary, of easy draining and refilling.

The oil used in such components should be selected from the normal W.D. ranges or comply with normal W.D. Specifications.

(*h*) Before a component (especially a valve) is used in an application which calls for a performance outside the maker's published rating, prior consultation must take place between the Equipment Design Authority and the component designer and manufacturer, to ensure that it will perform satisfactorily in the proposed role.

9. *Pre-set Components*

(*a*) These should not be unduly critical or interdependent and should have an adjustment range adequate for alignment purposes.

(*b*) They must have locking devices which are positive, easy to apply and release, and which do not affect the setting.

(*c*) Slot-ended control spindles for screw-driver operation may be used but care must be taken to ensure that the head is robust enough to stand constant adjustment without stripping.

(*d*) Controls for setting up for action, such as c.r.t. "X" and "Y" shift controls, although of a pre-set character, should be provided with knobs and locking devices. They should be conveniently positioned for the operator and protected from damage.

10. *Electrolytic Capacitors*

These should be avoided if they are liable to deteriorate. Where their use is unavoidable they should be capable of easy removal to simplify the preparation of the equipment before and after long-term storage.

11. *Valves*

(*a*) These should be selected from the "Services List of Preferred Valves." The necessity for ageing and selection of replacement valves is not acceptable, except in exceptional circumstances and after consultation.

(*b*) The valves selected should be proved capable of giving an operational life appropriate to the equipment in which they are used, and during the course of this operational life premature failures must be as few as is practicable. The percentage of premature failures that is acceptable will vary with different types of equipment. In certain cases "special quality" valves should be used.*

(*c*) Circuit designs should be rationalized so that a minimum number of different types is required.

(*d*) Circuit design shall be such that wide limits of valve performance are permissible.

(*e*) Valves must be loaded at less than their maximum rating.

(*f*) Valves must not be operated above their maximum temperature rating.

12. *Sliprings*

(*a*) Must be readily accessible for maintenance but should be protected from the ingress of dust and moisture.

(*b*) Spare sliprings should be provided where practicable for the extension of facilities and emergency repairs.

13. *Plugs and Sockets*

(*a*) Plugs and sockets of the standard joint-Service range must be used.

(*b*) Locking devices should be fitted.

(*c*) The tags of fixed plugs and sockets must be readily accessible for maintenance purposes.

(*d*) The mating should be unique for each function on any one equipment.

(*e*) Plug and socket pairs should only be capable of mating in the correct orientation.

(*f*) Wherever possible the female will be live and not the male.

14. *Screen Cans*

Where necessary, separate cans should be provided for individual sub-assemblies or components. The use of one large screen with several sections is to be avoided.

15. *Protective Devices*

(*a*) Consideration should be given to the more extensive use of resettable cut-outs, automatic in action if possible, in place of fuses.

(*b*) Indicating devices, e.g. warning lamps, are of great value in many circumstances. Their provision should be considered.

* See, for instance: E. G. Rowe, "The technique of trustworthy valves," *J.Brit.I.R.E.*, **11**, p. 525: Nov. 1951; "Special quality valves," **13**, p. 274, May 1953.

16. *Bolts, Screws and Nuts, and Plain Washers*

(*a*) These should be selected from the British standardized unified thread screw range where possible. If such a standard screw is not available or for various reasons is undesirable, British Asssociation sizes should be used. A minimum number of types and sizes should be used in any one equipment. Screws requiring special tools should only be used where their removal is likely to be infrequent.

(*b*) They should be captive and/or self-locking as far as possible.

(*c*) Quick-action fasteners may be used where the loading is light.

Design Requirements for Connections

17. Cable-forms and cable-looms must be accessible for repair and replacement. Spare cables should be provided in each "form" or "loom."

18. Long unsupported lengths of cables or wires must be avoided.

19. In cabinet-mounted equipments, connections to panels and units should be by a section of flexible cable, allowing the connections to follow the travel of the panel to the "out" position, thus maintaining supplies without the use of extension leads. Provision should be made for the easy replacement of the flexible section.

20. Connections of power supplies to cabinets, panels, etc., should be by means of plugs and sockets separate from those carrying functional data.

21. To enable wires and components to be speedily removed without damage to themselves or their binding posts, spills or tags, soldered joints should be made so that they may be unsoldered without the application of excessive heat. Multiple turns or wire around terminals must be avoided. Connections to tags should be restricted to one per tag-end; and alternatively tags with multiple or elongated holes should be provided.

22. The type of insulation used on connecting wire should not "run-back" appreciably on the application of heat in normal soldering operations.

Identification Requirements

23. *General*

(*a*) All assemblies and components, where size permits, should be marked with the appropriate catalogue number.

(*b*) The circuit reference of sub-assemblies or components should be marked on the chassis, etc., adjacent to each sub-assembly or component.

(*c*) Connections from multi-terminal components and assemblies must be easily identifiable.

(*d*) The fuse rating of panel fuses should be indicated on the panel.

(*e*) Modification record plates should be fitted to each main equipment. Each assembly likely to be repaired separately from the equipment should be provided with a means of recording modifications.

(*f*) Graduations and other marking should be of reasonable depth in order to obviate the necessity of re-engraving during overhaul.

(*g*) In large equipments each assembly and sub-assembly should be identified by a reference number or letter. In addition, production serial numbers should be shown, care being taken to distinguish between different contracts.

24. *Chassis Wiring*

In circuits which include valves, wiring should be colour coded in accordance with the B.S. Specification.

25. *Inter-connection Cables*

(*a*) The cores of inter-unit cables and leads must be identified by numbers adjacent to the terminations. Identification may be by means of a clear and durable numbered band or by all-coloured bands conforming to the International Resistor Colour Code. The digital value of the colour of a sleeve shall be printed on it as an aid to the user with defective colour vision and at least two printings of a number shall occur in each sleeve. When colour coding is adopted, the number must be read from the termination.

(*b*) Where multi-core cables with continuous core identification are used, additional core numbering is not required.

(*c*) Cables connecting two units or panels should be labelled at each end with the designations of the two panels which they connect. For example, "PZ/A."

26. *Plugs and Sockets*

Each plug and socket pair should be given a distinctive colour or combination of colours to guide connection, and act as a safeguard where mating is not unique.

Test Facilities

27. *General*

(*a*) The design and construction of the test gear should conform to the requirements set out above and should be more reliable than the equipment under test.

(*b*) The test gear should be as simple as possible to operate. Readings should be easy to interpret and devoid of ambiguity.

28. *Monitoring*

(*a*) Devices, particularly in large equipments, should be provided to permit routine checks on performance and to isolate faults to particular units or panels.

(*b*) These devices should normally be built into the equipment and there should be no necessity to remove covers, panels, etc., to carry out the check.

29. *Test Points*

(*a*) These are required to simplify the application of external test gear for rapid checking of the performance of the equipment, as a whole, by units and by components, and for the diagnosis of faults.

(*b*) Test points must be readily accessible.

(*c*) It must be possible without breaking circuit connections to measure supply and electrode voltages, and to indicate cathode currents where this facility does not prejudice circuit performance.

30. *External Test Gear*

(*a*) Existing test gear from the present range should be used where possible.

(*b*) Where existing test gear is inadequate, further equipment must be provided. Where technically and economically practicable, this new gear should be designed to cover the needs of old equipments and the probable requirements of other new equipments. It is of great importance that the number of types be kept to a minimum.

Part III* submitted by

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1. Introduction

The first essentials for radio, radar and similar electronic equipment in the Royal Air Force are that it should meet the stated requirement for operational performance and that the equipment should be highly reliable. It should be capable of operation in all parts of the world and, in the case of airborne equipments, at all altitudes; other essential requirements are ease of servicing and minimum weight.

The emphasis in this paper has been placed on airborne radio equipment, but it will be appreciated that the R.A.F. is a major user of ground radio equipment in its fixed, mobile and transportable forms; to a much lesser degree the seaborne problem is also present.

2. Reliability and Ease of Servicing

It is essential that any radio equipment for the Royal Air Force should have a high rate of serviceability. Serviceability can be defined as availability for use when required and depends on reliability, ease of servicing and the availability of skilled manpower.

The complexity and quantity of electronic equipment being introduced into the Royal Air Force will outstrip the ability of the Service to maintain the equipment unless every effort is made to make the equipment as reliable as possible consistent with the limitations imposed by the design requirements. Equally, it is essential that due regard be given to the servicing requirements arising from the acute shortage of skilled tradesmen in the Royal Air Force.

The actual design of equipment is not within the province of the Royal Air Force but it is apparent that maintainability can be aided by improvements, where possible, in the following: component reliability, circuit stability and simplification, protection of components, clear fault identification, accessibility of components for repair and replacement, and identification of these components.

Ideally the Royal Air Force needs equipment to have a maximum fault-free life coupled with a minimum of servicing. Unfortunately this question of reliability and maintainability conflicts at many stages of design. As an example, when a unit is broken down into sub-assemblies for easy replacement this generally means more plugs and sockets with an increase in the number of sliding contacts and the consequent reduction in reliability. On the other hand, if reliability can be assessed as the length of time the equipment is available for service in relation to the time out of service, any saving of time in servicing increases reliability.

However, let us assume that if the equipment has been designed to meet the Ministry of Supply Specification of an expectation of 1,000 hours' or 2½ years' life before servicing—other than accessible adjustments which need to be carried out—then the points affecting reliability have been watched. This leaves manpower, to be covered later in the paper, and design features to aid ease of servicing.

Some of the vital features which are laid down in Ministry of Supply specifications are as follows:

Squadron Level (first line)

(*a*) The equipment must be easy to disconnect, handle and connect with gloved hands.

(*b*) Assemblies should be interchangeable mechanically and electrically without need for adjustment.

(*c*) Limited-skill tradesmen should be able to determine if the equipment is working satisfactorily without complex tests and without touching the adjustments of the set. As an example, reliance on a "dip" reading on a meter means you must adjust to test.

(*d*) As far as possible tests should be carried out *in situ* and the "breaking of connectors" avoided.

Station Workshop Level (second line)

(*a*) Equipment should be made on sub-assembly principle and must be capable of being broken down without disturbing or damaging other sub-assemblies.

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U.D.C. No. 621.37/9 : 623.

(*b*) Sub-assemblies should be interchangeable and ideally no adjustments should be necessary on replacement.

(*c*) Components must be easy to identify, test and replace.

(*d*) Circuits should be designed to operate at peak performance under all normal conditions. Realignment should not require a high level of technical skill and once "set up" should stay so.

(*e*) Monitoring facilities should include identifications of all major waveforms and supplies.

3. The Limitations imposed on Airborne Radio Equipment

Problems of humidity, vibration, pan-climatic conditions and the packaging and transport hazards are common to all ground, seaborne and airborne equipments. Airborne equipments have, however, special problems of their own which need consideration during design. These are abnormal temperatures and temperature changes, changes in pressure, high acceleration and heavy vibrations. The main features of these problems are as follows:

Air temperature.—The range of temperature can vary in exposed parts of an aircraft from + 70° to − 70°C and even in pressure cabins from + 70° to − 40°C. With the rate of climb of modern military aircraft changes in temperature of 100°C can take place in a very few minutes.

Pressure changes.—Equipment has to stand a pressure differential according to the rate of climb or descent. As an example, equipment in an aircraft climbing from sea-level to 40,000 ft. has its pressure reduced from 14·7 lb/in^2 to 2·7 lb/in^2. Problems of high-voltage flash-over corona and cooling difficulties have to be faced.

Acceleration.—In some cases up to 13*g* must be allowed for in flight and up to 25*g* to avoid injury to a crew in a crash-landing.

Vibration.—The equipment can be subjected to very high vibration up to a frequency of 200 c/s within the aircraft and up to 500 c/s near the power unit.

The Ministry of Supply cover all these points in their testing schedule to which equipment is subjected before it is approved for Service use.

4. The Effect of Increased Complexity and Quantity of Equipment

The increasing complexity and quantity of electronic equipment installed in aircraft (a figure of over 4 tons for a modern bomber was quoted in a recent broadcast) has led to certain additional problems of which the following are typical examples.

(*a*) Weight saving has resulted in the possibility of reduction in strength and rigidity.

(*b*) The need for reduction in space has led to miniaturization with its problems of instability and difficulty of servicing.

(*c*) The large increase in the number of components (one equipment can comprise up to 2,500), means a reduction of reliability by sheer numerical ratio.

Manufacturers and the Ministry of Supply are well aware of these problems and are always taking active steps to alleviate them. Such methods as stronger but lighter metals, potted and printed circuits, more reliable components, and the reduction of the number of components in a given circuit, are all being used. It would appear however that as fast as an improvement is made, the Royal Air Force asks for another "black box" to be fitted and the weight and size problem is back again.

If we assume that everything possible is being done in this direction, is the Royal Air Force doing all in its power to keep equipment installed in aircraft to a minimum? Should the Service, knowing that unreliability and complexity are synonymous, reduce their demands and be satisfied with equipments with less performance and more reliability or, in some cases, no equipment at all?

For security reasons this problem cannot be examined in this paper but it must be obvious that as aircraft fly faster and higher they must become more difficult to find, catch and shoot down. Similarly, it is no use producing nuclear weapons and aircraft costing up to £500,000 each to carry them unless it has been ensured that the aircraft can reach its target, bomb it accurately and then find its way home and land whatever the weather. While the Service must play its part by avoiding at all costs unnecessary frills, electronic equipment must keep pace with modern air-warfare requirements.

5. The Manpower Problem

A recent report from the Select Committee on estimates stated that Royal Air Force non-flying personnel and civilians at home represents a force of 148,000 trained servicemen and women, 40,000 trainees and 46,000 industrial and non-industrial civilians. When it is appreciated that advanced and skilled tradesmen represent over 80 per cent. of this number it will be seen that the manpower problem is formidable.

To understand the problem it is necessary to understand the R.A.F. trade structure which was introduced in 1950 in order to divide the technical manpower available into trades that would enable the best possible utilization of their skill. The part of this trade structure with which this paper is mainly concerned is the Radio Engineering Group. Within this group (apart from trade assistants who have very little knowledge), there are mechanics, who can be termed "semi-skilled" and "skilled," and fitters, who are the "advanced" tradesmen. The "skilled" tradesmen can, generally speaking, be entrusted with routine, i.e. first-line servicing without close supervision, whereas the "semi-skilled" does the same class of work but has to be carefully supervised. The advanced tradesman can, at his lowest rank, carry out servicing at station workshop level, i.e. second line. This work includes the inspection, tuning, adjustment and alignment of assemblies and sub-assemblies. It also covers the diagnosis and rectification of faults. He is expected to have a short specialist course on any equipment on which he will have to do "third-line" servicing.

There is also the "command" ladder which an airman can climb—as this infers, he specializes more in man-management than in outstanding technical ability.

Unfortunately, in common with the rest of the country, the Royal Air Force is suffering from the lack of sufficient "advanced" tradesmen, especially in the electronic, radio, radar and instrument trades. In addition the Royal Air Force is in direct competition with industry for the available technical manpower. On the one hand, the trained and experienced man does not want to leave his niche in industry and on the other hand, men trained by the Service feel, rightly or wrongly, that civilian life is more attractive.

The Parliamentary Select Committee has recommended, as a matter of urgency, that a Joint Advisory Body, representing the Service and Supply Establishments and Industry should be set up to look into the whole question of skilled manpower. Until the Service sees results from this Body and from any schemes which might remove the deterrents to long-term regular engagements it will be forced to concentrate available "advanced" tradesman at higher levels of servicing and rely more and more on the expensive method of servicing by replacement.

6. Methods of Training and the Trade Structure

To meet the technical manpower requirements already discussed the Royal Air Force needs an intake of up to 40,000 airmen per year who need training of which the Radio Trades have their proportion.

This training to "skilled" and "advanced" levels has to allow for three major factors:

(*a*) The proportion of "advanced" tradesmen required in relation to "skilled" tradesmen.

(*b*) That three-quarters of the ground staff will stay in the Royal Air Force for five years or less and over half are either National Servicemen or on three years' engagements.

(*c*) That there is the maximum possible utilization of an airman's time in the service.

Advanced training is given in two parts:

Part 1.—Training in leadership, ground combat and trade subjects to the standard required by an N.C.O. in a skilled trade.

Part 2.—Consists entirely of trade training to advanced trade standard.

If the airman passes Part 1 only he can follow the "command" or man-management tree, if he passes Part 2 only he follows a technical career in the advanced trade. If he passes both he is capable of either job. At the present time there is quite a lot of flexibility in the system up to Sergeant/Senior Technician level.

All airmen who pass advanced training courses become Junior Technicians. On the command side the ranks are the familiar Corporal, Sergeant, Flight Sergeant and Warrant Officer with the provision that an airman must pass a Senior

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Man Management Course before he can become a Flight Sergeant. The advanced trade structure ranks are Corporal Technician, Senior Technician, Chief Technician and Master Technician. Each step has its time and qualification bar.

A direct-entry airman is given a course lasting approximately eight months to become an Air Radio Fitter. If he has already qualified as a Radar Mechanic the course is reduced to $6\frac{1}{2}$ months.

For the younger boy there are two other methods of entry into the ranks: these are as Boy Entrants or Apprentices. Boy entrants are given an 18-months course and pass out as Mechanics whereas the Apprentices, who are destined to be the backbone of the technical tradesmen, are given a three-year course and pass out as fitters. If a full and steady flow of entrants of a suitable calibre for apprentice training could be achieved the Air Force's higher maintenance problem would be considerably eased.

In the case of Technical Officers the regular officer enters by means of a Technical Cadetship. This consists of either a three-year course within the Royal Air Force or a four-year course of which three years is spent at a university. Short Service and National Service Officers can also become Radar Officers—in the case of a degree-qualified entrant the course is 12 weeks plus his O.C.T.U. training.

7. Workshop and Test Equipment

The problem of Workshop and Test Equipment for the Air Force can be divided into three parts—squadron, station and base repair. At Squadron Level the problem of checking serviceability and performance has to be carried out in the cramped conditions of the inside of an aircraft or externally in all weather conditions. In addition, the work has to be so organized that there is no competition between different tradesmen for the same place in the aircraft at the same time, but still allow for a fast turn round of aircraft.

If equipment has been tested and found unserviceable the equipment has to be transported, in its unpacked state, to the Station Workshop. With the increasing amount and complexity of electronic equipment the ideal Station Workshop would be a large, specially constructed building complete with air conditioning or, at least, dust-proofing. However, remembering the mobility problem, allowance must be made for probability of prefabricated or even vehicle workshops. Base Workshops should normally be of a better standard.

With the standard of workshops mentioned and the manpower availability already discussed there remains the question of test equipment. The requirements for the three stages of servicing are as follows:

Squadron Level.—Reliable and robust test equipment to enable mechanics to determine whether the equipment is working within acceptable limits—he must not be expected to make complex calculations or measurements. There is also the need for safe fitting and removal of equipment from aircraft.

Station Level.—Equipment should enable mechanics to trace faults to defective sub-assemblies and to test assemblies on the bench to give optimum performance.

Base Workshops.—To enable fitters to do a complete analysis of faults and alignment of circuits.

8. Development of Servicing Techniques and Availability of Information

There is a special unit whose task is to study and develop techniques of aircraft servicing. By sending skilled officers and N.C.O.s to see the new types of aircraft and radio in production they can work out full servicing schedules, giving number and grades of servicing personnel required. They can also decide what the programme of routine inspections should be. There is also another unit which keeps officers alongside the scientists at the Research Establishments and advises on the General Service technical requirements for new radio equipments. They also check servicing publications and train a nucleus of instructors for the training schools. This unit also assists the user Commands during the early stages of the introduction of new equipment.

Documentation is extremely thorough, the basic framework being an Air Publication comprising six volumes for each equipment. The volumes cover information as follows:

Volume 1.—General and Technical Information.

(This includes fault diagnosis)

Volume 2.—General Orders and Modifications.

Volume 3.—Equipment Schedules and Scales.

Volume 4.—Planned Servicing Schedules.

Volume 5.—Basic Servicing Schedules.

Volume 6.—Repair and Re-conditioning Instructions.

In Volume 4 work is timed and sequenced so that it can be done by a team of given size, whereas in Volume 5 the work is listed by trades, components or systems and need not necessarily be done by a team of given size.

These documents cover the whole field required for maintenance, but, like all technical documents, the necessary knowledge and ability are required to make use of them. Anything which can be done to simplify the information so that it can be used by tradesmen of less skill would have far-reaching effects on manpower utilization.

9. Conclusions

Equipment should be made as reliable as possible even at the sacrifice of ease of servicing though this must not be made the excuse for bad design.

A modern aircraft imposes great strain on equipment and great care must be taken early in design to watch these points, especially the problem of operating at high altitudes.

If the Royal Air Force is to be maintained as a modern and efficient fighting force, equipment must become increasingly complex and there must be a greater quantity. The R.A.F. must play its part by only asking for essential operational requirements without frills.

The manpower problem is a matter for grave concern, which is fully recognized, and awaits further action on the lines of the report by the Select Committee of Estimates.

The Royal Air Force has the requisite trade structure and training machine—all it requires is the right manpower.

10. Acknowledgments

The author wishes to thank the Air Ministry for permission to present this paper. The views expressed are his own and are not necessarily held by the Ministry.

Part IV* submitted by

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1. Introduction

This paper is concerned with the problem of maintaining and repairing electronic equipment fitted in ships and aircraft of the Royal Navy. In the case of aircraft, the discussion is limited mainly to those aspects in which the Naval requirement differs from the R.A.F. requirement. In addition to the electronic equipment fitted in ships and aircraft, the Navy is also responsible for the maintenance of electronic equipment fitted in Naval Shore Wireless Stations, Training Establishments and defended ports and harbours, but consideration of problems connected with this equipment is excluded as these problems are of a less specialized nature. "Electronic," as used here, includes wireless and radar.

2. Shipborne Electronic Equipment

Electronic equipment fitted in ships ranges from small and comparatively simple wireless sets and audio broadcasting systems to highly complex gunnery systems comprising a radar set and an electronic fire-control system feeding information to guns which are themselves automatically trained and laid by electronic servo systems. Consideration will be given mainly to these larger systems as these will bring out the Naval problems more clearly.

The fact that the equipment has to be fitted in a ship means:

(*a*) size and weight are restricted;

(*b*) the amount of duplication that can be indulged in and the amount of spare units and spare components that can be carried are limited;

(*c*) much sensitive and accurate stabilizing equipment must be included;

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(*d*) the equipment has usually to be fitted in a restricted space and hence problems of heat dissipation and ventilation arise;

(*e*) the equipment must be proof against continuous vibration over a large range of amplitudes and frequencies. It must have high resistance to shock. It must operate satisfactorily over a wide range of ambient temperatures and measures must be taken to enable it to operate in a damp and salt-laden atmosphere. (In special cases air conditioning can be fitted, but this adds extra weight and bulk.)

As a ship must be capable of operating for considerable periods away from a maintenance base, the ship must carry maintenance personnel capable not only of routine maintenance but also of fault diagnosis and repair. Large ships carry their own workshops, stores and maintenance personnel so that they can operate independently for several months at a time. Smaller ships have a more limited maintenance and repair organization and are dependent to a greater or lesser extent on a depot ship or maintenance base.

3. Naval Maintenance Organization

The maintenance and repair of both shipborne and airborne electronic equipment is carried out by officers and ratings of the Naval Electrical Branch. The normal method of entry for Electrical Officers is by the Cadet Entry Scheme, and under this system officers take an Electrical Engineering Degree Course at a university, and are given works training in addition to their normal training as naval officers.

There are two main types of Electrical branch ratings, Artificers and "Electrician" ratings. The Artificer is entered as an apprentice and does a five-year course. He is a fitter and turner and combines skill of hand with a high standard of electrical training. He is specialized in one of the following four categories—ship's radio (radar and wireless), ship's general electrical equipment (including electronic fire control), aircraft radio, and aircraft general electrical equipment. The "Electrician" rating is specialized in one of the same four categories. He has the same status in the Navy as the seaman, but is required to have a rather higher intelligence standard on entry. He receives workshop training in addition to his technical training, but does not achieve the standard of craftsmanship of the Artificer. Selected Electrician ratings receive additional skill-of-hand training and are then known as "Mechanicians." The lengths of a rating's technical courses vary with his specialization; the rating who specializes, for example, in ship radio will receive an initial course of 32 weeks at a Naval Electrical School. After about two years at sea, he will, if found suitable for advancement, receive a further course of 41 weeks to qualify for Leading rate, and will, if found suitable for further advancement, later receive a further course of 20 weeks to qualify for Petty Officer rate. The non-radio courses are somewhat shorter.

4. Maintenance Organization in a Ship

The basic policy employed in a ship is that of "preventive maintenance," the object being to concentrate on preventing failures occurring. Although the number of sudden failures which take place will be reduced by preventive maintenance, some will continue to occur. The ship's Electrical Department is therefore organized to make good sudden failures as quickly as possible, as well as to carry out routine preventive maintenance. The maintenance must also be planned to ensure not only that the equipment "works" but that during the time the equipment is required for use its performance does not fall below the designed performance.

As unnecessary handling and disturbance of electronic equipment can increase the failure rate, preventive maintenance consists mainly of periodical checks on the performance being obtained from the equipment and normally components are not replaced until readings obtained from test points, or meters fitted in the equipment, indicate that replacement is necessary. In this connection the value is stressed of any system which enables a drop in the performance of a component or sub-assembly to be detected, and thereby corrected, *before* the overall performance of the equipment has been reduced.

The main requirements of electronic equipment for fitting in ships are:

(*a*) Maximum reliability consistent with adequate performance and adequate maintainability.

(*b*) The provision of means for telling whether the equipment is working at its designed performance. The tests to determine this must be capable of being carried out: (i) reasonably quickly, (ii) in conditions of radio silence, (iii) without the use of aircraft, etc.

(*c*) It must be possible to diagnose faults quickly.

(*d*) To reduce the time required for repairing equipment, the equipment must normally be capable of being divided into units so that rapid repair can be achieved by the substitution of a defective unit by a spare unit.

(*e*) As the number of spare units which can be carried in a ship is limited, the units themselves must normally be capable of repair in the ship's workshop. For this reason components must be accessible and easily identifiable by reference to handbook diagrams.

(*f*) The use of sub-assemblies which cannot be repaired at sea (such as sub-miniature sub-assemblies or potted circuits) is more an economic and logistic problem than a maintenance one, and the question of whether these should be used would probably have to be answered largely on these grounds.

(*g*) The equipment will usually be operated by Naval ratings who are trained in operating but will have had little technical training. The equipment must therefore be designed so that the *operation* as opposed to the tuning and maintenance does not call for skilled adjustments to be made.

4.1. *Workshop Repair*

As stated above, skilled ratings are carried in ships, and in the larger ships comprehensive electronic testing and repair facilities are installed. Space, however, is always restricted, and working conditions are often bad (e.g. the ship may be rolling and vibrating); the units of the electronic equipment should, therefore, be designed with these adverse working conditions in mind, so that the work of repairing is kept as simple as possible. On the other hand, the skill and facilities available in ships must not be underestimated so that, for example, sub-assemblies are supplied in a sealed-up or otherwise unrepairable form when their repair would in fact have been within the capabilities of the ship's staff.

4.2. *Fault Diagnosis*

As officers and ratings capable of skilled fault diagnosis are carried in all the larger ships, it is not necessary to attempt to make fault diagnosis a purely automatic and unskilled procedure, though clearly the simpler the procedure the better. As, however, it is essential that faults in complex electronic equipment should be remedied as quickly as possible it is important that the means provided for fault diagnosis should enable the nature of the fault to be determined as quickly as possible, even if this requires the exercise of a certain degree of skill and judgment. It is difficult to move heavy test equipment about a ship in safety, and therefore test equipment should either be easily portable or built in to the main equipment.

The training of skilled maintenance ratings represents a considerable effort in time and money, and, therefore, where a choice of techniques is possible in the design of equipment, preference should be given to a technique which is already in use in the Navy, which ratings could be expected to be familiar with, or to one which involves the least training effort.

4.3. *Overall Dynamic Functioning Test*

In the case of a large complex electronic system, such as a fire-control system, it is not enough to know that each piece of electronic equipment is working correctly as a unit. It is necessary to be able to test the system as a whole, and this test must be a dynamic test so that the actual rates of follow-up, the degree of overshoot, etc., can be measured, as well as the final positions assumed for the moving parts.

4.4. *Equipment Handbooks*

Electrical Officers and ratings are given a good basic training, but cannot be trained in the details of every equipment they are liable to meet. They therefore have to rely on equipment handbooks for the details of equipments, and the precise way in which these handbooks are laid out, so as to provide officers and ratings with the information they need in the most suitable form, is an important factor in electronic maintainability.

5. Reports from Sea

The Navy attaches considerable importance to maintaining a two-way flow of technical information on electronic subjects between ships at sea and the Admiralty Design and Research Establishments. In the case of radar and wireless equipment, ships make reports every six months to the Admiralty Signal and Radar Establishment, Portsdown. These reports cover such subjects as suggested modifications in design for improving performance or accessibility. Suggestions and questions concerning other electronic equipment are sent to the Naval Electrical School, H.M.S. *Collingwood.* Here they are dealt with in conjunction with the appropriate Design Authority. A wide selection of all suggestions made from sea, together with the official answers, are issued to ships and other interested authorities so that all may benefit from the experience of one. These reports are one of the means by which existing electronic equipment can be improved, and the lessons learned from them are often embodied in the design of future equipment.

6. Sea Experience

So far as possible those responsible for designing its electronic equipment are given first-hand experience of the conditions under which it will be used and maintained. The day-to-day advice on the maintenance aspect of design is provided in the Design and Research Establishments by Electrical Officers, who will, of course, have had experience at sea in charge of electronic maintenance. In addition, however, arrangements are made for Designers and Senior Draughtsmen to spend short periods in sea-going ships, and Designers have frequently stressed the value of this experience.

7. The Manpower Problem

The Navy shares with the other Services, and indeed with the country as a whole, the problem of the rapidly increasing requirement for technical manpower of a progressively higher level. Naval electronic research and development, and to a large extent electronic design for ship equipment, are, of course, in the hands of the Royal Naval Scientific Service. For maintenance the Naval Electrical Branch is responsible, and here the policy is, broadly, to give the officers an education and training which is both broad and deep so that they can master future developments as quickly and easily as possible, while allowing the ratings to specialize in one aspect of their work so that they can reach an acceptable standard without prohibitively long courses of instruction. Even, however, with the degree of specialization referred to above, which still gives the Naval rating a far wider field than his counterpart ashore, it is impossible to cover in detail, in technical courses, all the equipment a rating will meet at sea. All ratings must, therefore, be given the best grounding in electrical knowledge which the length of course will allow so that they can tackle, with the help of the handbook, equipment which they have not been specifically taught.

8. Airborne Electronic Equipment

The main difference between the Naval and R.A.F. requirements for airborne electronic equipment stems, of course, from the restricted space available in an aircraft carrier compared with an Air Station ashore, and to the fact that a carrier may be operating close to enemy forces.

As only a limited number of aircraft can be carried it is necessary to reduce to the absolute minimum the time for which any aircraft is unserviceable, and this puts a premium on speed in replacing defective electronic equipment. Space limitations restrict the quantity of spare electronic equipment which can be carried which in turn means that so far as possible electronic equipment must be repairable on board. While the need for skilled diagnosis and repair is met by Electrical Officers and skilled ratings in a carrier, and while well-equipped workshops are fitted, space is, as always, restricted. This, and the poor working conditions often encountered at sea, must be borne in mind when deciding the standard of repair which can be carried out in an aircraft carrier. Fault diagnosis and the testing of the repaired equipment must also be capable of being carried out in conditions of radio silence. The limited area of the flight deck, and the very poor working conditions often encountered there, prevent any but the simplest checks being carried out on the flight deck.

The main advantage of carrier maintenance over shore maintenance is, of course, that the same full first- and third-line servicing and repair facilities are immediately available to carrier-borne aircraft however remote the corners of the world where the aircraft may be called upon to operate

9. Naval Electrical Liaison Officers

To ensure that the maintenance aspect of electronic equipment for the Fleet Air Arm is considered at all stages in the design and development of the equipment, Naval electrical officers are attached to establishments under the Ministry of Supply to advise on maintenance matters.

10. Conclusions

The facilities which must be provided in electronic equipment to enable fault diagnosis and maintenance to be achieved must invariably conflict to some extent with the requirements for maximum performance, reliability, and ease of installation. While the final design is bound to be a compromise between contending factors, it is believed that the best compromise will be obtained if the requirements for fault diagnosis and maintenance are clearly appreciated from the start and are allowed for from the earliest stage of design. It is appreciated, however, that those responsible for training the men who will maintain the equipment have an equal responsibility to look ahead and attempt to adjust the training to suit the trend of electronic progress in design.

11. Acknowledgment

This paper is published by permission of the Admiralty, but the opinions expressed are those of the author.

DISCUSSION

In opening the Discussion from the Chair, Rear-Admiral **Sir Philip Clarke,** President of the Institution, referred to the conflicting problems of reliability and maintainability. If equipment could be made 100 per cent. reliable one would not be concerned with its maintainability. If perfect reliability could not be obtained the next best thing would be predictability, in other words to predict how long an equipment or component would last and when it should be replaced. This, too, was not possible and consequently one had to strive for a combination of reliability and maintainability.

Admiral Clarke suggested that two precepts should be borne in mind by designers: firstly, the equipment must be usable by the personnel who were available and not by those one would like to have; secondly, the human link should always be used whenever it was fast enough and accurate enough.

J. P. Titheradge (Associate Member): I would like to reinforce the views already expressed concerning the very real need for thorough preliminary consideration of the operational requirements, by both the user and the project engineer, before the design stage is actually reached or production undertaken.

If designs can be simplified, weight and dimensions reduced, then obviously the maintainability problem is eased. I would like to quote as an example the transmitter type T.1131 which has been almost exclusively used by the R.A.F. for many years for ground-to-air communications in the v.h.f. band. This particular transmitter, which weighs some 6 cwt. and occupies a 6-ft. cabinet, produces a very moderate power output of some 30 to 50W. The majority of R.A.F. purposes can be met by a transmitter producing 5 to 10W at the aerial. With the T.1131, using conventional feeders with losses of 3 to 6 db, the effective power is actually reduced to this order.

A 5- to 10-W transmitter need weigh only 40 to 50 lb. and occupy less than 9 in. of panel space. Equality in overall performance with the T.1131 can be obtained by the use of modern low-loss feeders, and possibly high-gain aerials, and also by giving greater attention to the modulation characteristic. The simplification of the maintainability problem in all its aspects is obvious.

Inbuilt monitoring and metering facilities are often overdone, and can present a very serious source of possible faults. Provision of test points based on a standard multi-range instrument is surely preferable, and in most designs it is possible to bring the test points to a single contact panel for use with the standard test meter. This calls for development of a highly reliable, accurate and versatile instrument for maintenance personnel. (The existing commercial multi-range instruments unfortunately, are not in standard use throughout the three Services.) The use of such instruments, with simple shunts and multipliers in the main equipments would lessen the need for a built-in meter, etc., and so reduce the maintenance problem.

One very controversial point concerning equipment production is the method of soldering and making joints, i.e. the mechanical joint versus the unwrapped joint. In complex and miniaturized equipment, the unwrapped joint is infinitely preferable from the servicing angle: when maintenance personnel endeavour to unwrap the mechanical joint, damage is invariably caused to other components. Equipments employing unwrapped joints were introduced some years ago for use by the Police and Fire Services, and for other civil applications throughout the country. Among the many hundreds in use the fault incidence has been extremely low in spite of the very arduous conditions of continued service to which they have been subjected.

It does appear to me that the development of test equipment invariably lags behind the development of new types of service equipment. Often thoroughly up-to-date tropicalized equipment has to be serviced with signal generators and other test instruments of commercial civilian types. More emphasis should be placed on the development of test equipment to an even higher standard of robustness and reliability than the operational equipment it is intended to service.

D. L. Phillips (Associate Member): As a methods engineer I am interested in the suggestion by Wg. Cdr. Godfrey that the system of servicing by replacement is an expensive one. This system provides for immediate change of main assemblies on squadrons, and the replacement of sub-assemblies on stations, with the more detailed repair of sub-assemblies being done by specialized Maintenance Units. By doing this, in addition to a difficult servicing problem being overcome two major economies are effected.

First, a relatively low degree of skill is required of a large number of tradesmen who can be trained to "rule of thumb" methods. This means less training time and longer productive service, which when applied to National Servicemen is a major factor, when the short length of total service is taken into account.

Secondly, and perhaps the most important from an efficiency viewpoint, if every "in-use" aircraft flies to maximum target hours, the minimum number of aircraft will be required to fulfil a specified task. This state can only be achieved if aircraft are not grounded because of unserviceability. It follows therefore that if by operating a servicing-by-replacement system, the grounding of aircraft is eliminated—or cut to absolute minimum, then this saving in aircraft together with the saving in training overheads would more than justify the cost of providing adequate turn-round spares.

I would like the speaker's views on the question of cables and fixed wiring. Having accepted the fact that the removable electronic units can easily be replaced, it remains to ensure absolute reliability over a very much longer period, of the more permanent installation in the aircraft such as wiring and to a lesser extent connectors. These are items which can keep aircraft on the ground for a considerable time should faults occur in them, which happens usually with age.

A point of interest here is that Mr. Dummer produced tables of faults, quoting the percentage of faults. But that percentage of faults did not relate that to its "out-of-action" time. Therefore, although a low percentage of defects is reported, this might not indicate the amount of time that the defect caused, let us say, an aeroplane to be out of service. Is this point catered for in the Ministry of Supply specification, or does the same reliability clause apply as for removable units, namely 2½ years or 1,000 hours?

R. L. Duthie (Graduate): My own connection is with servo-amplifiers for fire-control work in general, and I place myself in the school favouring servicing by replacement, and the use of built-in test gear as suggested by Major Brenchley. In one such system a fixed pre-set test unit for the user has been provided with which he can make good/bad tests and, if necessary, replace the faulty unit with a spare which is kept warmed up in the same rack. Should it be necessary for a more skilled man to make tests with the unit while in the rack, he is supplied with a more comprehensive test unit giving him variable test signal facilities, and so forth, which will plug in in place of the normal pre-set unit. This approach seems to have been successful.

In a complex equipment, it is often necessary to use a large number of servo-amplifiers to perform different functions and control different inertias of different natures, and one design of amplifier has been made sufficiently flexible to cover this wide range of applications. The inevitable slight increase in complication is considered to be more than offset by the reduced training effort necessary as compared with that which would be necessary for a larger number of specially designed amplifiers for different applications; the spares position benefits correspondingly.

On the subject of test gear, Captain Naish's request for an overall response-tester for complex fire-control systems serves to illustrate an important point. If this test gear is to be simple, it is necessary to provide a highly skilled officer or rating to set it up and to interpret the results obtained. On the other hand a response-tester more easily set up and giving more direct answers becomes itself more complicated and thus potentially less reliable. This problem must arise I think in any sort of test gear. Simplicity of the test gear must be paid for in training of its user.

Certain types of valves from varying manufacturers, under a single C.V. type, have a wide range of tolerance and it is almost impossible to maintain production within reasonable limits without going to special circuits to stabilize stage performance against variations in valve characteristics which, of course, adds to the complexity and reduces the reliability of the equipment. Design authorities should be more willing to issue selected valves in the form of a special C.V. type and to simplify the design of the rest of the amplifier.

The unskilled or less-skilled man, such as the National Serviceman, could be more fully utilized if he had the help of fault-finding schedules and charts. In the "family-tree" form, these things become extremely unwieldy. If a simple, suitably codified form of schedule could be produced the necessary effort to train the man in its use would be well worth while. Work is being done on this problem.

Design authorities could help the designer by giving him more information on the standard test gear already in use in the particular Service. Captain Naish mentions the scheme run by the Royal Navy for taking design engineers to sea. I have personally found this of considerable value. More could be done if designers work with the Service maintenance people, thus gaining a better idea of their problems.

A. E. Lott (Associate Member): Valves figure prominently in analyses of faults and I think that this is due to lack of knowledge of "end of life" test points. With other components, the R.C.S.C. Catalogue of Inter-Service Standards for Components states the amounts by which components may vary under user conditions and this information can be used as a design criterion. For instance, Grade I resistors are specified as: "Resistors whose resistance stability under the test conditions specified in R.C.S.11 is within the limits of ±5 per cent. of the initial value."

It appears, however, that there is no comparable specification for valves. The only information available is that issued as acceptance tests for new valves, as laid down, for instance, in the Services List of Preferred Valves.

The American Standard Specification ET-107 gives a list of "end of life" test points which may be regarded as typical of the practice followed by American valve manufacturers. A valve is considered to have reached the "end of life" test point when at its rated filament or heater voltage, and specified electrode voltages, the following values have been reached:—

1. 65 per cent. of rated transconductance for r.f. and i.f. amplifiers.
2. 50 per cent. of rated conversion transconductance and 65 per cent. of rated oscillator grid current for converter and mixer types.
3. 50 per cent. of rated transconductance for general purpose triode types.
4. 50 per cent. of rated power output for power output types.
5. 40 per cent. of minimum rated direct current for diode types.
6. 80 per cent. of rated current or voltage for rectifier types.
7. 70 per cent. of normal alternating output voltage for resistance-coupled amplifier types.

Note:—Rated values are those referred to on R.M.A. Electron Tube Characteristic Sheets under maximum typical operating conditions.

The shortcoming of this method seems to be that (as far as can be ascertained) there is no indication as to how many hours of running time, under specified conditions, may be expected to elapse before the valve parameters have deteriorated to the extents listed above.

Current practice among British circuit designers appears to be to ensure that a given circuit will work with all circuit component tolerances at their worst extremes and the valve parameters at the lower values indicated in the acceptance specification for new valves. This, however, gives no indication of what useful life expectancy may be realized for a particular circuit.

It appears to be highly desirable, therefore, to establish "end of life" test points for valves as a guide to designers, indicating at the same time the number of hours that particular valves under particular conditions may be expected to operate before the "end of life" test points are met.

I understand that there have been one or two amendments recently to the Electronic Valve Specifications, and that there is now a specification for the C.V.4002 which does give various "end of life" test points.

However, Service establishments seem generally to use ordinary commercial valve testers which give an answer that bears no relation at all to the C.V. specification around which the equipment was originally designed. Until something is done to specify "end of life" test points of valves, these being related to a given life, and also to provide proper test equipment for the serviceman, so that he may ascertain whether valves are still within the specification for new valves, or the life specification for used valves, you are going to find valves high on the list of nominal failures.

This outlook is backed up by the results of an experiment carried out recently by American valve manufacturers in which all nominally faulty valves were collected, over a period, from the American Armed Forces and returned to the manufacturers for full testing. It was found that over 30 per cent. of the valves rejected were, in fact, within the acceptance limits for new valves.

M. James (Graduate): I am responsible for a certain part of the research and development of a guided weapon, and I should like to mention one important aspect of the overall problem—component reliability. To meet a particular standard of reliability we require 99·99 per cent. reliability in valves.

The valves in guided missiles are generally in series and the failure of any one is a serious thing. We can ask the valve manufacturers to supply valves guaranteed reliable to this percentage, thus requiring him to do a vast amount of statistical work on an enormous sample of valves. On the other hand we may test these valves ourselves to very nearly the design limits to which the weapon itself would be subjected. This raises the question: when should you stop testing? If we test to design limits for several minutes how near are we to the fatigue limit of the valve? If we fire these valves in a weapon and they fly for a few seconds, will the valves fail during this period due to the fatigue limit being reached?

H. C. Bertoya (Associate Member): An important factor bearing on the efficient maintenance of services equipment is the quality of circuit diagrams. Various articles have appeared in the *Journal*, and elsewhere, but the general quality of circuit diagrams as an explanation of the function of a circuit does not seem to improve. As an example, I had to examine the circuit of what seemed to be a complex double series-valve h.t. stabilizer supplying an amplifier. It transpired that the second series-stabilizer was the output cathode-follower, drawn on its side and away from the amplifier proper. Should a mechanic have a number of equipments to deal with, reference to the circuit diagram would probably be frequent, especially with the less familiar items.

J. A. Sargrove (Member): On this question of *discipline* in drawing circuit diagrams to make their function more quickly apparent, I would like to say that the latter half of B.S.530 : 1948—Graphical Symbols for Telecommunication—deals with this problem. I served for 2½ years on the Committee which prepared this Standard as Brit.I.R.E. representative and it owes a great deal to the work of Mr. Bainbridge-Bell.

P. Kellett: In the pre-war days a variable condenser was considered not as a unit but as a sub-assembly which we broke down into its component parts, such as plates and spindles. We then decided that the equipment we design should contain electronic components, rather than mechanical piece parts—the condenser becomes a component in its own right. The modern trend appears to be such that equipments will consist of sub-units, containing a number of components, such as an i.f. strip, modulator chassis, and other functional sub-assemblies, each being capable of being removed from the main unit and serviced individually.

Major Brenchley showed a small amplifier stage, and a crystal oscillator, each a one-stage unit. Does this indicate that tomorrow's trend is to break down the equipment into individual "stage units"? On the basis of economics in construction and servicing we may do worse than go in for small sub-assemblies, but not so small that they are too difficult to locate as sources of faults, and treat these sub-assemblies as consumable items.

L. Thomas (Associate): I am rather perturbed by the statement in Mr. Dummer's paper that he finds difficulty in obtaining maintenance information. One of the most essential jobs of a supervising maintenance engineer is to collect and analyse information on the performance of equipment. The fault data and analyses given in the paper are not complete. Perhaps Mr. Dummer has omitted the more detailed information on faults, valve life and so on. We in the Post Office are perhaps in a better position than Mr. Dummer for collecting maintenance data. We make a regular practice of analysing the operation and performance of all our equipment at least once a year.

Several speakers have made the suggestion of valve selection. It is Post Office policy not to accept equipment that involves valve selection, and for any such difficult applications, valves should be designed with closer tolerances.

With regard to i.f. amplifiers we have in the field at the moment a 10-valve i.f. amplifier of 65 db gain, 40-Mc/s bandwidth to 3 db points with an amplitude characteristic which is flat to within 0·1 db over a range of ± 10 Mc/s from centre frequency. There are no adjustments on the panel and valves can be changed freely. This amplifier is obviously a step in the right direction from a maintenance point of view. We also have scanning test equipment to test this amplifier.

Regarding out-of-service time, in a recent specification the Post Office have stipulated that the out-of-service time on a link should not exceed 20 seconds per annum.

J. L. L. Osborne (Associate Member): I am responsible for quality control of receiving valves, and I feel quite sure that the idea of selection of valves is wrong. The performance required must be obtained by correct design of both valves and equipment. It is not an economic proposition to select from a normal distribution of any component a small section of it and every effort should be directed to removing any shortcomings as a whole and not simply to test for certain parameters to special limits and throw out the rest of the valves.

The problem of life test end points is realized very clearly by the valve manufacturer, but it is very difficult to assess exactly. With a resistor or a capacitor there is not much which can change except its original value of resistance or capacitance. But with valves, there are so many parameters which may change and the important one for any particular user is the one which has to be considered from the point of view of life test end point. In certain of the new C.V. valve specifications for special-quality valves life test end points are quoted, but there are only about five or six parameters for which end points are stated, and it is quite likely that many users would consider other end points more important.

In order, satisfactorily, to test for these parameters, even in the ordinary Services valve specifications, the employment of several thousand pounds-worth of test equipment is necessary, and that equipment itself has to be maintained properly and has to be used properly. Hence, as Mr. Lott has said, often unsuitable commercial-type equipment may be in use.

N. G. Anslow (Associate Member) (*communicated*): I was interested in Mr. Dummer's figures for airborne radio equipment serviceability in both service and civil aviation. I note that no mention is made of defects which occur in electro-mechanical rotary devices such as rotary transformers, blower motors and selector mechanisms. It is my experience that with the exception of radio valves, these components cause at least half the number of defects for which apparatus has to be removed from the aircraft. With regard to other radio components such as capacitors and resistors, etc., very stringent test specifications have been laid down and are constantly being reviewed by the various committees in order to render fault occurrence most unlikely.

Wg. Cdr. Godfrey remarked on the conditions under which radio equipment operated and mentioned temperatures of —40° to +70° C. If indeed this temperature range were the case reliability might be better than it appears to be at present for on many occasions, due to insufficient cooling of the radio installation, the radio equipment is located in what amounts to a "hot spot" with a consequent ambient air temperature which is in excess of the specification figure. Furthermore, the radio designer may employ suitable anti-vibration mountings to protect his equipment, but if the connectors to the various boxes are clamped down to the air frame close to the equipment such that the installation is rigid and consequently the anti-vibration mounts are by-passed, it is not surprising if troubles arise due to vibration within the apparatus. I think it is time that more thought be devoted to engineering the radio installation during the design stage of the aircraft than designing the aircraft and putting the radio in any old corner which can be found irrespective of its suitability.

With regard to the ease of servicing or maintainability of equipment, the designer has to be most careful not to introduce potential faults for the sake of accessibility nor to produce a badly designed set which is bound to give trouble, but which is sold on the basis that it is built in such a form that servicing is easy. Surely diagnosis is the most difficult and consequently the longest part of servicing and fault finding, and consequently my vote goes for sub-chassis brick-type construction where the small chassis may easily and quickly be replaced and with each of these chassis provided with liberal test points to facilitate diagnosis by the service engineer.

AUTHORS' REPLIES

G. W. A. Dummer: There is, of course, a great deal of work going on in improving the reliability of both valves and components. Large contracts have been placed with valve manufacturers by the Ministry of Supply to improve reliability of valves and the same thing is happening in the component field. Working temperatures are going up, and the life of a valve or component is not known at temperatures up to 150°C or more. We are at the moment just starting a large programme of work on life *versus* temperature and vibration and humidity investigations may follow.

Replying to Mr. Kellett, I think the generally accepted practice now is to limit sub-assemblies to circuit functions. If you take a single stage you have to connect input and output feeders and heaters and h.t. supplies, and it rather makes for a multiplicity of connections. If you go in for a large block of ten valves you have lost a lot of the advantages of sub-units. I do not think anybody can generalize at this stage, and I think we are still learning. A four-valve or even a six-valve strip seems to be a sensible thing, but there are no hard and fast rules.

In reply to Mr. Thomas, I would suggest that the Post Office is in a more favourable position to the three Services, which are scattered all over the world with varying grades of servicing staff for reporting faults. The reason that A.E.R.E. are able to keep such an excellent record of faults is that all equipment has to be serviced through one organization. All sorts of schemes have been tried in the Services but I do stress that you cannot use them for any more than useful background information.

The Air Ministry does employ a Scientific Adviser, who is doing most valuable work on detailed studies of an individual squadron, or a particular section with a particular equipment. Ideally, to get scientific analyses you have to test every equipment under the same test conditions. This is quite impracticable bearing in mind the extent of the Services, so you have to be content with analyses such as are given in the paper, which are valuable inasmuch as they will tell us on which component we must put the most effort. It is obvious that the order of incidence of faults in components will change from year to year, but at least it will give us a guide.

Replying to Mr. Anslow, failures in electro-mechanical rotary devices do occur in practice and are sometimes given more importance as they result in failures of other components, and are usually a major disaster. The failures vary with equipments and in equipments containing large numbers of rotary transformers, blower motors, etc., can be quite serious.

There is no question, however, that all the analyses we do, all the specifications compiled and all the tests made, almost pale into insignificance beside the fundamental point of painstaking attention to detail. On behalf of the Ministry of Supply, therefore, I would like to put in a plea for the co-operation of all the valve, component and equipment manufacturers in stressing this.

Major R. B. Brenchley: I want to refer to Mr. Titheradge's remarks regarding the controversy about soldered connections: whether they should be wound round the tag many times, be clenched, or just go straight through the hole. The standard has been laid down in RCS 1000 and multi-turn joints are expressly forbidden.

I should like also to take up his point about the need for rugged test equipment especially designed for Service use. I heartily agree with this opinion and it may give him some comfort to know that we now have quite an extensive range of such instruments, the use of commercial pattern gear in the field now being more the exception than the rule.

Wg. Cdr. G. C. Godfrey: Built-in test equipment is highly desirable and should be possible for all ground equipment—it is in fact normal practice. Airborne equipment is a different problem owing to the penalty of extra weight and space. There should, however, be a minimum of "breaking" of connectors to test any equipment.

With regard to all-enveloping test equipment, at squadron level test equipment must be simple to use and as portable as possible—one special performance tester to each type is the ideal. At station workshop level I agree that there should be as much standardization as the complexity and variety of equipments allow.

Everyone is aware of the vital need for test equipment to be available at the same time as the main equipment and various steps are being taken to achieve this aim. However, test equipment designers do need to know what they are required to test and this in itself means that the main equipment is developed first.

On the question of valve and component life, attempts have been made by the Royal Air Force to obtain figures of the running hours for equipment but generally speaking this is impossible. Whenever a piece of equipment goes back to station workshops a component may be changed and that means the new one has a different running time in comparison to other components in the same "box." I am of the opinion that components should only be changed when a failure is "catastrophic" or the actual performance of the whole equipment is down. "Ruggedized" valves are welcomed but it is understood that the testing of valves to their fatigue limit before issue normally reduces their life in the service.

The production of electronic equipment and the aircraft as an entity is an ideal which is nearly impossible to achieve except in the most specialized cases. The problems include:

(*a*) need for equipment to go into many different types of aircraft;

(*b*) a new type in electronic equipment may need to go into an old aircraft;

(*c*) aircraft performance requirements must limit the size, shape and positioning of electronic equipment, e.g. limit on scanner sizes;

(*d*) the cylindrical "cans" needed for pressurization.

The remarks on the simplification of design of equipment using the transmitter T.1131 as an example do not make allowance for the fact that this equipment is out-dated and out-moded and is not worth redesigning—new equipments however have improved in design. I agree that maintainability can be improved by simplification of design but do not agree that reduction in weight and dimensions have the same effect. The speaker's remarks on aerial gain are fully supported—there is a case for system engineering as normal practice.

Captain A. J. B. Naish: I think we are all impressed by the idea of being able to have sub-assemblies to change instead of individual components, as discussed by Mr. Kellett, and this is already done to some extent. But the Navy particularly would suffer a logistic problem in having to carry about such an enormous number of these sub-assembles. If one can get a reasonable amount of standardization, progress will be made in these replaceable sub-assemblies.

Naval thought agrees with Mr. Anslow's statement that as radio equipments become larger and more complex it is more than ever necessary to attempt to design the aircraft to suit the radio as well as designing the radio to suit the aircraft. It is also agreed that diagnosis is normally the most difficult part of maintenance and the "sub-chassis brick-type construction" is favoured where this is practicable. Accessibility is, however, still a requirement in the sense that the "bricks" themselves must be easy to get at and an individual brick must normally be repairable in a ship's workshop.

Referring to the question of automatic systems of fault-finding, and fault-finding charts, in the Naval School, H.M.S. "Collingwood," servicing manuals have been produced in which fault-finding has been made as easy as possible. But there are limits to what can be done in this way and in the end it is simpler and more satisfactory to give the rating a reasonable background knowledge of how a thing works than to try to give him some automatic fault-finding system. You are defeated very soon by the complexity which grows and grows as you try and make the fault-finding system more automatic.

With regard to the interesting point raised by Mr. Duthie on the complexity of test equipment, the Navy will generally accept comparatively simple test equipment, if this simplicity gives greater reliability and saves space, because the highly trained personnel necessary to interpret the results have, in any case, to be borne in ships for diagnosis and repair. Test gear of a more direct reading type may, however, have to be fitted in cases where the answer must be obtainable in a very short time.

* * *

A vote of thanks to the principal speakers and to those who took part in the discussion was moved by Lt.-Col. **J. P. A. Martindale**, Chairman of the Programme and Papers Committee. In the course of his remarks he urged that the potential user should not ask for any facilities in equipment which were not strictly necessary.

THE PHYSICAL SOCIETY'S 1955 EXHIBITION

A further report on items of interest to radio and electronics engineers.

Of the independent exhibits by University Research Laboratories, the three that probably attracted most attention were by Mr. D. M. Tombs, of Imperial College. He demonstrated a corona triode valve working in air, which is a device convenient for handling very high voltages at very low currents; the valve parameters were: μ 5, r_a 500MΩ and g_m μ25A/kV. A further development in this field was a corona wind loudspeaker whereby a matrix of needles produced air movements which could be controlled to radiate acoustically by means of a signal on an interposed grid.

The third item shown was a linear electrostatic loudspeaker consisting of three plain parallel electrodes, the outer two being open-mesh grids across which a high polarizing voltage is maintained. The third electrode is of very thin polythene covered with colloidal graphite to make it conducting. If this third electrode has the same potential as the position it occupies between the two outer electrodes there will be no force acting upon it; however, the application of an alternating voltage to it will tend to move it and so set up sound waves. A particular advantage is that the force tending to move the diaphragm is directly proportional to the applied voltage, and it appears that the response of the loudspeaker is smooth from zero frequency up to the limits of hearing.

These developments in what is often called "microamp-kilovolt" engineering are not only of research laboratory interest. In particular, the electrostatic loudspeaker may well have an application in providing a high-fidelity reproducer for use with television receivers, since the necessary high polarization voltage is already available. It is understood that a number of manufacturers are carrying out investigations into the practical aspects.

The D.S.I.R. Mechanical Engineering Research Laboratory showed a number of units developed as basic components for the assembly of timers, frequency meters, frequency dividers, counters and batching counters; these all used cold-cathode decade counting valves and a feature of the units was that decades can be paralleled for a quick check of any suspected fault.

Two approaches to the ultrasonic gauge problem were shown by Dawe Instruments and Kelvin and Hughes respectively. The former utilizes the distance between resonances of standing waves in the thickness plate under examination, while the Kelvin and Hughes instrument applies a short pulse simultaneously to the specimen and a short liquid delay line of adjustable length. The return pulses from both are displayed on a cathode-ray tube and by adjusting the line length can be brought to coincide; the line length is calibrated in terms of corresponding depth of, for instance, mild steel and has a range of ¼ in to 4 in.

An interesting device for use with the Kelvin and Hughes detector was demonstrated. It is an Automatic Compensated Scanning and Recording Apparatus which not only carries out an automatic and rapid examination of the sample under test but simultaneously presents a true and permanent paper record of the examination. Warning and alarm systems are incorporated and the complete facilities extended by the apparatus confines human participation in the detection and interpretation of flaw echoes to that of a supervisory nature only.

The trend in radioactive gauges for industry is to make them more robust and less liable to need re-calibration. Ekco Electronics featured a thickness gauge in which standardization was carried out automatically over 30 minutes; the instrument also has facilities for automatic thickness control.

Backscattering technique is made use of in a gauge by the same firm which, using gamma rays emitted from cobalt 60, enables steel thicknesses up to half an inch to be measured where only one side of the sample is accessible. The principle of operation is that when gamma rays pass through steel, a proportion will be deflected by Compton scattering, of which some will be scattered through 180°. During this process they will lose energy to the extent of twice the Compton wavelength. If cobalt 60 is used as a source, the backscattered radiation will return at about 200 keV. By means of a differential discriminator circuit the reflected photons are selected from the primary radiation and fed into a counting ratemeter circuit.

A DESIGN FOR SCANNING AND E.H.T. GENERATORS TO OPERATE A TELEVISION PROJECTION SYSTEM FROM 170-V H.T. SUPPLY*

by

E. F. Wale (*Associate Member*)†

SUMMARY

The advantages to be gained in a projection receiver by dispensing with the mains transformer are discussed. Details of various unsuccessful attempts to achieve a satisfactory unit for operation from 170-V main h.t. supply line are outlined. It is concluded that a method of combining high-voltage pulses from the line output circuit and from an e.h.t. generator offers the most practical solution. A complete time-base unit from the grid of the synchronizing pulse separator onwards, is then described, particular attention being given to the more novel features. Some aspects of a new frame separator are first discussed, and then a description is given of the e.h.t. and scanning output circuits with the associated regulating circuit. From a comparison of components used it is shown that the circuit enables a saving in cost to be achieved.

1. Receiver H.T. Supplies

One of the basic requirements of any direct-viewing television receiver is that it must be as mechanically versatile as possible so that the same assembly may be presented to the public in a variety of cabinets, both table and console. There is no fundamental reason why this principle should not be applied to projection receivers as well, but in practice certain mechanical problems arise which are peculiar to these receivers alone, particularly to the table models. While keeping the cabinet size to a minimum, the principal difficulty is to fold the required optical path round the cabinet and still leave room for the electronics.

Considerable saving in space could be effected by the removal of the conventional mains transformer, and by deriving the main h.t. supply for the receiver direct from the mains via a half-wave rectifier, as in current direct-viewing equipment. Other advantages attendant upon the loss of the mains transformer especially applicable to projection television are:

(1) less weight; (2) less cost; (3) less volume; (4) the removal of the magnetic field generated by a mains transformer.

It is worth noting that to provide the main h.t. supply for a projection receiver with its higher current demands, direct from the mains via a half-wave rectifier, results in a supply potential of no more than 170 V when a 200-V d.c. supply is in use.

Unfortunately there is one major obstacle to be overcome when accepting the 170-V condition—that is to provide an e.h.t. supply with a regulated potential of 25 kV up to at least 250 μA drain.

1.1. *E.H.T. Power Pack Criteria*

The main requirements for a new e.h.t. supply unit applicable to these conditions are:

(1) It must provide an output of 25 kV over a current range of at least 0–250 μA, with a steep fall-off when the regulation becomes ineffective.

(2) It must run from a 170-V supply of variable but low impedance (variable due to the changes of tappings on mains dropping resistors for different supply voltages). In other words, the e.h.t. unit itself must exhibit an inherently steep fall in output at load currents which would cause the cathode-ray tube wattage to approach a dangerous value.

(3) It must be as economical as possible.

(4) Any failure must not produce a destructive voltage.

(5) It must provide as little interference as possible in the remainder of the receiver.

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† E.M.I.E.D. Ltd., formerly with McMichael Radio, Ltd., Slough, Bucks.
U.D.C. No. 621.397.621 : 621.397.682.

This latter point needs to be considered in detail immediately. The only way to allow large pulses to be generated in a receiver, without the picture being affected, is to make these pulses occur in the flyback of line or frame time bases when the picture is blacked out. Of these two the frame flyback can be discounted as time constants and inductances become too large to be economically practicable. The e.h.t. generator must therefore run at 10,250 c/s and be locked to the line scanning generator in the correct phase.

One disadvantage of this frequency is that it does not permit the equation for optimum pulse repetition frequency* to be satisfied, which results in an operation of lower all-over efficiency in power conversion. However, in view of the other advantages finally accruing from the use of this frequency this disadvantage was accepted, particularly as h.t. current is relatively cheap in an a.c./d.c. design.

1.2. *Available Sources of E.H.T.*

Two obvious possibilities spring to mind when a source of high voltage at 10 kc/s is sought; the line time base itself, or an entirely separate unit. The line time base is not very promising as a source of e.h.t. for a projection receiver but was carefully considered and eventually found unsuitable.

At first sight the second alternative of an entirely separate generating unit seems very attractive. The only link with the line time base would be the acceptance of a driving pulse so that both output circuits would be independent, and each could be designed to an optimum. The line circuit would consist of a conventional oscillator and output stage (probably with an efficiency diode). The line oscillator would also drive the e.h.t. output stage. In the anode circuit of this output stage (which would include its own efficiency diode) would be the high-voltage unit and the regulating voltage source to provide bias for the output valve.

The mode of operation of such an output stage is restricted. The use of the efficiency diode, which is necessitated by the low h.t. voltage, normally precludes the production of a large negative pulse following the initial positive pulse. So the circuit is limited, under normal conditions, to producing a succession of positive unidirectional pulses. To use these pulses to produce the required high voltage they must be rectified by a half-wave rectifier or some doubling or trebling circuit. All the cascade rectifier circuits for unidirectional pulse working require some impedance in the wiring to charge one capacitor from another; when any power is being handled this impedance must be a high-voltage rectifier. This valve will require a heater winding and the unit will be using THREE rectifiers to accomplish voltage DOUBLING. This three-valve doubler brings with it heater windings and capacitors all of which have varying high-voltage potentials. Corona difficulties loom large at once.

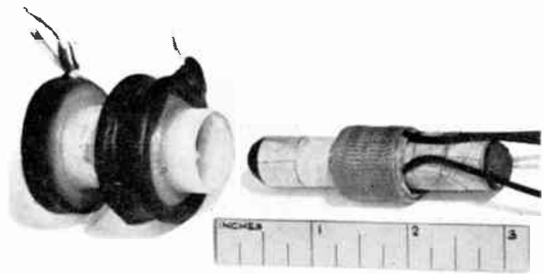


Fig. 1.—Photograph of experimental coil capable of providing 22·4 kV d.c. at 6·25 W by single half-wave rectifier.

1.3. *Investigation into the Use of a Single Rectifier*

If half-wave rectification could be achieved the assembly would be so much simpler that not only would the component costs be cut but the unit would have a fair chance of operation in air. This type of circuit was considered and the first obvious difficulty was the step-up ratio required in view of the output valve ratings. The maximum peak positive pulse allowed on the anode of the only type of valve readily available commercially to the author's company is 7 kV. To achieve an output of 25 kV d.c. a step-up ratio of at least 3·6 is required, which has not hitherto been achieved in practice. In order to obtain maximum coupling a closed circuit ferrite core was first tried. As was expected the results were disappointing in this application and only confirmed the necessity to try some other approach. The maximum voltage that could be obtained at 6·25 W was just over 16 kV. The

* "Projection Television System." Mullard, Ltd.

basic reason for the failure of this anode circuit was the low values of Q realizable with a closed magnetic circuit irrespective of the gap.

The obvious method of raising the Q of the winding is to use an open circuit core. The difficulty of obtaining sufficient coupling is immediately apparent but, as the realizable values of Q are very much higher, this method was considered in some detail. In the early stages this method showed some promise but was finally defeated as well. The final figures achieved were:

Output voltage	22·4 kV
Output load	80 MΩ
Output watts	6·25 W
Cathode current	152 mA
Screen grid current	27·5 mA
Boosted voltage	375 V
Output valve pulsed anode potential	6·6 kV
Efficiency diode cathode potential..	4·3 kV
Negative overswing on rectifier ..	4 kV approx.

A glance at these figures will show that everything was running very close to the limit ratings and the circuit was consuming a considerable amount of power, nearly 32 W in fact. The secondary coil was wound on a polythene former which carried the heater winding as well (Fig. 1). No attempt was made to impregnate this coil. The only treatment it had was to paint the outside of the two pies with wax to prevent corona, nevertheless considerable corona did occur at several other places.

1.4. *Combination of two output circuits*

As the attempts to use a separate generating circuit with a single rectifier had been unsuccessful, attention was turned to the search for an alternative system. If the final design is to include a line output circuit and an e.h.t. generator circuit it is possible to obtain a high-voltage pulse from both sources. If some method can be found of adding these outputs then sufficient total output could be obtained. A possible method is shown in Fig. 2a. Here the reservoir capacitor C1 is returned to the e.h.t. transformer. The secondary of this transformer is wound to produce a negative voltage to earth. (All voltage polarities shown in Fig. 2 refer to flyback pulse voltages.) The two output valves are driven by the same pulse which fact considerably eases the design of the drive circuits.

This output circuit does operate satisfactorily but the impedance which is necessary to isolate the final smoothing capacitor C2 (which is the c.r.t. coating) can only take the form of another rectifier; so the circuit appears as in Fig. 2b. Each rectifying valve can be heated from a separate transformer which does not make corona control of the heater windings themselves too difficult, but the e.h.t. coil causes trouble as there exists a very large potential between the heater winding (positive) and the outside of the secondary (negative).

The circuit described later in this paper was finally evolved to overcome this difficulty. It

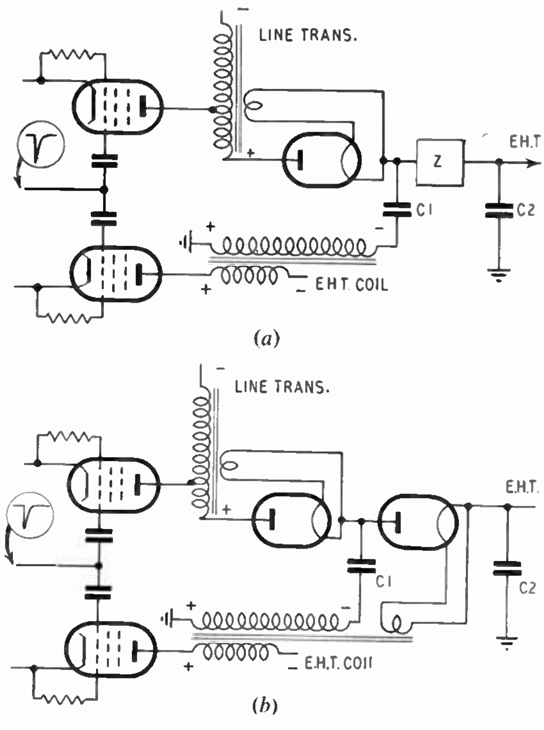


Fig. 2.—Methods of combining sources of e.h.t.

fulfilled the major requirements of the specification and while being more complicated than a single rectifier supply offers a practical solution to the problem. Although the circuit used two rectifiers the high potentials are confined to so few points that the unit operates satisfactorily in air provided normal precautions be taken against dust and humidity.

2. A Complete Time-base Unit

Before considering Fig. 10 in detail some of the reasons for the various circuits taking the form they have assumed must be given. Fly-wheel synchronizing is included because it is being extensively used in the more expensive receivers into which class any projection receiver must fall. For this reason also a slightly more expensive frame separator circuit is used. The definite improvement in "hold," interlace and interference immunity which it gives are very acceptable, particularly on a large picture. As the e.h.t. generator is intimately connected with the line scan generator, the protection circuits take a new form. Protection circuits are necessary to ensure that the cathode-ray tube passes little or no current with a focused beam when either of the time bases fails, but in this circuit failure of line scan will automatically deprive the cathode-ray tube of its final anode voltage. Hence the only protection necessary is against failure of frame scan.

2.1. *Frame Synchronizing Separator*

In Fig. 3 is shown the basic synchronizing-separator circuit with waveforms; the operation of the circuit has already been described by Patchett.* From the eight broad transmitted pulses this circuit produces a single large uni-directional pulse of length 7·5 μsec delayed by half a frame pulse from the transmitted ones. On the odd frames the pulses are 25 per cent. shorter as the valve current has not had time to reach its full value, as can be deduced from curve E. This can possibly give a maximum interlace error of 46/54 but such an error had not been observed in practice up to the date when the patent applications were filed.

Subsequent to the criticism on interlace that Dr. G. N. Patchett offered in May 1954, the circuit was further investigated with various types of frame oscillators. It was found that the criticism is justified with certain types of oscillators particularly with blocking oscillators depending on a transformer for phase reversal. Multivibrator oscillators are not so susceptible to the trouble and can be designed to give virtually perfect interlace when fired by this synchronizing circuit.

The difficulty can be overcome by using a pentode instead of the triode Vt. If the electrode supply potentials are arranged so that the anode current reaches its maximum value in a time less than half a line, the pulse output of the circuit will be identical on odd and even frames.

It can be seen from Fig. 3b, curve E, that the anode current is increasing throughout the line period due to the rising voltage on the triode anode, curve D. Other considerations prevent L1 being made large enough to prevent this. The result is that when a half-line precedes the frame pulses, the inductive energy in L1 is less than when a full line precedes. The pulse output at C is therefore smaller. By confining this anode current increase to the first half of each line the inductive energy in L1 is made the same on odd and even frames giving identical output.

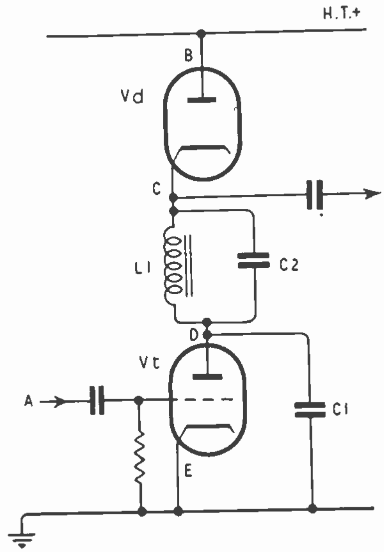


Fig. 3a.—Basic frame synchronizing separator.

In a practical circuit built on these lines the pulse output was approximately 50 V.

The above refinement was not found necessary, however, in this particular development as the oscillator design catered for this variation.

This single short pulse is superior to any form of integrated pulse in ensuring good interlace and is constant in amplitude over very wide variations of signal strength due to the very large drive to the valve which fulfils the function of that designated Vt in Fig. 3a. The grid drive

* G. N. Patchett, "A critical review of synchronizing separators with particular reference to correct interlacing," *J.Brit.I.R.E.*, **14**, pp. 191-214, May 1954.

to this valve is obtained from the anode of the main synchronizing separator and is normally in excess of 100 V. As the only requirement is that the grid drive shall exceed the grid base of Vt obviously a very large reduction of received signal strength is necessary before the operation of this valve is affected, particularly as the preceding main synchronizing separator will itself possess a limiting characteristic. Interlace and hold remain constant down to a level where there is barely any detectable modulation on the screen.

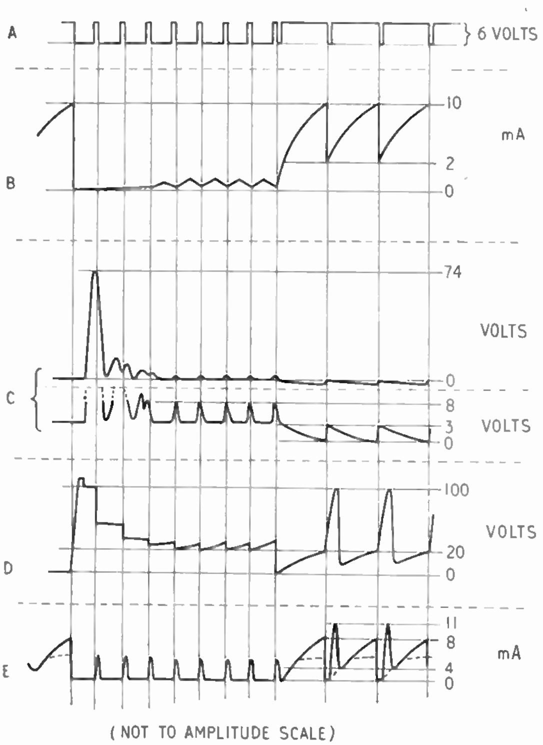


Fig. 3b.—Waveforms round circuit of Fig. 3a.
A. Grid drive must be greater than grid base of triode Vt.
B. Measured with 100-ohm resistor.
E. Measured with 10-ohm resistor.
All waveforms taken on high impedance oscilloscope.

Due to the fact that the circuit depends for its operation on the triode being cut off for a considerable period of time, any interference pulses of less than 10 μsec, however large in amplitude, cannot produce any output from the circuit. (Much impulsive interference reaching the separator falls into this class.)

In Fig. 10, V1A is the main synchronizing separator of normal design, the output of which drives V1B which is the frame separator. The h.t. supply to V12A and V1B is reduced to keep the valves within limits.

2.2. *Frame Time Base*

The pulse output from V1B is used to lock V13, a multivibrator type of frame oscillator which is conventional except that its natural frequency is very low. This low frequency is made possible by the large synchronizing pulse, and it gives a large degree of interference immunity within the oscillator itself. The oscillator drives an output stage of normal design (V14).

2.3. *Line Oscillator and A.G.C. Pulse Amplifier*

The output from V1A also drives the grid of V2A via a differentiating network which removes the long frame pulses. The grid of V2A is biased to remove most of the positive overswing resulting from this differentiation. Thus the output from V2A consists of a train of short equal pulses with steep leading edges of constant amplitude. This signal is applied to V4B, whose grid circuit is biased to remove the positive portion of the pulses. The output of V4B consists of positive pulses whose leading edge, being driven from the differential overswing from V2A, corresponds to the back of the synchronizing pulse.

The width of the output pulses from V4B is kept down to 7 μsec and so these pulses are used for gating the a.g.c. circuit in the "back porch" after the synchronizing pulses.

The full output from V2A is used to lock the flywheel oscillator V2B. This is a usual sine-wave oscillator with V3 as the discriminator and V4A as the reactance valve. L2 is the tuned phasing winding. Oscillator action between cathode, grid 1 and grid 2 is used to reduce, as far as possible, the anode circuit's effect on the oscillator action.

If such a circuit is set up at rest so that the transformer windings are exactly in tune and the reactance valve current is in the centre of its range (as if (*a*), no synchronizing pulses are applied, but (*b*), the frequency is correct), the a.c. output from the anode will be passing through zero at a time corresponding to the synchronizing pulses. But as the voltage output of the circuit is required to be of peak amplitude at a point in time which corresponds to the synchronizing pulse, then adjustments must be made to the tuned windings to produce this condition.

This adjustment results in the reactance valve current moving towards one end of its travel, and so limits the "pull-in" range in one direction. It is better practice to arrange that the frequency and phasing of the circuit are basically the same whether synchronizing pulses are applied or not, as this quiescent condition gives the maximum hold range.

The output of V2B is therefore fed to V5A via a series circuit, very flatly tuned, which gives the necessary phase rotation. The anode waveform of V2B would approach a square wave if this series circuit were not loaded on to it. The back kick from this circuit, however, modifies such a square wave and produces the unusual waveform shown.

2.4. *Drive Amplifiers*

The large drive to V5A produces in the anode circuit a short, large negative pulse whose leading edge corresponds to the leading edge of the original synchronizing pulse. The large grid current drawn by V5A produces a convenient source of bias for the reactance valve.

The pulse output from V5A is differentiated to drive V5B which produces a large negative pulse, the leading edge of which corresponds approximately to the trailing edge of the synchronizing pulse. Therefore V5 produces two negative pulses, the first of which starts at the same time as the leading edge of the line synchronizing pulses and the second of which starts approximately in the middle of the line-blanking period, which is of 18-μsec maximum duration as shown in Fig. 4.

The outputs from V5 are used to drive the output valves V6 and V8, and provided that the pulse produced in the anode circuit of V8 (driven by V5B) has a duration of 8 μsec or less, it will have terminated before the start of the modulation of the succeeding line. This satisfies the condition for preventing interference appearing on the screen and corresponds to a minimum natural frequency of 62 kc/s, which is considerably less than that which is achieved in normal practice.

2.5. *Line Output Stage*

V6 and V7 with L6, L7, L8 and L9 constitute a normal line output scanning circuit with V6 as the driving pentode, V7 the efficiency diode, L6 the auto-transformer and L8 the deflector coils. L7 is a differential width control arranged so that the transformer always sees a constant load irrespective of the adjustment of width; L9 is the linearity control. This type of circuit has been fully analysed by Emlyn Jones.*

L6 is wound on an open Ferrox rod of ½ in diameter and carries a heater for V10 and an over-wind to supply V10 anode. This valve will deliver 14·5 kV at 325 μA.

The emphasis in this circuit is on e.h.t. power and h.t. current economy as the scanning power required is small compared to that which can be obtained from such a circuit.

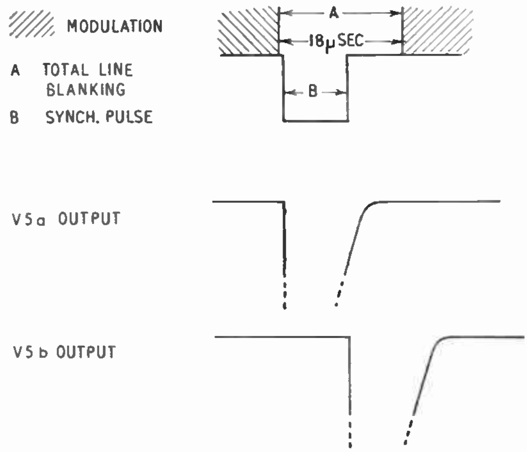


Fig. 4.—Phasing of driving pulses and transmitted B.B.C. waveform.

2.6. *Additional E.H.T. Output Stage*

V8 and V9 with L10 comprise a similar circuit except that no scanning action is required. Due to the larger stray capacitances loaded on the over-wind by CR1, V10, V11, etc., this circuit delivers only 10·5 kV at 325 μA.

2.7. *Operation*

The sequence of the operation of the time-base unit is shown on a time scale in Fig. 5.

* Emlyn Jones, "Scanning and e.h.t. circuits for wide-angle picture tubes," *J.Brit.I.R.E.*, **12**, pp. 23-48, January 1952.

V6 is cut off by the first driving pulse from V5A, and the pulse from L6 charges CR1 to 14·5 kV. The negative side of this capacitor is

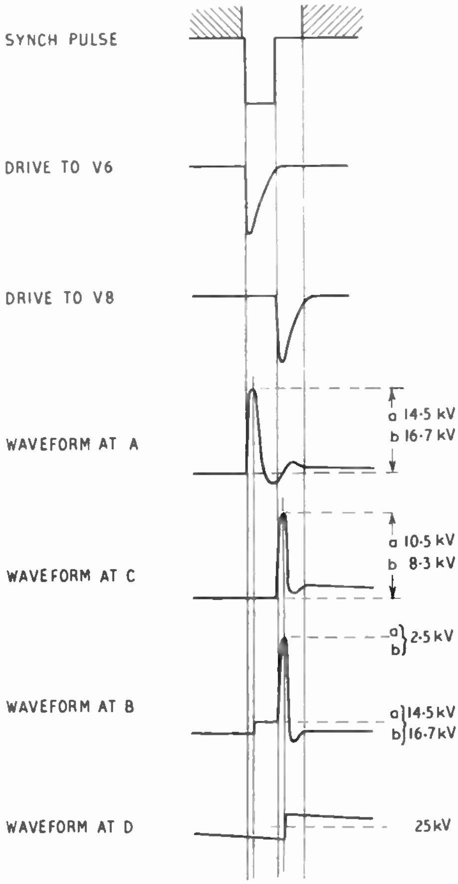


Fig. 5.—Waveforms round output circuit of Fig. 10. a *and* b *denote full load and no load conditions respectively.*

connected to the over-wind of L10, and this point is effectively earthy as V8 is still conducting. The natural frequency of L6 is about 110 kc/s, so that the output pulse is completed and V7 starts conducting less than 5 μsec after the start of the pulse from V5A. Eight μsec after the initiation of the action of V6, the drive from V5B cuts off the anode current in V8, and L10 produces an output of 10·5 kV which is added to the charge already on CR1 to charge CR2 via V11 to 25 kV. The natural frequency of L10 is about 145 kc/s, so that the action of this circuit is complete and V9 is conducting 3·5 μsec after the start of the pulse from V5B or 11·5 μsec after that from V5A.

The total-line blanking period is 18 μsec maximum so this allows the oscillator V2B a total error of 6 μsec in phasing before there is the possibility of any interference appearing on the screen. This is an adequate margin.

At no point in the circuit, except on V10 cathode and on V11 with their heater windings, is a greater voltage generated than in current television-receiver practice. This eases the winding and assembly problems considerably.

Figure 6 shows the first experimental scanning and high-voltage output unit. The capacitor (500 pF) (extreme right) feeds the regulating circuit. The final reservoir capacitor (CR2) does not appear as it is made up of the e.h.t. output lead and the capacitance of the final anode of the cathode-ray tube to earth. This capacitance has a nominal value of 500 pF, and in practice shows a maximum tolerance of 10 per cent. This variation of 50 pF does not appreciably affect the action of the regulating circuit as allowance can be made for it.

2.8. *Regulating Circuit*

The requirements for the regulating circuit are unusual compared to other generators in that the two output stages have to be controlled for different reasons. The line output stage must provide a constant scanning current in the deflector coils irrespective of e.h.t. loading. (If the grid leak of V6 is returned to earth the scanning current will vary 10 per cent. from no e.h.t. load to full e.h.t. load.) So a controlling bias must be applied to V6 grid to keep the scan constant.

A large negative voltage can be obtained by rectifying the pulse voltage across the deflector coils and, after backing off this negative voltage with a fixed positive voltage, the resulting voltage can be applied as controlling bias to V6 grid. A circuit designed on these lines is shown in Fig. 7. The regulation is very effective due to the large amount of feedback obtainable.

However, the reduced inter-winding coupling, due to the open Ferrox rod core, allows the e.h.t. output voltage from L6 to fall from 16·7 kV to 14·5 kV for 0 to 300 μA drain when the circuit is regulated for constant scanning current. Therefore V8 must be regulated so that

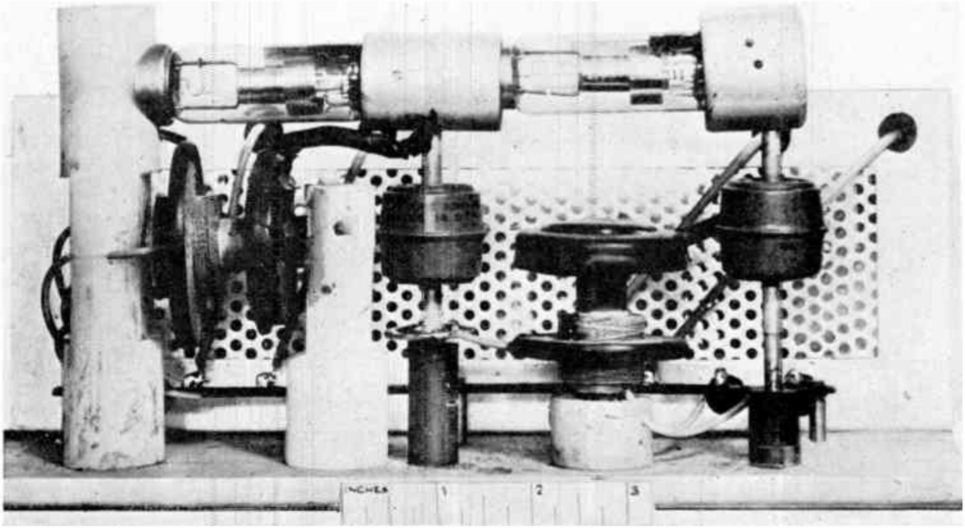


Fig. 6.—Photograph of first experimental output circuit.

the output from L10 *falls* from 10·5 kV at 300 μA drain to 8·3 kV at zero drain. This is an unusual requirement and difficult to obtain by using any pulses from L6 and L10 unless V8 is regulated from the output from L6. A sufficiently large voltage differential could be obtained by tapping the pulse voltage from a point fairly high up L6, but this leads to difficulty in handling the high voltages used and in obtaining a large enough fixed voltage to back off the resulting negative bias.

One method which would overcome the difficulty would be to relate the main bias supply directly to the e.h.t. load current, and not to any pulse voltages existing on the coils. The amplitude of the ripple voltage on the e.h.t. reservoir capacitor varies directly with the load current.

If, from the ripple voltage, a positive d.c. voltage is obtained and this is backed off by a suitable negative potential the resultant bias voltage will fluctuate with the characteristic needed in this application.

In Fig. 8 is shown the basic schematic for such a control circuit. The ripple voltage across CR is fed through a low-pass filter F to an amplifier A. The low-pass filter is necessary to remove the pulse voltage existing in the output circuit due to the capacitive feed of the e.h.t. rectifier and any stray pick-up. The output of the amplifier is rectified by V1 and supplies a positive voltage across R1, which increases as the e.h.t. load increases. A positive pulse from

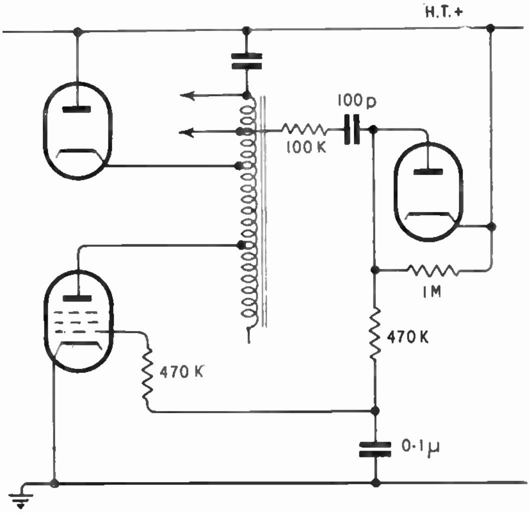


Fig. 7.—A normally effective regulating circuit.

the line transformer is rectified by V2 and, the output being taken from the rectifier anode, provides a negative voltage across R2b. The outputs of these separate rectifiers are combined to give a voltage which, at full load, is just sufficient to prevent grid current flowing in the output valves. The driving pulses to the output valves are so shaped that the onset of any appreciable grid current in the output valves causes the output to fall by distorting the drive waveform from optimum. As the e.h.t. drain is reduced the bias gets progressively more negative. The change in bias is more than is required to keep the scanning and voltage outputs constant so the bias is delivered to the two output valves from dividers across the supply. The line valve requires less bias change than the e.h.t. valve.

The complete circuit is shown in Fig. 10 where V15 and V16 with their associated components comprise the control circuit. The ripple voltage, free from the high-voltage d.c., is fed to V15 via the low-pass filter which removes all the pulse voltages except a small derivative of that generated by L10. This is largely removed by the clipping action of V15 grid. (In Fig. 5, the waveform across the reservoir capacitor (at point D) is shown without any stray pulse pick-up. This is, of course, strictly inaccurate, but to show the complete complex waveform would only be confusing to that part of the discussion.)

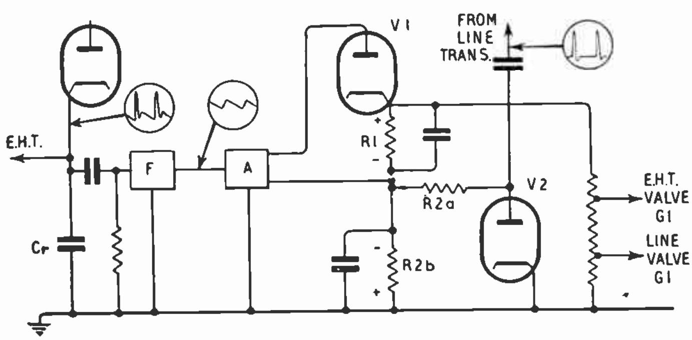


Fig. 8.—Schematic of basic regulating circuit.

The ripple voltage at V15 grid is of 5-V amplitude at full load. The output of V15 of 87-V amplitude, peak to peak, is rectified by the shunt-fed diode V16a, giving 35-V d.c. across the 220-kΩ load resistor. V16B is also shunt fed with the positive pulse appearing across the deflector coils. The negative output from the anode appears across the 100-kΩ and 10-kΩ load resistors. The 100-kΩ potentiometer is adjusted so that, at full load, the negative voltage between points G and H equals the positive voltage between F and G. Thus, no potential exists across the divider chains feeding the grids of V6 and V8. The whole circuit is, however, negative to earth by the voltage existing across the 10-kΩ resistor between point H and earth. The residual bias prevents any appreciable grid current flowing.

Under no load conditions the positive voltage between F and G virtually disappears and the negative potential between G and H is fed to the divider chains. The potentiometers supplying the grid are of such a value that (*a*), V6 supplies the same scan current as before, and (*b*), V8 generates sufficient e.h.t. to keep the total e.h.t. output voltage constant.

By adjustment of these two potentiometers supplying the grids a large degree of over or under compensation can be realized. At the correct settings a constant scan generator and a substantially zero impedance e.h.t. generator are obtained over a range of load currents from 0–325 μA at 25 kV.

Theoretically it is necessary to adjust the two grid potentiometers, the 100-kΩ bias zero set and the 10-kΩ fixed bias resistor if perfect regulation is to be realized. If this is done the regulation curve can be reproduced exactly under all conditions of valve and component tolerance. In practice this is fortunately unnecessary and, provided the bias is correctly set at full load, a family of output curves shows sufficiently close agreement to justify this simplification.

Any increase in e.h.t. drain above 325 μA causes the output to fall rapidly as the natural regulation of the circuit takes effect, assisted by the fact that V6 and V8 will draw grid current which modifies the shape of the driving pulses and further reduces the output.

2.9. *Failure to "Safe"*

One requirement of any regulating circuit is that any failure and particularly any valve deterioration or failure shall not produce an excessive or destructive output. As the whole of the regulating circuit, apart from V16B, handles a positive supply, any failure here will reduce the output by allowing an excessively negative bias to appear.

Complete failure of V16B results in a large positive bias appearing on the grids of V6 and V8 and the h.t. fuse will blow. Only under conditions of light load will the failure of V16B cause the output to rise unchecked, when it will reach about 32 kV at zero micro-amps. It is easy to arrange that a discharge to earth from the high-voltage terminal occurs under these conditions. The resultant load current causes the h.t. fuse to blow as before.

Failure of drive to either or both output valves also causes the fuse to blow. So the valves and transformers are protected against drive failure.

2.10. *Susceptibility to Supply Variations*

The disadvantage of this circuit is that it is not self-compensating and so the scanning and e.h.t. outputs fluctuate with the h.t. supply. A change of h.t. of 1V produces approximately 100-V change of e.h.t. The only modifying influence is that an increase of h.t. tends to produce a greater output from V16B. With the present wide fluctuations of mains supply voltage which occur in many parts of the country, further development to overcome this effect would be advantageous although the variation of 2 kV produced by a change of 10 per cent. in supply voltage would not be destructive to any part of the equipment except V10 and V11 and then only over a long period. Nor would it prevent the complete receiver operating provided the c.r.t. focus was compensated or adjusted.

The small variations of the h.t. supply impedance brought about by changes in the mains' tapping for different supplies causes the regulation curve (B, Fig. 9) to tip slightly up or down. However, this departure from the nominal is not great enough to be objectionable.

2.11. *Protection Circuit*

It is necessary to ensure that if either or both the scanning generators fail, the cathode-ray tube passes no current else the screen phosphors will be damaged.

Normally, it is necessary to derive potentials proportional to the line *and* frame-scanning potentials, sum the two and feed the resultant voltage to the cathode-ray tube bias supply.

In this design, any failure in the line circuit automatically causes e.h.t. failure. It is only necessary to use a protection circuit for the frame circuit. V12B is the diode used for this. A positive d.c. voltage is obtained from the a.c. output appearing at the anode of the frame output valve (V14). This positive voltage supplies the screen grid of V5A. The output of V5A

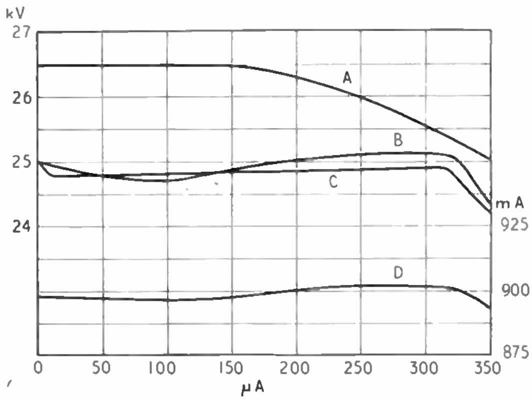


Fig. 9.—Performance curves.
A *e.h.t. limit for safe c.r.t. operation.*
B *e.h.t. regulation curve for new 170-V unit.*
C *e.h.t. regulation curve of 350-V unit.*
D *scan regulation curve of new 170-V unit.*

varies only slightly with screen grid supply voltage fluctuations from 75–140 V. Slightly less than half-frame scan is equivalent to 75 V. This means that for all normal adjustments of the frame circuit no change in brightness or focus occurs. If, however, the frame scan fails, or falls to a dangerously low level, the e.h.t. will disappear when the fuse blows.

3. Cost Comparison

The final criterion of all commercial designs is whether the cost and additional sales features, if any, warrant its production. The new sales features in this case are (1) ability to operate on an a.c./d.c. supply of 200 V upward, and (2) possibility of replacement of rectifiers in the field (this shows a considerable saving for service work over the cost previously of replacing the complete coil, rectifiers and capacitors in an oil-filled box). Against these must be set the fact that the circuit is more complicated.

As far as the cost is concerned it is fair to compare only the output stages and power

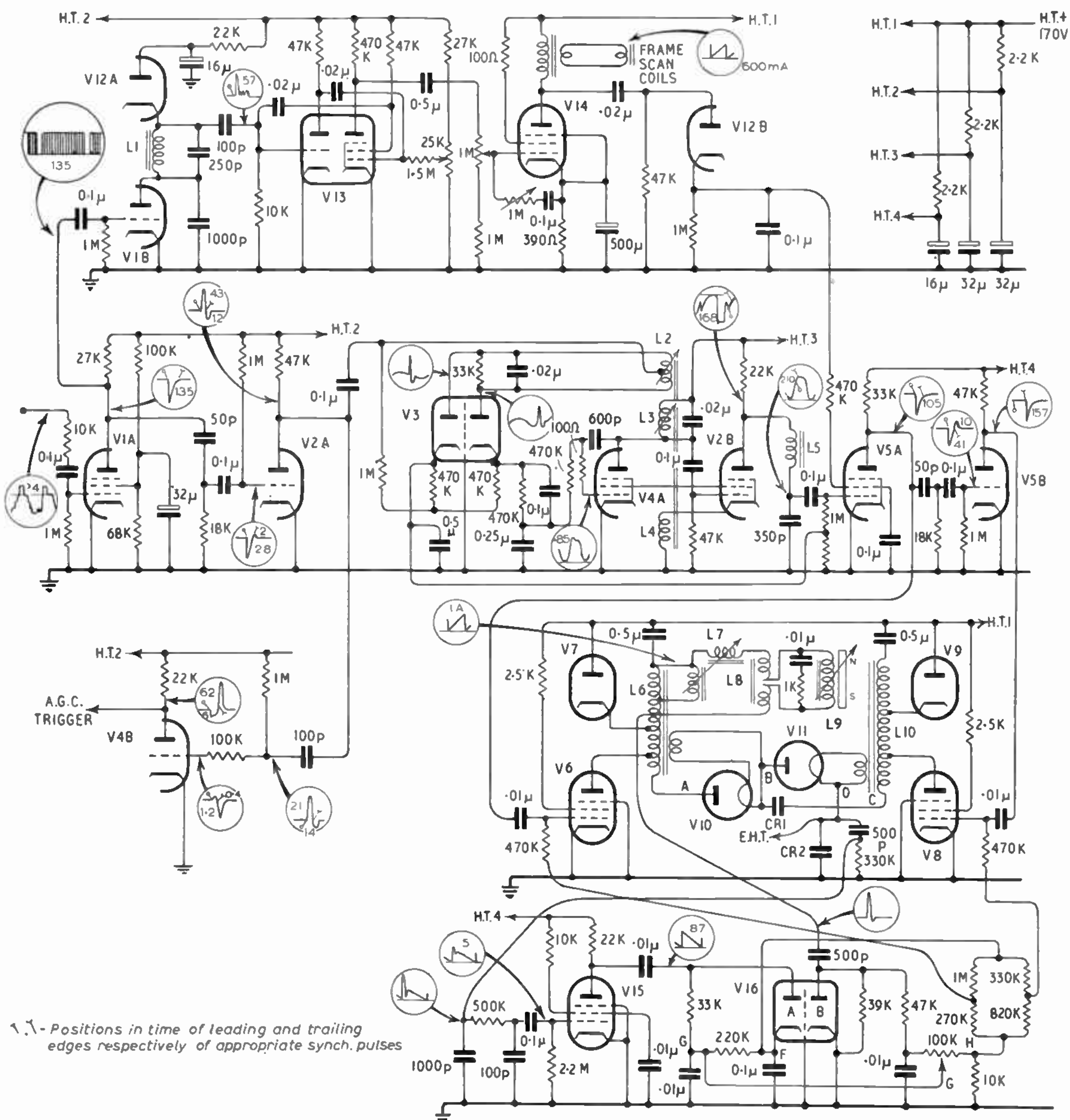


Fig. 10.—Complete experimental time-base unit. The figures given with the waveforms indicate the amplitude above or below the baseline as shown; the units are volts except where specified as being amperes.

V1A	Synchronizing separator	PCF 80	V5A	Line drive amplifier	PCF 80	V11	H.V. rectifier	EY 86
V1B	Frame synchronizing separator		V5B	E.H.T. drive amplifier		V12A	Frame synchronizing diode	EB 91
V2A	Line synchronizing amplifier	PCF 80	V6	Line output valve	PL 81	V12B	Protection diode	
V2B	Line oscillator		V7	Line efficiency diode	PY 81	V13	Frame oscillator	PCF 80
V3	Discriminator	EB 91	V8	E.H.T. output valve	PL 81	V14	Frame output valve	PL 82
V4A	Reactance valve	PCF 80	V9	E.H.T. efficiency diode	PY 81	V15	Regulating amplifier	EF 80
V4B	A.G.C. pulse amplifier		V10	H.V. rectifier	EY 86	V16	Regulating diodes	EB 91

Table 1

Component Comparison

Circuit A:	Circuit B:
LINE OSCILLATOR	LINE OSCILLATOR
LINE OUTPUT VALVE	LINE OUTPUT VALVE AND EFFICIENCY DIODE
LINE OUTPUT TRANSFORMER	LINE TRANSFORMER AND RECTIFIER
REGULATING VALVE	REGULATING AMPLIFIER AND DIODES
E.H.T. OSCILLATOR	INVERTER
E.H.T. OUTPUT VALVE	E.H.T. OUTPUT VALVE AND EFFICIENCY DIODE
E.H.T. COIL, 3 RECTIFIERS, 3 CAPACITORS	E.H.T. COIL, RECTIFIER, 2 CAPACITORS
MAINS TRANSFORMER	MAINS DROPPING RESISTOR
8 valve elements	11 valve elements
7 valves and	9 valves and
3 high-voltage capacitors	2 high-voltage capacitors
10	11

supplies as all the circuit prior to V5 might apply to any design. V5A would be any normal time-base oscillator supplying the drive to V6; and V5B the inverter to drive V8; or it is conceivable V5A and V5B might be a multivibrator delivering outputs of the correct amplitude and time displacement to drive the output valves direct.

In Table 1 is shown a block comparison of a conventional circuit using existing components, (A) and of the relevant portions of the circuit described in this paper (B). For comparison purposes, by grouping together the valves and high-voltage capacitors as components of approximately equal cost, it can be seen that circuit B uses 11 of these circuit elements as opposed to 10 in circuit A.

Without an efficiency diode, although operating from 350-V h.t. the normal line transformer (A) is assembled on a closed iron core, while this new line transformer (B) is a simple wave winding into the former of which is slipped a 2-in × ½-in Ferroxcube rod.

The new e.h.t. coil (B) is similar to the above, but smaller, while the corresponding high-voltage unit (A) is assembled complete with three rectifiers and capacitors and then oil impregnated and sealed in a can. The only precautions necessary with B are to make the screens round L6 and L10, V10 and V11 relatively dustproof. No ventilation is required. Circuit B uses only dropping resistors in the power pack. The total saving to the factory accruing from the use of circuit B would be at least £3 and possibly more, depending on production facilities available.

7. Acknowledgments

The work described was undertaken in the laboratories of McMichael Radio, Ltd. and the author wishes to thank the directors for permission to publish this paper.

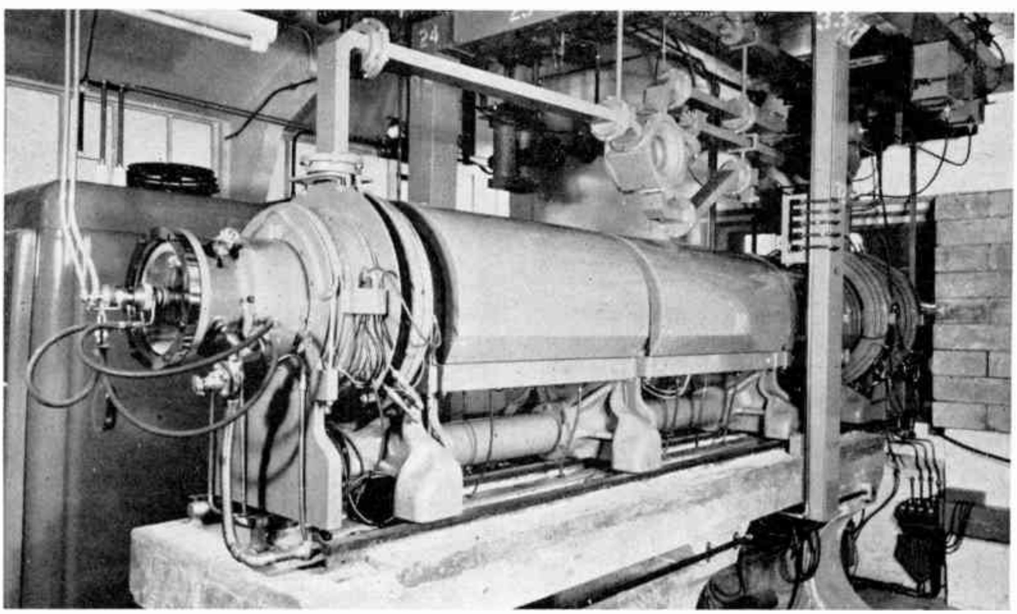
A 15-Million Volt Linear Accelerator

The installation of a 15-MeV travelling wave linear accelerator at the Physics Department of St. Bartholomew's Hospital College, London, is an important event in medical research. The machine is intended for the treatment of patients, but for the first few years it will be used entirely for fundamental research on the action of radiation on living tissue and on the best methods of the treatment of cancer.

The new linear accelerator, the largest and most powerful of its kind for medical purposes anywhere in the world, has been produced at Mullard Research Laboratories and is similar to the 15-MeV machine at A.E.R.E., Harwell, which is used exclusively for nuclear physics research. The operation is similar in principle to the 4-MeV machine at the Christie Hospital, Manchester, described in the April *Journal*. The higher accelerating voltage, however, necessitates a wave guide of 6 metres length, which is constructed in six sections.

Fundamentally, the accelerator is a source of high-energy electrons, which, usually, bombard a metal plate, producing high-energy x-rays for the treatment of deep-seated tumours. Under these conditions the output is 3,300 roentgens per minute at 1-metre distance. The repetition frequency of the radiation pulses is 500 per second and with the extremely high output the number of pulses for an exposure has to be counted electronically.

In addition, the St. Bartholomew's accelerator can produce a beam of 15-MeV electrons directly for treatment; the therapeutic value of high-energy electrons has only recently been demonstrated, and has many advantages over high-energy x-rays in the treatment of certain types of tumours. A third use of the accelerator will be as a source of fast neutrons, the effect of which on living tissue has yet to be investigated. The neutrons are produced when electrons bombard a uranium target.



The first three sections of the Mullard 15-MeV Linear Accelerator, showing the gun, the rectangular waveguide leading from the magnetron, the associated feedback circuit, and the modulator. There is a centre member (just visible) between the two three-metre sections carrying an oil diffusion pump for evacuating the system to a pressure of about 3×10^{-6} mm; the electron gun can be isolated from the vacuum enclosure for cathode replacement. A 3½-ft. thick concrete wall separates the last three sections and the x-ray head from the apparatus shown; the control desks are in a separate room in the temporary building.

Report of the Mobile Radio Committee

Mention has already been made of the setting up last year by the Postmaster-General of a Committee to advise on the questions affecting all users of v.h.f. mobile radio services and especially the problems arising from the Government's decision to clear Band III (174-216 Mc/s) for television. The Committee has now made its report and the Postmaster-General (Earl De La Warr) stated on April 6th that he had accepted it on behalf of the Government.

The present space provided for land mobile services is in two groups of frequencies: the low band (a total of 5·1 Mc/s between 72 and 88 Mc/s) and the high band (170·85 to 171·05 Mc/s and 180·85 to 183·95 Mc/s). The frequencies in the low band are not affected by the decision to clear Band III. Most of the various categories of the land mobile services (apart from police and fire services which have a separate allocation in another part of the spectrum altogether) operate both in the low and on the high bands. At the end of December 1954, there were about 6,700 private stations (base and mobile); of these just under two-thirds were in the low band and just over one-third in the high band.

The principal recommendation, therefore, is that the services at present within the television band should be reaccommodated within the space available between the top of the maritime mobile band (165 Mc/s) and the bottom of the television band (174 Mc/s). This plan will provide 32 channels, each consisting of the "base" frequency and the "mobile" frequency as well as nine channels for single-frequency services. It is considered that a "guard" band of approximately 3 Mc/s (which may be reduced to 2 Mc/s in the light of experience) between the upper limit of the land mobile band and the lower limit of the nearest television channel will be sufficient to prevent appreciable interference.

The Committee hopes that it will be possible to almost double the potential capacity of the band within the next year or two since manufacturers were unanimous that it would be practicable, due to technical advances, to reduce the width of frequency channels from the present figure of 100 kc/s to 50 kc/s.

One of the points which has been strongly urged by mobile radio users is security of tenure of allocations and here the Committee recommend that no change should be made for at least five years in the *bands* of frequencies in the v.h.f. range. A minority report by Captain L. P. S. Orr, M.P., representing the Mobile Radio Users' Association, however, considered that this security of tenure is not sufficient. It asks also for compensation to those users who will have to change their operating frequencies, but the Committee could not agree with either of these criticisms.

The eventual use of u.h.f. for land mobile services was also considered by the Committee since the frequency band of 460-470 Mc/s (which is likely to be extended downwards to 450 Mc/s) has already been allocated for fixed and mobile services, although so far manufacturers have not developed equipment for it, mainly because of its limited width. While present estimates of the cost of u.h.f. equipment are considerably higher than for comparable v.h.f. equipment, the Committee feels that increased production will make matters more favourable in this respect and recommends that the question of further development in the u.h.f. band be tackled vigorously and urgently.

The need for regular consultative machinery has been urged from a number of quarters and the Committee recommends that an advisory body be appointed which would examine such problems as the sub-allocation plan, channel widths, further development generally, and the possibility of catering for developments in the u.h.f. range.

The Report emphasizes that the majority of frequencies allocated to mobile transmitters will remain unaltered and the object throughout has been to keep the cost to the user to a minimum The extent of modification to equipment will vary in individual cases, but assurances have been given by the manufacturers that resources will be adequate to carry out the transfer provided that reasonable notice is given. A broad estimate of the time required for a complete change-over of the 2,150 mobile and 250 base stations affected would be about a year.

The Committee is therefore confident that the development of mobile radio can now proceed without the previous uncertainty which users had experienced in the past.

A NOTE ON TRACE-TO-TRACE CORRELATION IN VISUAL DISPLAYS: ELEMENTARY PATTERN RECOGNITION*

by

P. McGregor, Dip. El., (*Associate Member*)†

SUMMARY

In intensity-modulated visual displays used for the detection of pulse signals in noise, e.g., the P.P.I., the B-scan cathode-ray display, or the chemical recorder display, a normal requirement is to recognize the signal not only by its amplitude but also by the fact that it extends across two or more scans or traces.

This means, in effect, that detection is partly a matter of recognizing the correlation of signal pulse from one trace to the next. In this note, subjective measurements of the effect of this correlation on the threshold signal/noise ratio are given and discussed. It is shown that over the range of input signal/noise ratio from —10 to 0 db, the reduction of threshold is about 2·2 db per doubling of the number of traces, as compared with the 1·5 db theoretically obtained from "integration" of successive traces.

1. Scan-to-Scan Integration

In cathode-ray displays of the P.P.I. type (as used in radar sets) or of B-scan type (i.e., a sector of a P.P.I. displayed on rectangular co-ordinates of range and bearing), the effect of the superposition (or "integration") of successive scans along the same line is well known. The integration is effected by the afterglow of the phosphor, and detection of the echo-signal is greatly improved because it adds coherently. For n scans added in this way, it is generally accepted that the detection threshold (defined as that signal/noise ratio at the input for which detection is always just obtained, or is obtained with a stated degree of certainty) is lowered in a ratio $n^{\frac{1}{2}}$, or by 5 log n decibels, provided the threshold signal/noise ratio is lower than unity. Actually the exact law of the improvement depends on the type of rectifier used for rectifying the received signals and on the criterion assumed for detectability, as discussed elsewhere;[1] if the criterion

$$R_{b2} = \frac{\text{change in d.c. on application of signal}}{\text{r.m.s. of a.c. (noise) when signal is absent}}$$

is taken, and a linear rectifier is assumed, then the depression of the detection threshold for two and for four scans added together is shown in Fig. 1 for a range of values of the input signal/noise ratio. The calculation is made from the signal-and-noise formulae given by Tucker and Griffiths.[1] The improvement in threshold is seen to be 3 db per doubling of the number of scans at high threshold signal/noise ratios—where the rectifier behaves linearly—and 1·5 db at low thresholds, where the rectifier behaves in a square-law manner.

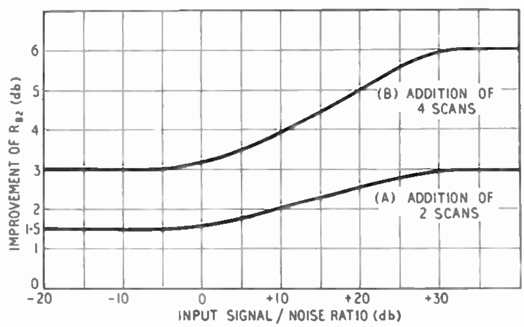


Fig. 1.—Improvement of signal/noise "criterion" (R_{B2}) due to "integration" of scans.

2. Trace-to-Trace Correlation

A rather different process which has much the same effect is used in chemical recorders,[1] which form part of echo-sounding and echo-ranging sets used for navigation,[2] underwater survey and fishing,[3] etc. Here successive traces are recorded on paper side-by-side instead of superimposed. An echo-signal from a particular range then forms a line on the paper, while the

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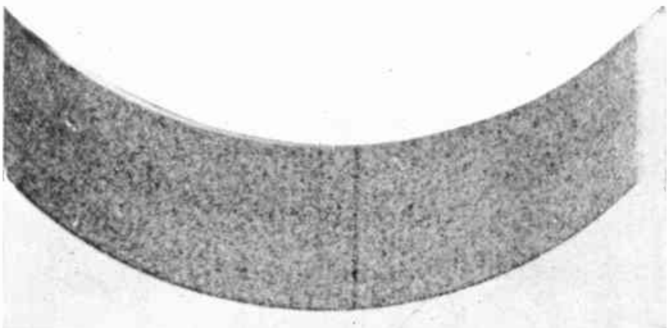
† Royal Naval Scientific Service.
U.D.C. No. 621.396.963.3:

random background forms no pattern at all—see Fig. 2. The detectability of the signal is greatly increased by this effect, and the detection threshold is lowered. The effect is clearly not integration as previously discussed, but can be regarded as trace-to-trace (or scan-to-scan) correlation. It does not seem practicable to calculate the magnitude of this effect, as it depends so much on a purely psychological response of the operator. Consequently, some subjective measurements have been made to determine the law of threshold depression with increase in number of scans.

Dimensions, bias, dynamic range, etc., were kept approximately the same in both cases, but the recorder was used in normal room lighting, and the cathode-ray tube in complete darkness. A photograph of the cathode-ray display is shown in Fig. 3. The scan rate was 84 scans per minute.

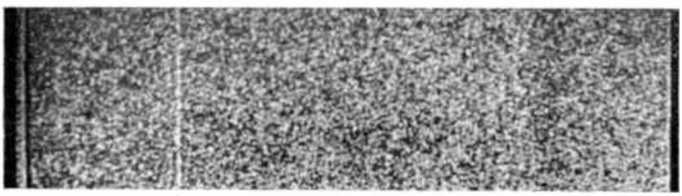
For each value of the input signal/noise ratio, starting from the lowest and rising in 1 db steps, and for each display, each operator was asked to look for the signal and prove correct detection by stating its range, or distance along the trace, which was varied from one test to another.



↑
SIGNAL PULSE

Fig. 2.—Chemical recorder display. Signal/noise ratio —3 db.

This instrument records the signal amplitudes by the release of iodine in paper impregnated with potassium iodide. The paper travels slowly in a direction at right-angles to the time-base deflection of the stylus which carries the signal current. The position of the mark along the trace thus indicates the range of the echo, and the intensity of the mark represents its amplitude.



↑
SIGNAL PULSE

Fig. 3.—Cathode-ray tube display. Signal/noise ratio —3db.

Twenty observers were used, and the signals were 2 msec pulses of 10 kc/s carrier against a background of white noise filtered by a circuit with 1 kc/s bandwidth centred around 10 kc/s. Input signal/noise ratios ranged from 0 to −10 db. The scan duration was 700 msec, and the paper speed was such that successive traces were roughly contiguous, i.e., there was no gap and little overlap. An exactly similar display using the same signals was also set up on a large cathode-ray tube with long afterglow, the successive traces being written one below the other, contiguously, by the use of a Y-timebase corresponding to the paper speed of the recorder.

The time taken for detection to be achieved was recorded up to a maximum of 3 minutes. The medians of the results of the 20 operators are shown in Fig. 4. The best fitting straight lines (determined by "least squares") are drawn through the points and show that:

(*a*) The cathode-ray display, which had no "permanent memory," was about 1 db inferior to the recorder, whose paper record gave it a "permanent memory." This difference, being a relatively small one compared with the scatter of the individual observations, is probably not very reliable.

(*b*) The rate of improvement of threshold with increase in the number of traces is very close to 2·2 db per doubling of the number; this figure appears quite reliable.

The conclusion from (*b*) is that trace-to-trace correlation gives an improvement in detectability greater than that theoretically obtained from integration, since over the range of signal/noise ratios used integration would give, from Fig. 1, between 1·5 and 1·6 db per doubling.

This lowering of detection threshold with an increased number of contiguous scans has, of course, an ultimate limit which is believed to be a function of the angle of acceptance of the observer's eye.

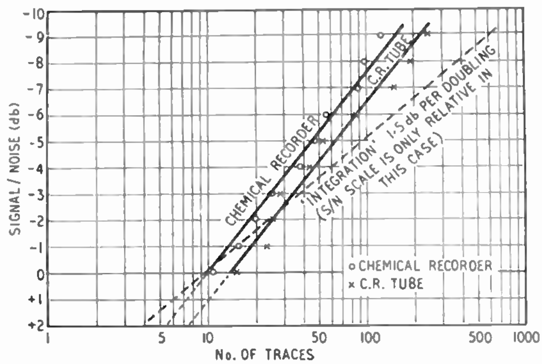


Fig. 4.—Depression of threshold of detection with increasing number of scans. (Medians of experimental results from 20 observers.)

In this experiment, the time limit imposed for the recognition of the signal ensured that this limit was not approached, since the maximum trace length used was less than 2·5 inches.

No precise estimate of the actual limit has been made, but at the viewing distance of the experiments it is unlikely to correspond to a trace length of less than 6 inches.

3. Implications as regards Pattern Recognition

It will be appreciated that the process examined above is a form of pattern recognition. On a single trace, with the signal-pulse duration equal to the reciprocal of the noise bandwidth, detection can be made on no other basis than that of the signal amplitude; if this does not exceed the largest noise peak on the scan, it will not be detected. If, on the other hand, the signal is known to extend over

(*a*) more than one trace-width on the chemical recorder display,

or (*b*) more than one trace-width on a P.P.I. or B-scan display (owing to the angular size of the target or wide beam of the radar),

or (*c*) more than one unit of noise-peak duration along the length of the scan (owing to the extent of the target in range or to the longer duration of the signal pulse),

then it is reasonable to assume the results of Section 2 apply in all cases, since it is clear from Figs. 2 and 3 that the background contains no feature which distinguishes one axis from another. The detectability of larger targets is thus calculable in relation to smaller ones, and the work can therefore be regarded as a contribution to the study of more general pattern recognition.

5. Acknowledgments

This paper is published by permission of the Admiralty but any opinions expressed therein are personal to the author.

Thanks are due to Dr. D. G. Tucker and Mr. J. W. R. Griffiths for helpful discussions during the course of the work and preparation of the paper.

6. References

1. D. G. Tucker and J. W. R. Griffiths, "Detection of pulse signals in noise," *Wireless Engineer*, **30**, p. 264, 1953.
2. H. F. Galway, "Echo-Sounding at Sea" (Pitman, London, 1952).
3. D. H. Cushing, "Echo-sounding and fishery research," *The Listener*, **52**, p. 170, 1954.

7. Appendix: Note on Visual Correlation

In the usual forms of intensity modulated visual displays, the signal is only recognized at low signal/noise ratios by the eye appreciating the formation of a pattern building up from a succession of contiguous traces. The time-correlation between successive traces is, in effect, converted by the display into a visual correlation manifest in the form of a particular pattern. It is clear that "visual correlation" is less restricted in its application than the "correlation" of mathematical theory.

NEW BRITISH STANDARDS

The British Standards Institution has recently issued the following new and revised Standards, copies of which may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1.

B.S. 448 : 1955. **Electronic Valve Bases, Caps and Holders. Sections B3G and 4.** Price 1s. each.

Section B3G gives details of the B3G valve base outline and associated valveholders. Section 4 describes a jig suitable for use with the holder insertion and with withdrawal force gauges specified in other sections of B.S. 448. (See *J.Brit.I.R.E.* for March, 1954, page 128.)

B.S. 559 : 1955. **Electric Signs and High-Voltage Luminous Discharge-tube Installations.** Price 5s.

The standard covers low and medium voltage signs (excluding exit signs for cinemas, etc.) irrespective of the lamp employed, and high-voltage luminous discharge-tube installations for external or internal use on circuits up to and including 5 kV to earth, whether used for publicity, decorative or general lighting purposes. It does not cover the lamps and auxiliaries operating below high voltage, which are the subjects of other British Standards.

Appendices deal with suppression devices for radio interference caused by flasher signs, and with the testing of the materials for non-flammability.

B.S. 661 : 1955. **Glossary of Acoustical Terms.** Price 6s.

This standard was first issued in 1936 and the advance of techniques in the fields of Acoustics has rendered necessary many changes in the contents and arrangements of the new edition, about 80 new terms having been added (an increase of about 40 per cent.).

The main changes are: the enlargement of the section on Recording and Reproduction to keep pace with techniques, particularly that of using magnetic tape and wire, which are finding applications in many fields, and the inclusion of a new section which mirrors the emergence of Ultrasonics from laboratory demonstrations to varied industrial applications. A section on the subject of underwater sound, which in 1936 was mainly limited to Naval application, has been included.

The section headings in the new edition are as follows: fundamentals; propagation; hearing; transmission systems; ultrasonics; underwater sound; instruments; recording and reproduction; music; architectural acoustics.

B.S. 771 : 1954. **Synthetic Resin (Phenolic) Moulding Materials.** Price 6s.

The most important change in this revised edition is the introduction of a simpler statistical technique without loss of discrimination. Crossbreaking strength is now included as an additional requirement and the standard temperature for tests involving immersion in water is raised to 25°C on the grounds of greater convenience. It also prescribes for the following properties of eight types of phenolic moulding materials: impact strength, surface resistivity after immersion in water, volume resistivity, heat resistance, power factor, permittivity, tensile strength, water absorption, plastic yield, electric strength, acetone soluble matter.

Methods of test for each of the specified properties are given, together with methods of test for powder density and bulk factor, flow properties, shrinkage of mouldings, density of mouldings, crushing strength, shear strength and elastic modulus in tension.

B.S. 1117 : 1955. **Fine Resistance Wire for Telecommunication and Similar Purposes.** Price 2s.

This standard applies to wires of diameter 0·0005 in to 0·012 in, the tolerances being closer than those prescribed in B.S. 115. The materials are divided into four classes according to application, viz.:

(1) Applications where low temperature coefficient of resistance is of primary importance (such as precision resistances and instruments).

(2) Applications where the temperature coefficient of resistance is important, but may be larger than that permitted for Class 1, with a maximum working temperature of 200°C.

(3) Applications where the working temperature does not exceed 300 C.

(4) Applications involving the use of materials which possess non-tarnishing characteristics coupled with a substantially linear temperature coefficient of resistance.

Tolerances on resisitivity, resistance, and uniformity of resistance are listed, and maximum values for the temperature coefficient of resistance over given temperature ranges are specified for each of the four classes of materials. Requirements are also laid down for the physical condition of wires, and a mechanical test is specified for wires that are not ordered to a special temper.

B.S. 1311 : 1955. **Sizes of Manufacturers' Trade and Technical Literature (including Recommendations for Contents of Catalogues).** Price 2s. 6d.

This standard specifies sizes of manufacturers' and suppliers' trade and technical literature, including catalogues, brochures, leaflets and books containing technical information working and operating instruction sheets, data sheets and erection and installation instruction sheets for plant and equipment.

B.S. 2540 : 1954. **Silica Gel for Use as Desiccant for Packages.** Price 2s. 6d.

B.S. 2541 : 1954. **Activated Alumina for Use as Desiccant for Packages.** Price 2s. 6d.

Whilst the grade of desiccant described in these standards may find application for uses other than packaging, the limits for dust, pH reaction and ammonia and ammonium compounds have been specified with the objects of affording protection to the contents of packages against risk of corrosion by fine particles of the desiccant leaking from their containing envelope into the bulk of the package.

A Code for the use of these materials has already been published under the authority of the Packaging Standards Committee as B.S. 1133, Section 19. (See *J.Brit.I.R.E.* for March, 1954, page 129.)