THE RADIO AND ELECTRONIC ENGINEER

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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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BRITISH CHARTERED ENGINEERS

A BRIEF announcement in *The Times* on 2nd August 1965 summarized an achievement for which many British engineers have worked during the past three decades. The announcement by the Privy Council stated that Her Majesty The Queen had been pleased to grant a Royal Charter of Incorporation to the Council of Engineering Institutions.

Thus the status and unity of the British engineering profession has received the greatest seal of approval. This has been achieved by the voluntary co-operation of the thirteen Chartered Engineering Institutions in forming the Engineering Institutions Joint Council (now called the Council of Engineering Institutions) in 1962.

The Institution of Electronic and Radio Engineers has certainly been in the vanguard in advocating the formation of such a body and the registration of engineers.† In his Presidential Address to the Institution in 1942 Sir Louis Sterling said:

> "If registration (*of engineers*) is essential in war, it is equally necessary in peace, in order to ensure proper utilization of man-power and as a means of checking overcrowding of an individual profession. This will not mean that any individual profession will become 'closed' . . . registration will assist in the control of training to ensure prospects of employment with a future.
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> "Since engineering is now recognized as so much a part of any nation's life and, in fact, international life, it is obviously of some importance to consider what standards of professional conduct (and ability) are required of its practitioners."

The Charter of the Council of Engineering Institutions provides for the establishment of the title "Chartered Engineer", for the exclusive use of persons registered by the Council. Professional engineers who were corporate members of a constituent Institution on the 3rd August 1965 are entitled to describe themselves as "Chartered Engineers", and to use the abbreviation "C.Eng.". They will be individually informed in due course of their registration as Chartered Engineers and will remain on the register *so long as they are corporate members of a constituent Institution.*

Thereafter, to become a Chartered Engineer a person must have been admitted to corporate membership of a constituent Institution.

There are many links between the individual Institutions and their counterparts in the Commonwealth and other countries. These links will continue as the main and most efficient means of dealing with matters relevant to specific disciplines.

The thirteen British Chartered Engineering Institutions comprise 130,000 corporate members. There are also over 100,000 Associates or Graduates who will not, of course, be able to secure registration as "Chartered Engineers" until they have first of all secured corporate membership of a constituent Institution. This will first involve the securing of academic qualifications acceptable both to one of the sponsoring Institutions and to the Council of Engineering Institutions.

Finance for the new Council will be provided annually by the thirteen Institutions *pro rata* to the number of corporate members. With a first year budget of £50,000 and H.R.H. the Duke of Edinburgh as Charter President, the Council of Engineering Institutions is now well equipped to make tangible contributions toward the advancement of engineering and the engineering profession. G. D. C.

† e.g. "The Status of the Engineer" *J.Brit.I.R.E.*, **17**, p. 137, March 1957.

INSTITUTION NOTICES

New Secretary for N.E.R.C.

At the Institution's 40th Anniversary Dinner, Admiral of the Fleet the Earl Mountbatten of Burma, K.G., expressed appreciation for the help the Institution had given in the formation of the National Electronics Research Council. The following announcement has been published in the current issue of *N.E.R.C. Review*.

"Since the inception of the National Electronics Research Council in 1961, Mr. Graham D. Clifford has been seconded by the Institution of Electronic and Radio Engineers to be the Secretary of N.E.R.C. This has been in addition to the permanent appointment he has held since 1937 as Secretary of the Institution.

"At a meeting of the General Committee of N.E.R.C. held on 10th June 1965, the Chairman of N.E.R.C., Admiral of the Fleet the Earl Mountbatten of Burma, referred to the voluntary work which Mr. Clifford had done in establishing N.E.R.C. as an Incorporated body and which had materially assisted the Council in reaching the position where it could justify the appointment of a paid and full time Secretary.

"Mr Clifford will continue to assist the Council by following up the preliminary discussions which Lord Mountbatten has already had in Australia, Canada, India and New Zealand on the formation of similar Research Councils in those countries.

"The Institution of Electronic and Radio Engineers has Divisional or Section Offices in those countries and Mr. Clifford will be revisiting Canada in October, and India, Australia and New Zealand early in 1966.

"As from 1st September 1965 the new Secretary of the National Electronics Research Council will be Lt. Col. J. P. A. Martindale, B.A., B.Sc., M.I.E.R.E., A.M.I.E.E., A.F.R.Ae.S., A.M.I.E.(Aust).

"After regimental service Colonel Martindale joined the Technical Staff of the army in 1948. He served in various Technical Staff appointments with the Ministries of Supply and Aviation, the United Kingdom Atomic Energy Authority, and as a member of the staff of the Royal Military College of Science.

"During the last five years Colonel Martindale has been employed in the electronics industry."

In December 1964 Colonel Martindale took up duties as Technical Officer of the Institution. He has now been released from Institution duties in order to take up full time work for the National Electronics Research Council.

New Headquarters for N.E.R.C.

In addition to providing secretarial and administrative facilities, the Institution of Electronic and Radio Engineers has also accommodated N.E.R.C. in the Institution's headquarters at 8–9 Bedford Square. As from 1st September 1965 the National Electronics Research Council will be occupying its own premises at 50 Bloomsbury Street, London, W.C.1.

Classified as a 'Building of special or architectural interest' under the Town and Country Planning Act, 50 Bloomsbury Street immediately affords some 2,500 square feet for the accommodation of the administrative staff of N.E.R.C. and technical staff now being engaged on the Selective Dissemination of Information project which has been started by the Council.

The new telephone number for N.E.R.C. is Museum 2076 (3 lines).

Solid State Physics Conference

The Institute of Physics and The Physical Society will hold a conference on "Solid State Physics" in the Renold Building, Manchester College of Science and Technology from 4th to 7th January 1966. This conference will follow the same general pattern as previous meetings held in Bristol.

Offers of papers, accompanied by synopses of not more than 200 words, should be sent before 12th November 1965 to the Papers Secretary, Professor S. F. Edwards, Department of Physics, The University, Manchester 13. The presentation time for contributed papers will be about ten minutes.

Inquiries regarding attendance and accommodation should be sent to the Meetings Officer, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1.

Index to Volume 29

The June 1965 issue completed Volume 29 of *The Radio and Electronic Engineer* which covers the period January–June 1965. An Index to the volume is enclosed with this issue.

Correction

The following amendment should be made to the paper on "The Rhometer: A Continuous Impurity Monitor for Liquid Metal Circuits" published in the June issue of *The Radio and Electronic Engineer:*

Page 331, footnote: Mr. A. R. Eames is now with the Control and Instrumentation Section of the Authority Health and Safety Branch at Risley, in Lancashire.

Fortieth Anniversary Dinner

On 24th June last members of the Institution and guests gathered in London at the Savoy Hotel under the chairmanship of the President of the Institution, Colonel G. W. Raby, C.B.E. The Guest of Honour was Admiral of the Fleet the Earl Mountbatten of Burma, K.G., Charter President of the Institution and Chairman of the National Electronics Research Council.

Proposing the Toast of the Guest of Honour, Colonel Raby began by saying that the Institution did not hold an Annual Dinner, preferring to wait until there was a special occasion to celebrate. He continued: "We are gathered here tonight for two purposes. First to celebrate the Fortieth Anniversary of the founding of our Institution. And forty years is indeed a long time in the relatively short span of life of one of the youngest of the modern fields of technological developments. And let us also at this time remember, and pay tribute to those men who had the wisdom, the foresight and the courage to form such an Institution, not for their own benefit, but for the benefit of others and particularly for the benefit of future generations. We are grateful and indebted to them. How happy those men would be if they could know how effective their early efforts were as measured by the success of the Institution during the past forty years of dedicated service and endeavour.

"The second reason for gathering here tonight is to honour and pay tribute to a man, who notwithstanding the high offices he has held and the active service life he has led, has nevertheless been a member of this Institution for no less than thirty out of those forty years—Earl Mountbatten of Burma".

Referring to the guests, the President especially welcomed His Excellency the Italian Ambassador, Signor Gastone Guidotti. The President cited the indebtedness of the radio engineering profession to his countryman, the late Signor Marconi—a fact recognized by the Institution in its annual award of the "Marconi Premium".

Colonel Raby continued: " Your Excellency will also remember your country's enterprise in encouraging continued development of radio and electronics by the establishment of the 'International Telecommunications Prize' which was founded by the City of Genoa. And we are honoured that our Institution is requested to make nominations for that Prize. Indeed I am proud to inform your Excellency that we have with us this evening a person whom we nominated and who actually received the Prize for his contribution to the transatlantic telephone cable project in 1955 whilst he was Director General of the Post Office—Sir Gordon Radley. Sir Gordon is an Honorary Member of this Institution and the author of our last Clerk Maxwell Memorial Lecture.

"To our Commonwealth guests we give a warm welcome. We are proud of our Commonwealth efforts just as we are proud that Great Britain is the Mother of the Commonwealth. And in this connection we have particular cause to remember that M not only stands for Mother, but it also stands for such remarkable people as Leslie McMichael, a great pioneer in the early radio industry, and later to such dedicated men as William E. Miller and George Marriott, both of whom I am delighted to say are here with us tonight.

"Nineteen years ago we celebrated our 21st Anniversary in this very room and used that occasion to induct as President of the Institution Admiral the Viscount Mountbatten of Burma. In his Presidential Address he suggested projects for possible future development and particularly stressed the wartime

Charter President and present President welcomed every guest and member.

congestion in the ether and the desirability of being able to use single frequency allocations several times over. He mentioned some possible post-war applications of radar, and some ideas about how electronics might be applied to other branches of engineering.

"He very much wanted to talk about the application of computer techniques because—and I quote his own words—'Our present systems of indexing methods are antiquated and illogical'. And remember that was in 1946. He then suggested that the reference library of the future would be contained in a memory machine! And this is precisely what we are trying to do today. What a pity it is that we did not take up these ideas then, for now we have to go back over those nineteen years to add to our store or bank of knowledge.

"But once Lord Mountbatten is satisfied about a possibility he concentrates upon it—however long it takes—until the idea becomes a practical reality. And I can tell you that although it was nineteen years later, the first project started by the National Electronics Research Council of which he is the Chairman, was on the Selective Dissemination of Information.

"During his first Presidency—nineteen years ago—we arranged the first of our post-war Conventions. We again ran up against the problem of security in discussing British achievements, but this time we took a lead from the President and put on a display with the aid of the French Air Force. We also demonstrated at that Convention a communications link between this country, Australia, India, Canada and New Zealand—again a very practical example of Lord Mountbatten's interest in the Commonwealth—to which I will refer again later.

"Subsequently, we held Conventions both on atomics and on the possibility of satellite communications, and in both cases Lord Mountbatten was not only a great source of help but, in fact, opened these Conventions personally and played a notable part in the discussions.

"Returning for a moment to his first Presidential term, it will be recalled that soon after his election he became Viceroy of India. Most men would have immediately resigned from the office of President of a learned Institution on the grounds of being too busy and too remote. But not at all. What he did do was to call an emergency meeting of the Council just before he left for India, appointed two Executive Vice-Presidents, and somehow found time in the midst of one of the greatest concentrations of power ever delegated to one man in the recorded history of this country to advise on the more urgent problems which were then facing our Institution.

"So far as we are concerned, it is a very special page in our history and in our memory, yet I can tell you that even though he was the last Viceroy of India, with all the pomp, circumstance and power that exalted office entailed, nevertheless Lord Mountbatten was not wholly satisfied with what he had done for the Institution during that first Presidential term. In fact when he came back from India he immediately talked to us of the need for building up our Commonwealth relationship. And that I may say is how our present substantial Commonwealth links were forged. It was suggested that the best way we could achieve a true Commonwealth relationship for the Institution was to present a petition to Her Majesty for the honour of a Royal Charter, and Lord Mountbatten

Lord Mountbatten with the President, Col. G. W. Raby, and the Secretary.

became an active member of our Charter Committee. When we were advised that our Petition had been successful, we felt that it was right and proper that for the first time in our history we should elect a Member to become President for the second time. Needless to say, that Member was Admiral of the Fleet the Earl Mountbatten of Burma, and we did this so that he will always be remembered in our Institution as the Charter President.

"Under our Charter, we are only allowed to elect one Honorary Member each year, and so when he had completed his term of office as Charter President, we asked him if he would agree to accepting Honorary Membership. Eventually we did succeed in convincing Lord Mountbatten that he should accept the final honour that the Institution can bestow."

The President, on behalf of his colleagues on the Council and on behalf of members throughout the world, then presented Lord Mountbatten with the scroll which bore testimony to all he had done for the Institution during the past thirty years, and as positive evidence of his election as an Honorary Member.

Colonel Raby continued: "Of course we take pride in the fact that a Member of the Institution has been so widely recognized and honoured for his public services, and that he should have reached the peak of the Service which he entered years ago as a very humble midshipman. Neither do we forget the very considerable service he has given and is still giving to Great Britain, to the British Commonwealth and indeed to the World.

"It is, I think, a commentary upon your whole life, Sir, that you have always been dedicated to making progress and not accepting life as you found it.

"In the early 1930's 'wireless' as it was then called, was in its very early stages. Television was but a dream and the word 'electronics' had not passed into the English language, but you had already perceived the importance of this field of science to your own Service—the Royal Navy.

"And if for nothing else, you would have earned a place in the realm of radio achievement by your editorship of the Admiralty Handbook on Wireless Telegraphy—which soon became and has remained a basic textbook.

"In your early years with the Institution you were invited to become a Member of the Council and we still possess your letter saying that because of a very busy life in the Service you could not promise to give as much time to the Institution as would normally be required of a member of the Council. That letter was written in 1936. In point of fact, you have given us your ideas and much of your time. If you had been able to give all the time that you wished, one wonders what greater heights the Institution might have scaled?

"The fact is that throughout his thirty years' association with the Institution, Lord Mountbatten has given much service to our cause and to the cause of science and engineering in general. He always energized this Institution into action if he thought that by our participation he could get something done or an idea ventilated.

"His memory is of course a well known characteristic. For example in 1946 and in this room he said, in referring to the future possibilities of electronics, that he had been delighted to hear that a special research survey was going to be initiated by the government—I don't know which government it was—but in point of fact, nothing was done. But in all those years he did not lose sight of the desirability of co-ordinating radio and electronics research and it was as a direct result of his address to the Radio and Electronics Industry in 1961—fifteen years later—and his subsequent talks with government and universities that the National Electronics Research Council was founded.

"Our Institution has always believed that an organization such as N.E.R.C. was badly needed if Great Britain is to be kept in the forefront of progress and development in electronics. We congratulate you, Sir, on having formed N.E.R.C. and we are looking forward to hearing from you as its Chairman about your hopes and ambitions for N.E.R.C.'s future.

"I realize that in trying to do justice to this toast I have been guilty of omissions, but I have no doubt that judgment in one form or another will be passed upon me in due course by our very good friend the Hon. Mr. Justice Ungoed-Thomas, whom we are particularly pleased to have with us this evening. To him and all our guests I would say that I hope they are as convinced, as I am convinced, that the Institution has proved beyond doubt that its formation forty years ago was not only a national necessity but it has also proved to be a national blessing."

Before finally proposing the toast of the Guest of Honour, Colonel Raby said: "As our Members know, it is our custom to entertain the immediate Past President at a dinner of the Council and Committees and to present to him a small memento of his term as President. As it was not possible to arrange such a dinner when he completed his term as Charter President, I want to use this memorable occasion to make another presentation to him on behalf of all our members at home and overseas."

Colonel Raby then presented to Lord Mountbatten a dictating machine appropriately inscribed. He also announced that the Council of the Institution was establishing the Mountbatten Premium in order to perpetuate Lord Mountbatten's long association with the Institution.

Lord Mountbatten made Honorary Member

The Scroll of Honorary Membership presented to Admiral of the Fleet the Earl Mountbatten of Burma, K.G., at the Institution's Dinner states:

"On the Thirtieth day of March 1935 Commander Lord Louis Mountbatten K.C.V.O., was elected a Member of the Institution."

The citation continued with reference to his work in the development of radio equipment, to his authorship of technical papers, and to his service first to the Council of the Institution, then as a Vice-President, as President of the Institution in 1947 and finally named as Charter President in the Institution's Charter of incorporation dated 31st August 1961.

Lord Mountbatten, as guest of honour at the Institution's Fortieth Anniversary Dinner, made the following reply to the toast proposed by Colonel G. W. Raby:

"My own association with this Institution over the past thirty years has been most rewarding to me, both in the professional sense of getting things done and in the many friends I have made, with whom I have been able to share a common interest in the fascinating world of electronics.

"For these reasons, I shall always value this Scroll of Honorary Membership.

"In it the Council of the Institution has most generously referred to the part that I have played in the development of our Institution.

"I am very proud to join our distinguished list of Honorary Members and thank you, Mr. President, and all our members, for awarding me this distinction.

"Every Institution, Society, or Club develops its own characteristics, and over the years I have seen the generous support which has always dominated the Institution's activities.

"I am so glad, Mr. President, that you have referred to some of our Past Presidents and to their contributions to the Institution's work in a real endeavour to do something for the common good.

"This spirit has certainly been carried on by Colonel Raby. How he manages to do this, whilst being able to arrange for Great Britain to be in the vanguard of progress in the field of atomic power, beats me. But it makes us all the more grateful.

"I am sure everyone here will wish to congratulate you, Colonel Raby, on the success of your design for the new Dungeness gas-cooled reactor.

"As so much has happened in the last four years, I think it remarkably kind of the Council still to remember my year as Charter President and to present me with this tape recorder as a memento of my term of office. I can assure you, Mr. President, that it will be very useful to me and whenever I use it I will, of course remember the I.E.R.E., particularly as this recorder was designed and patented by a member of our own Institution.

"In the forty years that have elapsed since I was a Lieutenant in the Royal Navy specializing as a Wireless Officer, there have been tremendous developments in electronics. I joined the Royal Navy as a small naval cadet in May 1913. I went to sea in Admiral Beatty's famous flagship, the battlecruiser *Lion*, in July 1916. I shall be leaving my post as Chief of the Defence Staff on 16th July this year. I shall thus have spanned about half a century of life in the Services.

"Looking back on the electronics side, which has always held a particular fascination for me, I remember the great battlecruiser *Lion*, with its 42 coal-burning boilers and its 600 stokers. Our main transmitter was the Type 1 Spark Transmitter; our receiver was the Model Outfit C using a crystal, and in our second office we had a Poulsen-arc Continuous Wave Transmitter. The first valves only came to sea the same year as I did. The electronic part of the *Lion*'s equipment was valued at £900.

"Yet in 1939 our greatest and latest aircraft carrier, the old *Ark Royal*, had electronic equipment valued at £13,500. The latest guided-missile destroyer we are now building, the *Fife*, has electronic equipment valued at £3,200,000.

"Could there be any more dramatic demonstration of what electronics has meant to the Navy and indeed, to the Services and the electronics industry?

"The specialist Officer in today's Defence Services is not only required to be a qualified engineer, but also a man technically capable of understanding new innovations. Unfortunately, increasing technical knowledge is not matched by the appropriate increase in the number of recruits to the engineering profession. Nor is the shortage of properly qualified engineers confined to Great Britain. It is a world problem.

"It is splendid therefore, that at long last all the Chartered Engineering Institutions have got together and formed the Engineering Institutions Joint Council so that such problems as the recruitment of more engineers can be tackled as a joint effort.

"The Joint Council is ideally placed to maintain an up-to-date register of all chartered engineers. The information which could become available as a result of such a register would be of tremendous help to the

Government and to educational authorities in the steps that they have jointly to take to remedy the present shortage of qualified engineers. Information on the number of men who have specialized knowledge of new and old technologies is extremely important if the country is to make the maximum use of its most valuable asset, which is man-power.

"The fact that The Duke of Edinburgh has agreed to become first President of the Joint Council shows the importance H.R.H. attaches to the Institutions 'getting together' to work for the common good. I am sure we will all agree with him.

"Our own Institution has already contributed ideas as to how the E.I.J.C. may make an immediate impact on the public mind. I hope particularly that serious consideration will be given to our proposal to arrange a mass 'get together' of engineers; a Convention perhaps in which each Institution becomes responsible for the proceedings for one day. Whether a man is a mechanical, electrical, production, or electronic engineer, he can benefit by cross-fertilization of knowledge; he can understand the other man's problems and may, in fact, be able in his own specialist way to contribute to the solution of those problems. I think that to organize such a Convention would be a very worthwhile function of the E.I.J.C.

"All the Institutions publish very commendable Journals. We all know the trouble, however, of keeping up-to-date in our own particular speciality. Too often we are ignorant of what is happening in other fields. I believe therefore that E.I.J.C. could do much to keep all Chartered Engineers informed of progress in other branches of engineering, possibly issuing abstracts or digests of the papers that are published in the individual Journals. I am quite sure that the Committee on Information Retrieval set up by the National Electronics Research Council would welcome discussions with the E.I.J.C. on this particular idea.

"Our Institution's support of an Engineering Joint Council was published as far back as 1943. We are very pleased to be one of the petitioners for the grant of a Charter to the Engineering Institutions Joint Council, and I am particularly pleased to see here tonight the Chairman of E.I.J.C., Sir Robert Wynne-Edwards.

"The goodwill which has already been shown toward the formation of the Joint Council does not, of course, as Sir Robert well knows, dispose of the individual characteristics of the supporting Institutions! I am the last person to suggest that in the common purpose of working together any person or Institution should lose their own individuality! The Institutions have become the repository of knowledge in their particular fields of engineering and, based on that knowledge, the arbiters of the knowledge required in order to practice in that particular profession and to be entitled to the status of a Chartered Engineer.

"The continued existence of the Institutions is, of course, dependent upon the expansion of their particular technologies. In much the same way, the future success of any growing industry is wholly dependent upon the acquisition of new knowledge. In short, the exploitation of new knowledge is the only means to ensure the success of any industry in the very competitive world in which we live."

Referring to his address to the Radio and Electronics Industry Council in 1961, Lord Mountbatten said: "I took the opportunity of saying that I thought there was not enough 'working together' between the scientists and industry, and that the industry should look at the whole question not only of backing our scientists but using the results of their endeavours more quickly.

"After a number of informal meetings at which Ministers of the Government, leaders of industry and representatives of our universities had discussions, they finally invited me to found the National Electronics Research Council.

"The constitution of N.E.R.C. includes representatives of every Government interest concerned with electronics, the electronics industry, the universities, and the colleges of advanced technology. I know of no other case in Great Britain or, indeed, in any other country of the Commonwealth, of such a voluntary association of Government, industry and universities getting together for the common good.

"I want to emphasize the voluntary side because it has, in fact, meant getting voluntary help. It was not a question of just simply having an advisory body; the universities and colleges came across with ideas. Industry has voluntarily provided the necessary finance to get N.E.R.C. established as an incorporated body. A truly magnificent example of how people can 'get together' in a worthwhile common cause.

"The first task we set ourselves in N.E.R.C. was to show how our research facilities were being deployed. The collaboration given by universities, Government departments, and industry indicated that there were a number of fields in which either there was excessive duplication or insufficient effort. With this information we were able to go ahead with examination of possible —and profitable—lines of future research. In order to aid this effort, we concurrently examined the project of information retrieval.

"You have, Mr. President, very kindly referred to the views that I expressed in 1946 on the need for using electronics—in this case the computer—as a means of enabling us to keep abreast of current knowledge. What we now call the S.D.I. project—to give its full name 'The Selective Dissemination of Information'—has, in fact, received the backing of the present Government who have undertaken to finance the first phase of our investigation.

"The potential of the system is almost unlimited. It could prevent needless duplication and increase efficiency in British electronics research by bringing to the attention of each worker all the newly-published information of special importance to him. But it need not be limited to one subject field, however vital. The system designed for our investigation, and the techniques and computer programmes used, will be immediately applicable on a national scale to any or all other branches of science and technology.

"I am sure there is no need for me to expand on the tremendous importance of taking every step to resolve what I referred to twenty years ago as the 'information explosion'. Unless we do this we shall inevitably duplicate and waste our total effort in research. Moreover, we shall continue to miss those fields in which research might be most profitably financed.

"The consideration of this one idea alone has, of course, led to the need for seeing whether, particularly in the Commonwealth, we can exchange and similarly benefit from the ideas being examined outside this country. There are great areas of research which are tremendously expensive—I need only refer to satellite communications as an example—in which it might be of benefit if a number of countries were to collaborate. Basically, however, we must first know what each country is doing and I believe that the first step is to see if we can have discussions with a body corresponding roughly to our N.E.R.C. in each country of the Commonwealth. During my travels in the last twelve months I have been able to get first hand reactions to this idea. I find that there is a real willingness in countries of the Commonwealth to co-operate with Great Britain on a N.E.R.C. basis.

"Since N.E.R.C. was founded and became a going concern, we have had a change of Government. The new Government has taken the initiative to found a Ministry of Technology. This Ministry has a Parliamentary responsibility for the very important electronics industry and the contribution it can make to the economic life of the country.

"We, in N.E.R.C., had to consider how we could best help the Government and the new Ministry in their efforts.

"I have been so busy travelling round the Commonwealth as Head of the Mission on Immigration that it was only on my final return a fortnight ago that I was able to call on the Minister of Technology, although we had had some preliminary discussions when I happened to have met him on several other occasions.

"We had a very friendly discussion about the future of N.E.R.C.; whether to dissolve the incorporated body and offer our services as an Advisory Committee to the Minister; or whether we could be of greater help by continuing as a separate body but, of course, offering all possible help to the Minister.

"Mr. Cousins made it clear that he would be glad to accept either suggestion.

"I subsequently had a full discussion with my colleagues on the General Committee of N.E.R.C. and, after considering every point of view, we unanimously came to the conclusion that we could best help the Minister if we were to carry on as an independent body.

"When I saw Mr. Cousins yesterday he confirmed to me that he was perfectly happy that we should carry on in this way. We want to do everything we can to help him in his most important job. We welcome the formation of the Ministry of Technology and wish to play our part in ensuring its success. I am grateful to Mr. Cousins for his helpful attitude all the way through.

"In this instance, whilst we may reasonably hope to secure Government financial support for important projects, such as that on the Selective Dissemination of Information, we must be prepared to finance ourselves on these counts: firstly, the necessary administration of N.E.R.C.; secondly our publications and other means of publicizing information among those interested; thirdly, we may have to be prepared to back our own judgment if necessary in undertaking certain projects on which enough parties agree.

"It is essential that we should clearly understand these obligations. It gives me personal pleasure, Mr. President, to say publicly how well our own Institution of Electronic and Radio Engineers has already contributed to the cost of N.E.R.C.

"Before the Council could be financed, the Institution readily agreed to carry out our first research survey, and provided the administrative facilities necessary for the conduct of our business.

"I would also like to pay tribute to the acceptance of the invitation I extended to the Institution of Electrical Engineers, as well as to our Institution, for the Research Committees of the two Institutions to meet together. As a result of which, we now have a Projects Committee of N.E.R.C. which is equally composed of members of both Institutions.

"We have now made it possible for both these major Institutions to be represented on the General Committee of N.E.R.C. In this way, the constitution of the governing body of N.E.R.C. is representative of all those who are interested in the development of electronics research in Great Britain.

"With the evidence of such goodwill, I have been very pleased to carry on as the unpaid Chairman of N.E.R.C., and look forward very much to developing our Commonwealth relationship and thereby giving practical effect to my own plea that by getting together we can accomplish much.

"I cannot end my comments on the work of N.E.R.C. without again paying a great tribute to the Institution of Electronic and Radio Engineers for the really great contribution they have made in the initial stages of forming N.E.R.C., both by providing accommodation and the services of its own administrative staff. I know that my colleagues on N.E.R.C. will always feel that we owe a great debt to the Institution during our infancy, although we are now taking steps to have our own independent organization.

"Mr. President, Your Excellency, my Lords and Gentlemen: I have not in this reply sought to excite your imagination by referring to any spectacular development in the field of electronics, since my colleagues are already investigating many new ideas and it is they who will, in due course, promulgate these ideas in the name of the National Electronics Research Council.

"Mr. President, I would like to thank you for making this such a personal occasion for me. It is, I realize, given to few men that they may become an Honorary Member of the Institution and even to become President. I have been very proud to serve our Institution on two occasions as President, and I thank you again for the honour you have done me by electing me an Honorary Member.

"During the whole of my active life with the Institution, we have had only one Secretary—and he did not intend to be permanent! He first agreed to help the Institution when it was having teething troubles because he had faith in the future of what we then called 'Wireless'. In fact, Graham Clifford has remained with us for over 28 years, and is today the doyen of the Secretaries of our Chartered Engineering Institutions.

"His enthusiasm for Britain and our Institution has even found expression through one of his hobbies—heraldry. Sir Anthony Wagner will confirm that our Grant of Arms, so well produced on this menu, was developed from the basic work of Graham Clifford.

"Four years ago I asked the Council of the Institution if I could use Mr. Clifford and his staff to assist me in forming the National Electronics Research Council. His understanding of our purpose and enthusiasm for our objects did much to achieve in record time our legal status and consequent world-wide interest. All this he has done voluntarily.

"We, in N.E.R.C., now realize that we must appoint a full-time Secretary, but my colleagues on N.E.R.C. share with me our thanks to the Institution, Mr. President, for all the help that you have given to us in our formative years and especially for the loan of your Secretary.

"For my part, I am looking forward to giving as much of my time as possible to fostering the great potential that N.E.R.C. can offer this country in the further development of one of our most exciting branches of science.

"For this reason, I shall of course, continue to give all the help that I can to our Institution, and of course, to N.E.R.C.

"Thank you once more, Mr. President, and all of you who have contributed to make this such a wonderful evening; an evening I shall never forget."

The Hon. Mr. Justice Ungoed-Thomas in the typically humorous mood which characterized his toast to the Institution. On his extreme right, Professor P. M. S. Blackett sitting next to the President.

A report of Sir Lynn's speech will be given in the next issue of the *Journal*.

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An Analysis of Results obtained on an Aircraft Data Link out to 1300 nautical miles (2400 km)

By

W. J. BATTELL, B.Sc.†

Summary: An analysis is given of results from an experimental transmission of data on h.f. from an aircraft flying across the Atlantic during the year 1963. Dummy messages were transmitted from the aircraft for two-minute periods every fifteen minutes on about forty-two crossings.

The procedure adopted in the analysis was to simulate various coding and error detection systems by means of computer programs and to apply these to the recorded data. By this means an estimate could be made of the relative merits of the various systems in affording protection against the interference and signal mutilation that were experienced during the airborne experiment.

Four systems have been simulated and in each case it has been assumed that the air-to-ground message will consist of 20 five-bit characters transmitted at 100 bauds. The analysis indicated that, if half of the total channel time were available for air-to-ground messages, a typical flight would have completed an average of 400 to 500 aircraft messages per hour for the range 350 to 1300 nautical miles and at no time would it have taken longer than about sixty seconds to contact an aircraft.

1. Introduction

Enthusiasm for data links for civil aviation has ebbed and flowed over the last few years, but the basic need to improve communications will always remain. The ever-present overcrowding of the radio frequency spectrum has helped to maintain a continued interest in the subject and prompted the British Ministry of Aviation to sponsor studies of the sort that are described in this paper. Two firms have contributed to the work described here, the Marconi Company on the radio communication requirements and the General Electric Company on coding and related problems.

Potential user support from British Overseas Airways Corporation was available to the Marconi Company and together they conducted an experimental transmission of data on h.f. from a B.O.A.C. aircraft flying across the Atlantic during the year 1963. This paper analyses the data, which were recorded on punched paper tape.

A survey of the available frequencies for communications and their respective properties shows that, with light and simple equipment, h.f. is about the only way of achieving radio telephony or its data equivalent for ranges of 1000 miles and more. Satellites are a possibility for the future, but supersonic transports are likely to be introduced before satellites can reasonably be expected to extend the available communications. With this prospect in view this paper sets out to assess and improve the reliability of a narrow-band frequency shift keying system on h.f.

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The American Radio Technical Commission for Aeronautics through its Special Committee SC–100[1] has suggested a message structure which consists of a synchronizing signal of a number of alternate noughts and ones followed by a seven-digit Barker start pattern.[2] The reversals give an indication within a narrow band circuit that a message is about to commence and the digit phase may at the same time be extracted to sample the following digits at their most advantageous position in time. Together with the Barker start, this pattern allows the designer to produce circuits to operate where the message becomes garbled just before the synchronization completely fails. In all that follows, therefore, synchronization and start are similar to the SC–100 proposals and are assumed to be perfect and the degradation of the system due to failure to synchronize or start properly is not considered. The SC–100 proposals involve long messages which are incompatible with fading and bursts of interference so a maximum message of the order of twenty five-bit teleprinter characters, or one hundred bits, has been selected for the analysis.

2. Improving Message Reliability

Figure 1 shows a block diagram of a transmitter and receiver which may be used to combat extraneous noise or fading. Each symbol X_n has associated with it a discrete noise waveform of duration T seconds and the coder selects the waveform to be sent. Stored in the receiver are these same noise waveforms and a computer is used to compute the symbol probabilities. For additive white noise the symbol with the largest cross correlation coefficient is the most probable, when the X_n's are equally probable and have the

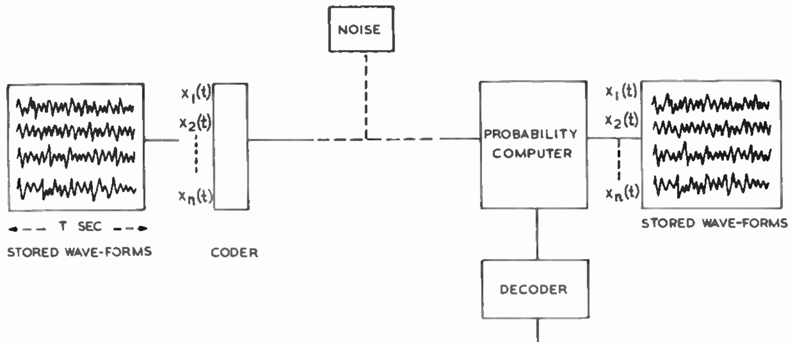

Fig. 1. Idealized communication system.

same total energy. To obtain the cross-correlation coefficient the received waveform must be normalized to a unit r.m.s. value and then multiplied with each of the stored waveforms. The coefficient is the mean value of the product at corresponding times (i.e. at intervals of T seconds). A noiseless channel, with a large value for T and fine-grained waveforms, i.e. suitable bandwidths, would give very nearly zero coefficients for all but one symbol which would be unity. In practice the computer selects the symbol by comparing coefficients and selecting the largest. It also can give an estimate for the probability of each character being correct and can give an overall estimate for the probability that the complete message is correct from the value of the coefficients.

Clearly the extraneous noise is the unknown parameter and hence the system cannot be optimized unless the interference can be predetermined. For fades, the duration of the symbol T must be extended through the fade to allow the computer enough waveform to get a good value for the symbol probability. We are forced therefore drastically to slow down the information rate to satisfy the fading conditions. Many systems are characterized by bursts of noise and to ensure a high probability of accurate recognition of all characters, T again must be long to satisfy the worst conditions. If, however, a feed-back path is available the system may be made to adapt itself to the noise by adjusting T. Two possibilities are available, firstly the value of T might be varied by command, or secondly, the value of T might be made small to allow satisfactory operation for normal conditions and with the aid of the overall computed message probability the computer would command a repeat if the message validity was in doubt.

It is considered that the system likely to meet the needs of civil aviation would be a roll-call system with a modest but fixed value of T and the ground would call each aircraft in turn until a good message was obtained.

Noise waveforms are not easily dealt with, so in all that follows the characters are coded with 0's and 1's and the experiments are designed to measure bits in error. A small loss in precision results, but digital techniques simplify the instrumentation. It is possible to code, for instance, a thirty-two character alphabet in an optimum cyclic manner, making each character look noisy in appearance. This results in simple coders and decoders and the waveforms can be generated sequentially without the need for storage. The correlation process is also simplified in that the received code is compared with the permissible codes and the code with the smallest distance is selected. The distance of a code means the number of the differences in the 0's and 1's.

The theorems of Shannon[3] enable the limiting capacity of a noisy channel to be determined. The elementary symbol is considered to consist of the bit, where the bit will be assumed to be a choice between two equiprobable events, and the noise is assumed to introduce errors with a probability p. Then if an '0' is received the *a posteriori* probability that '0' was transmitted is $(1-p)$ and that a '1' was transmitted is p. Shannon defines the equivocation $H_y(x)$ or the measure of the ambiguity of the received signal as

$$H_y(x) = -[\overline{1-p} \,.\, \log_2 \overline{1-p} + p \,.\, \log_2 p]$$

Table 1

Error rate p	Equivocation $H_y(x)$	Channel capacity	Code efficiency
1/1000	0·08 bit/symbol	0·92 bit/symbol	92%
1/20	0·28 bit/symbol	0·72 bit/symbol	72%
1/10	0·46 bit/symbol	0·54 bit/symbol	54%
1/5	0·72 bit/symbol	0·28 bit/symbol	28%

Table 1 shows the limiting capacity under varying degrees of error probability. Referring to Fig. 9, we find that the system can, under poor conditions, be subject to error probabilities of 0·1 and higher for some portions of the flight. A degree of redundancy of 100 to 200% is therefore required to correct these errors.

3. A 5 + 5 Code Single Error Correcting

In an environment where bursts of interference are occurring the shortest message has an obvious advantage. Some repeats will have to be made, but for the major portion of the time correct reception will result. Also if each character has its own check digits, most of the message is printed out correctly and a single repeat will fill in the blanks. Small blocks protected by check digits are inefficient in their ability not only to correct but also to detect errors and the Shannon limit for the capacity of the channel is never reached. However, a small block size is economical in storage circuitry and in the following analysis the teleprinter code protected by five-check digits is considered.

Let the teleprinter character be u_1, u_2, u_3, u_4, u_5, and let the transmitted character be $v_1, v_2 \ldots v_{10}$. The encoding procedure is as follows:

$$
\begin{aligned}
v_1 &= u_1\\
v_2 &= u_2\\
v_3 &= u_3\\
v_4 &= u_4\\
v_5 &= u_5\\
v_6 &= \quad u_2+u_3+u_4+u_5\\
v_7 &= u_1 \quad +u_3+u_4+u_5\\
v_8 &= u_1+u_2 \quad +u_4+u_5\\
v_9 &= u_1+u_2+u_3 \quad +u_5\\
v_{10} &= u_1+u_2+u_3+u_4
\end{aligned}
$$

'+' = modulo-2 sum

The received digits are $w_1 \ldots w_{10}$, mutilated by the interference. The receiver accepts $w_1 \ldots w_5$ and carries out the encoding procedure which originally took place at the transmitter. These summations (modulo-2) are then compared with the received check digits $w_6 \ldots w_{10}$. By this means an error pattern is generated $s_6 \ldots s_{10}$ and it is these syndromes which contain the information necessary to accept, correct or reject the received teleprinter character $w_1 \ldots w_5$. Table 2 shows the error patterns generated by a single error in any one of the ten positions in the ten-digit code. No errors will produce an error pattern consisting of five zeros.

The decoder counts the number of errors and if the answer is zero or one it assumes that there are no errors or that the error is in $w_6 \ldots w_{10}$ and that character is accepted. If the count is four then the complement of the pattern is added (modulo-2) to the character. For counts of 2, 3 or 5 the decoder does not attempt correction and the character is made a blank.

Table 3 shows the operation of the code for all errors from zero to ten. For instance, of all possible

Table 2

Single errors

Checks →	s_6	s_7	s_8	s_9	s_{10}
Error positions	Error pattern				
v_1	0	1	1	1	1
v_2	1	0	1	1	1
v_3	1	1	0	1	1
v_4	1	1	1	0	1
v_5	1	1	1	1	0
v_6	1	0	0	0	0
v_7	0	1	0	0	0
v_8	0	0	1	0	0
v_9	0	0	0	1	0
v_{10}	0	0	0	0	1

combinations of two errors, namely, 45, all are detected and produce a blank, and of all possible combinations of three errors, 40 out of 120 produce incorrect outputs.

Table 3

	Number of errors										
	0	1	2	3	4	5	6	7	8	9	10
Correct	1	10	0	0	0	0	0	0	0	0	0
Incorrect	0	0	0	40	90	76	80	40	5	10	0
Blank	0	0	45	80	120	176	130	80	40	0	1

Figure 2 shows the encoder. Time is divided equally into two periods such that the switches as drawn are set for digits one to five and then switched over for digits six to ten. Parallel loading is used here; each character of five digits is set into the shift register at digit time of 1, 11, 21, . . . etc. The first five shift

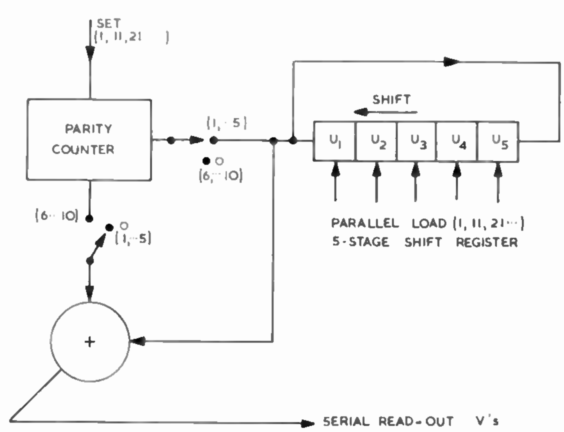

Fig. 2. 5 + 5 encoder.

pulses shifts out $u_1 \ldots u_5$ through the adder. These appear at the output of the adder (modulo-2) unmodified, as the other input to the adder is set at nought. While $u_1 \ldots u_5$ are being sent, the parity counter produces the sum $u_1+u_2+u_3+u_4+u_5$ and by re-circulation of the digits the shift register now contains the information as before and the parity counter contains the sum. The switches change and u_1 is shifted out through the adder to be added to the sum $u_1+u_2+u_3+u_4+u_5$.

$$v_6 = u_2+u_3+u_4+u_5 \ (u_1+u_1 = 0) \text{ etc.}$$

While the second set of u's are being shifted out it would be possible to read-in serially and inhibit the re-circulation.

Figure 3 shows the decoder. In the first time interval digits $w_1 \ldots w_5$ are fed to a parity counter and shifted serially into the shift register. During the second time interval, $w_6 \ldots w_{10}$ are added via adder 2 to the self-generated $w_6 \ldots w_{10}$ coming out of adder 1 and the error pattern is shifted into the error pattern shift register. Also in time interval two, the digits are re-circulated in the input shift register. The error count is also made in the second time interval. Time interval three or the first interval of the next character causes the digits in the input shift register to be pushed out through adder 3 to be added to the complement of the error pattern shift register. Two, three and five errors produce an output from the error counter equal to all '1's' and this waveform via the OR circuit produces an all 1's output (teleprinter blank), cancelling out the mutilated output from adder 3. Zero and single errors from the error counter inhibit the complement addition to adder 3. Both serial and parallel read-out is shown.

The type of decoding is called syndrome decoding as the operation on the received character $w_1 \ldots w_5$ depends on the syndrome patterns $S_6 \ldots S_{10}$. For higher order error correction this is complicated and a correlation type decoding is better suited. The 5+5 code is an assembly of words whose distance or difference in 0's and 1's is always four or greater. That is, if a single error occurs, the mutilated word is within a distance of one from that sent and a distance of three from an unknown character. Two errors give distances of two from the sent character and two from the incorrect character. Some two errors would be unambiguous, some would have a 50/50 chance of being correctable and others a less chance. We have chosen to blank all two errors in the syndrome decoding process to simplify the decoding. A correlation decoder would consist of a ten-bit register to store $w_1 \ldots w_{10}$ and an encoding circuit with a counter to generate all the code words in rotation. These are compared, very quickly, with the input word and the distance or difference added up. Distances nought or one transfer the selected character to an output store, all other distances produce a blank. This process involves more circuitry than the syndrome decoding, but is the only method suitable for the next code.

4. 5 + 10 Code Triple Error Correcting[4]

A system with an average bit error rate lying within the range 0·001 to 0·01 requires a 5+5 code to give a satisfactory performance. For error rates 0·01 to 0·1 the redundancy must be increased to 200% and a 5+10 Bose-Chaudhuri code will have a greater chance of success. This is a cyclic linear code, i.e. the first or

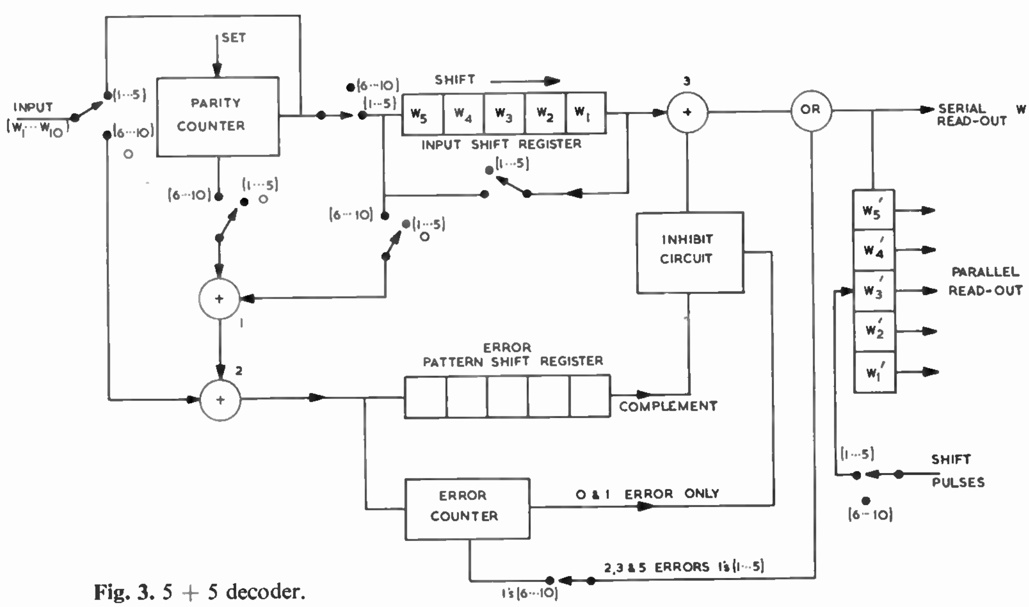

Fig. 3. 5 + 5 decoder.

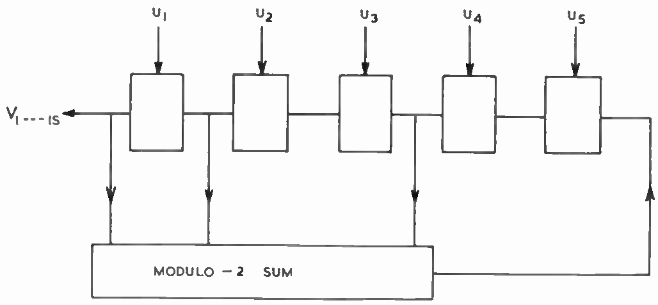

Fig. 4. 5 + 10 encoder.

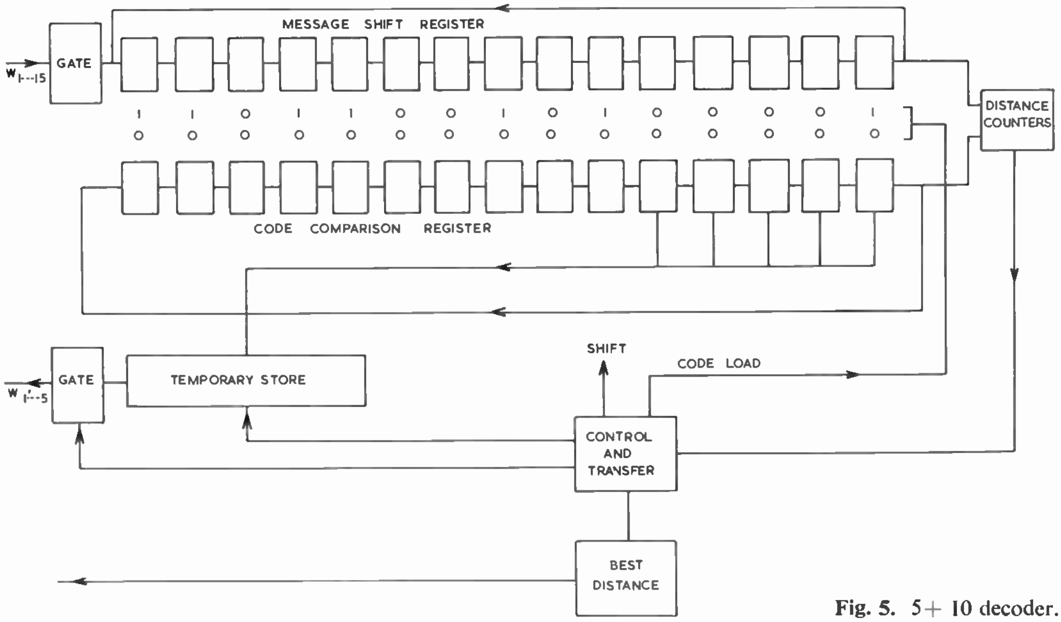

Fig. 5. 5+ 10 decoder.

last five digits are the actual five digits of the uncoded character in clear binary, and the last or first ten digits are check digits. Any cyclic shift of any of the thirty-two 15-digit coded characters is another (or the same) coded character. The code is simply generated by a five-stage feedback shift register synthesizing the relation

$$v = (D^2 + D^4 + D^5)\, v$$

where D = unit delay

$+$ = modulo-2 sum

Figure 4 shows the uncoded five-bit character loaded into the register in a similar manner to the 5+5 code and in this case the first fifteen digits represents the coded word. Investigation into the structure of this code shows that it may be divided into two complementary sets and each word is a distance of seven to any within its own set and a distance of eight to any in the complementary set. Three errors may therefore be corrected.

Correlation decoding is the simplest and all codes may be generated within a circulating shift register of length fifteen. The all-1's and all-0's are special and the register is loaded firstly with all-0's and, after one cycle, with one of the characters, say 100001010011011. From then on the registers rotate with the lower one given a jump every fifteen shifts. Fifteen codes and their complements are compared with the input. Figure 5 shows a simplified block diagram of a decoder. All thirty codes together with the all-1's and all-0's are compared with the received word and the first five digits are transferred into a temporary register and replaced when a code word producing a smaller distance is found. At the end of each correlation only codes which produced apparent errors of three or less are released, anything else is made a blank. The apparent distance for the selected code is available as an output.

5. Comparison of Coding Methods on an Idealized Model

It is possible to evaluate the various coding methods on an idealized model, assuming that the only form of interference is due to circuit noise.

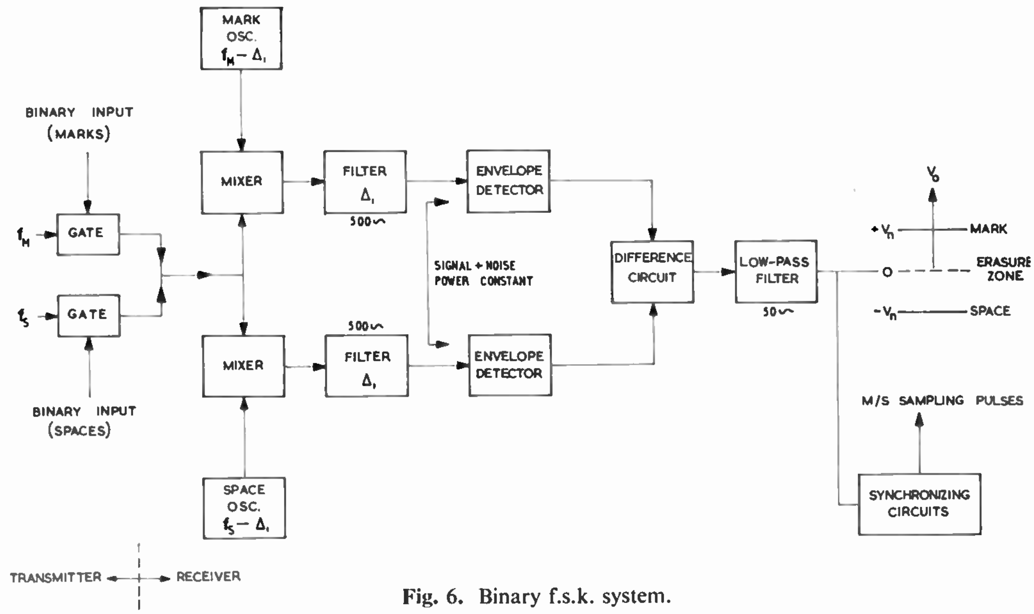

Fig. 6. Binary f.s.k. system.

As the channel is disturbed by multipath and possibly by Doppler spread a noncoherent detection mechanism has been selected. Also for the same reason phase-shift and amplitude modulation are rejected leaving a simple binary f.s.k. channel which is well known and tried. A discriminator is excellent for good signal/noise ratios, but has a well-defined capture threshold. To give a gradual degradation, the discriminator is replaced by twin filters at the mark and space frequencies followed by a linear detector. The digit rate is assumed to be 100 bauds and after detection and subtraction the signal is passed through a low-pass filter of bandwidth 50 cycles. Digit shape after the filter is very nearly Gaussian and this waveform passes to the decision circuits. The synchronizing circuits select the digit frequency and produce a sampling pulse at the middle of the digit. By making the bandwidth of the synchronizing circuits very much less than 50 cycles the effects of noise are predominately within the signal channel and the position of the sampling strobe is accurately maintained at the maximum of the Gaussian-shaped signal. It is assumed here that the synchronization is maintained until zero signal results. The fairly flat topped pulse is sampled with a strobe that is 10% of the pulse width and three zones are set up, for mark, space and erasure. The erasure zone has been assumed to be 10% of the total mark and space excursion. Should the signal waveform fall within the erasure zone any time during the strobe, the pulse is considered doubtful.

To this idealized system (Fig. 6) the teleprinter code has been applied in the following five ways:

(1) 5+10 code, triple error correction, higher order detection and erasure for greater than three doubtful digits out of fifteen.

(2) 5+5 code, single error correction, multiple error detection and erasure for greater than two doubtful digits.

(3) 5+1, single parity check without the erasure zone detection.

(4) 5, with erasure zone count of one or greater.

(5) 5, unprotected.

These are plotted in Fig. 7 as the probability of correct reception or the probability of error against signal/noise ratio for signal-plus-noise power constant into the two linear detectors. From the figure it can be seen that coding is very much more effective than null zone detection, but null zone detection used in conjunction with a code may prevent the acceptance of errors in fades or in very poor signal to noise conditions.

6. Description of a Marconi-B.O.A.C. Experiment

In collaboration with the Marconi Company and B.O.A.C. an experiment in data transmission was conducted during the year 1963. Briefly the No. 2 h.f. transmitter of a B.O.A.C. *Britannia* was modified to transmit automatically frequency shift keying reversals (010101 . . .) for a two-minute period every fifteen minutes. Five channels in the 2·9, 6, 8, 10 and 13 Mc/s aeromobile bands were used. The receiving equipment was installed at Birdlip Radio Station, Gloucestershire, where diversity pairs of suitably directed rhombic aerials were available for the

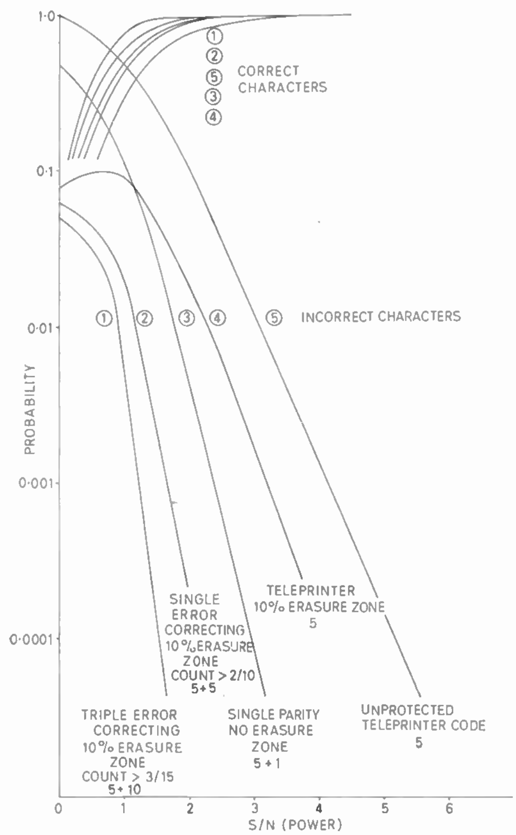

Fig. 7. Teleprinter code applied to a binary f.s.k. system.

receiver. Results were obtained on about forty-two crossings of the North Atlantic.

The telegraph reversals were received, shaped and amplified by a conventional diversity telegraphy receiver as used on point-to-point systems. The signal was then compared with a synchronous local signal at the centre of each mark and space element. If the comparison showed the received element to be of opposite polarity to the local element then it was counted as one error. The errors were punched on to five-hole paper tape. Before recording the two-minute period eight five-hole characters were put on to the tape to identify the start of the transmission and at the end of the period four five-hole and four blank characters were punched.

At the same time as the errors were punched on to the tape a magnetic tape recording was made of the signal. The two were played back to check the cause of the errors and each test period was then allocated a label to denote the time of transmission, the range of the aircraft, the radio frequency used, the modulation parameters and the presence or absence of interference from other stations.

A copy was then made of the original tape, any errors due to misalignment of the equipment being edited out and the label characters added. Figure 8 shows a period slightly worse than average where the main cause of errors was due to interference from radio telephony. A feature of interference from transmitters radiating a continuous carrier is that it produces continuous 0's or continuous 1's, which is identifiable in a system which should produce alternate 0's and 1's. Fading and static also cause short bursts of errors.

7. Computed Statistics

With the aid of a computer it was possible to take the processed tapes and to sort out the periods in range brackets, day-time and night-time, winter and summer. Also the errors obtained in various block sizes were calculated to give some indication of the performance of various codes. Figure 9 is a typical flight and shows the bit error rate for each two-minute period. The average bit error rate is within the range 0·01 to 0·1 and consequently the 5+5 code is likely to give only marginal benefit while the 5+10 code has a greater chance of providing a worthwhile system improvement. Bursts of errors will overload

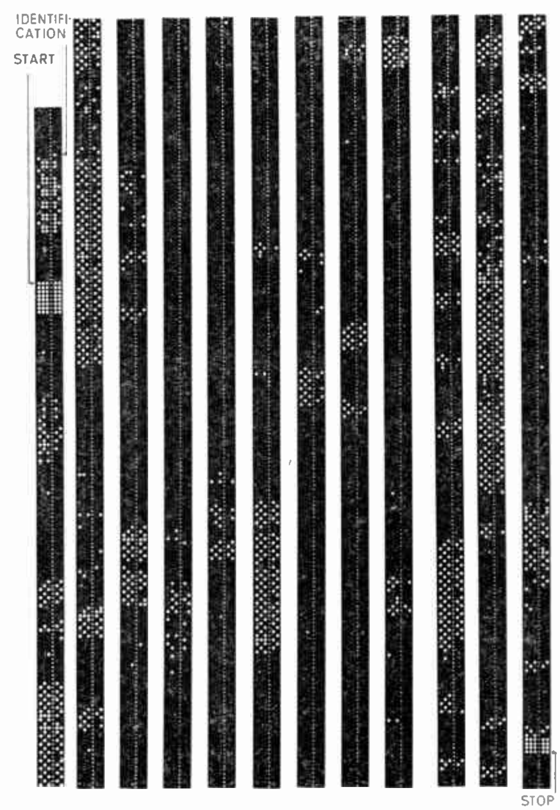

Fig. 8. Error tape record Prestwick/Montreal. 600 n.m. 0157 G.M.T.

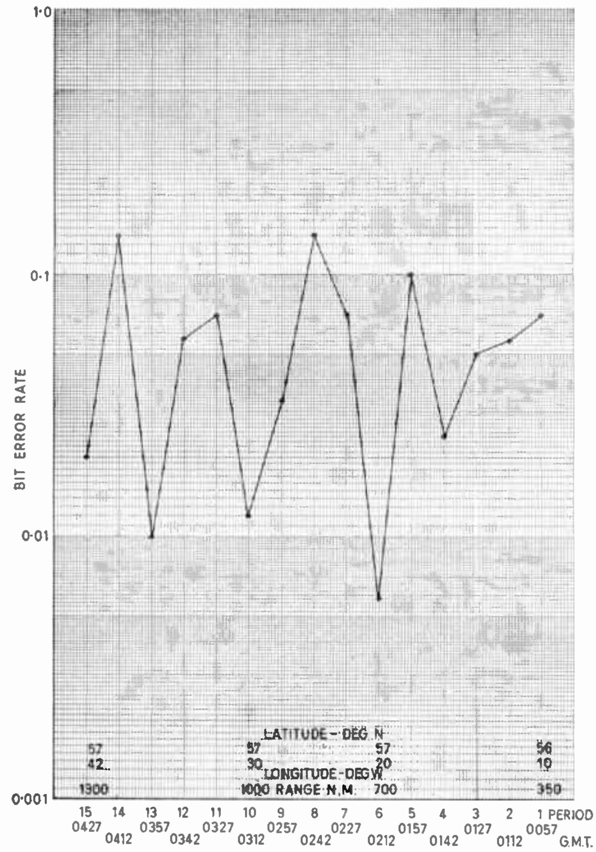

Fig. 9. Sample bit error rate Prestwick/Montreal.

any code and if some means could be found to randomize the errors the codes will have a greater effectiveness.

Any character code can be made burst error correcting by interlacing the characters within the message in a manner similar to time division multiplex. If a 20-character message is assumed, each character consisting of 5+5 digits, then the first digit of each of the 20 characters is transmitted in the first 20 symbols, the second digit of each of the characters in the second 20 symbols transmitted. A block of 20 errors in 200 would give one error in each character and these would all be corrected.

A program was written to extract a 20-character message with interlacing for both the 5+5 and the 5+10 code. The length of message for the 5+5 code was 200 digits and that for the 5+10 code 300 digits.

Figure 10 is a typical block containing interference. The five-bit error patterns are written in order down the page from top to bottom and the output characters 1 to 20 are read across. Interference starts at the input character number 38 and continues to 48, 11 characters occupying 55 bits or, approximately, one half-second. Twenty-four errors occurred and as no more than three reside in each of the 20 characters across the block, all would have been corrected by the 5+10 code. Without interlacing, the first characters with errors 37, 38, 39 would have had three errors and would have been corrected, but the second 40, 41, 42 would have contained eight errors; 43, 44, 45, five errors; 46, 47, 48, eight errors and would have given incorrect characters. The tendency to show a symmetrical distribution of errors even after interlacing, results from the fact that the same character was transmitted throughout this test and when the receiver is captured the error pattern is symmetrical. In practice with a normal message the symmetry will not be so pronounced and the chance of getting four or more errors will be reduced for the interlaced working.

Table 4 shows a comparison of the 5, 5+5 with and without interlacing, and the 5+10 with and without interlacing. Test 20 has been used for this plot as it is fairly typical for the year's results.

A worthwhile, but not spectacular, improvement is obtained with increasing complexity.

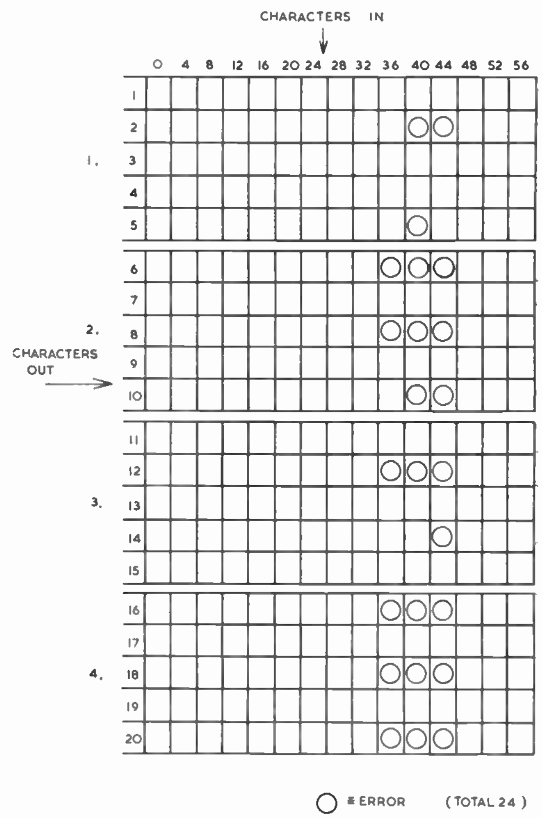

Fig. 10. Effect of interlacing on interference (300 digit block 5 + 10 code).

Table 4

Test 20. Prestwick–Montreal, 27th April 1963

	% Correct				
Period	5-unit	5 + 5 1 error corrected	5 + 5 interlaced (200) 1 error corrected	5 + 10 3 error corrected	5 + 10 Interlaced (300) 3 error corrected
1	78·0	80·1	80·6	88·9	92·0
2	85·4	87·8	88·4	94·2	96·9
3	85·8	90·5	91·8	93·9	98·2
4	89·7	94·2	97·8	97·1	99·9
5	75·1	75·0	78·8	81·4	85·4
6	98·5	98·5	99·5	99·2	100·0
7	84·0	85·6	85·4	89·5	90·3
8	68·3	70·9	73·0	78·0	84·2
9	92·8	94·8	96·5	98·0	99·5
10	96·0	96·7	98·6	99·4	99·9
11	83·1	83·7	89·6	88·5	88·9
12	87·3	87·7	90·0	91·3	93·6
13	90·4	97·6	99·5	99·7	100·0
14	68·2	69·8	76·1	75·8	78·3
15	90·2	95·0	97·0	98·3	99·7

8. Four Simulated Systems

The simplest system that could be devised would be to use the unprotected teleprinter code and repeat the message. The smallest number of repeats which will yield a possible solution is three since this enables a majority decision to be taken. This is about all that can be done since all errors transform the sent character into another apparently good character and only in special cases can an error be detected. On this basis, it is assumed that a 20-character message will be sent as a whole three times in succession in reply to one interrogation. Interference on the same channel affects frequency shift keying systems in a manner which tends to produce an all-0's or all-1's character and to take advantage of this it is assumed that these two characters are forbidden within the message.

No account is taken of the interrogation or selective calling mechanism beyond assuming that half the channel time is available for the air–ground message. Perfect synchronization and 'message start' are also assumed. Every character is examined for interference, i.e. all-0's or all-1's and these are rejected. The messages are stored and compared character-by-character and the complete message is accepted for some such criterion as two out of three characters in each position the same or three out of three the same. If this condition is not satisfied a further interrogation is made and a further three messages added. For a 30-character alphabet the chance of getting any particular character in error will be one in thirty, so that the chance of building up an error is fairly small. Also, a blanked character cannot contribute to an error. One set of conditions, out of the very many possibilities for acceptance, was worked out from the previous statistics to give an acceptable error rate. These were programmed into the computer and a continuous run made on the error tape from Test 20.

1 interrogation	2/3	or better for all characters.
2 interrogations	3/6	,, ,, ,, ,, ,,
3 interrogations	4/9	,, ,, ,, ,, ,,
4 interrogations	5/12	,, ,, ,, ,, ,,
5 interrogations	6/15	,, ,, ,, ,, ,,
6 interrogations	7/18	,, ,, ,, ,, ,,
7 interrogations	8/21	,, ,, ,, ,, ,,

If the conditions are not satisfied in seven interrogations STOP and START AGAIN.

Three hundred and ninety-seven completed calls were made in 30 minutes of calling time. Six messages had 1 character wrong in 20 and no message contained greater than 1 error. In two cases, the acceptance conditions were not fulfilled and the calling sequence recommenced. Thirteen interrogations was the maximum required to get the message. Of the 6 errors, 3 occurred in a single interrogation and the others in higher numbers of repeats.

The second system to be simulated consisted of a 20-character message using the 5+5 code. The reply to each interrogation in this system consists of a single transmission of the message in its coded form, i.e. 200 digits. The first operation is to inspect each 10-bit character for interference, which in this case is 0101010101 and 1010101010, but in practice will be the all-0's or all-1's patterns. The first system described above had interlacing, in that each character of the message was sent three times spread out at 100-bit intervals. Here this advantage is not available, but instead the code will detect and correct errors. One interrogation of 200 bits could provide the message, but if this is not the case further interrogations will be required and these are stored and compared character-by-character. The computer inspects the syndromes and corrects all single errors, detects all double errors and of all triple errors and greater, 2/3 are detected and 1/3 accepted incorrectly. The rules for addition of the characters are determined by the syndromes. Firstly, no blanked character is allowed and secondly a character with an all-zero syndrome will take preference to one which was corrected. A further safeguard, to prevent the code being overloaded, was programmed into the system. Any message which had four or a greater number of characters with syndromes not equal to zero was considered unsuitable and rejected.

In a real-life system the ground would have been able to contact a total of 508 aircraft and of the replies received eight messages would have had one undetected error and two messages had two undetected errors. One error occurred in each of three single interrogations, one in a four, one in a three and both double errors occurred in a three.

The third system to be simulated was the same as the previous one, except that an interlacing operation replaces the elimination of interference. Each block of 200 digits is rearranged in a way similar to that used in Fig. 10. Bursts of errors are now spread out, but long spells of interference still become concentrated within a few characters. The ability to blank out the interference has been lost, but the code is still able to detect errors, and overload is prevented by the rejection of messages with four or more characters with syndromes not equal to zero. Fortuitously, the total number of aircraft contacted was again 508. Of these, three messages had single undetected errors occurring in multiple interrogations, one double undetected error, two four undetected errors and one five undetected errors, also in multiple interrogations.

The fourth system to be simulated was similar to the previous case except that the redundancy in each character was increased to allow for triple error correction, i.e. $20 \times (5+10)$. Interlacing is assumed and each message is considered alone. Addition of corrupted messages in an attempt to extract the correct information has been left out so that the storage problem and program required are very much simplified. In this case a simple decoder is possible. Four errors and greater are considered as incorrect characters, but in practice about half of these would be detectable and blanked. To prevent overload a total error count is made in each message of 300 bits and the message is rejected if this number is 27 or greater.

The system would have dealt with 441 aircraft. Seven messages had one error each, half of which would have given errors in practice and the other half could have been blanked.

9. Survey of the Systems

Table 5 collects the results together to indicate the average number of aircraft calls which would have been possible during Flight 20, Prestwick to Montreal, for the range 350 to 1300 n.m. A 50% utilization of the channel is considered practical for the selective calling and reply. The errors obtained are also given, together with the maximum time taken to obtain a message for the worst conditions during the flight.

Table 5

	Average number of aircraft calls per hour 50% utilization	Chance of one or more characters error, per message	Chance of more than one character error, per message	Maximum time to get message (seconds)
System 1 3 × 20 × 5	397	0·015	—	78
System 2 20 × (5 + 5)	508	0·02	0·004	32
System 3 20 × (5 + 5) Interlaced	508	0·014	0·008	44
System 4 20 × (5 + 10) Interlaced	441	0·016†	—	60

† With correlation decoding this figure is likely to be half errors and half rejected characters.

The capacity of the channel for the four systems is probably adequate and could only be extended two to one, by using two r.f. channels. A 100-baud channel is accommodated in a 500-c/s pass-band, so that one speech channel could support several data channels. The shorter message using the 5+5 code produces a higher capacity, but the superior properties of the 5+10 code, used with interlacing, should result in a smaller chance of error.

The 5+5 code used in Systems 2 and 3 is simple and syndrome decoding is possible for single error correction. In the case of the 5+10 code, syndrome decoding is very complex and correlation decoding is the only practical method. Because of the cyclic structure of the code, all the code words may be generated from just one code within a shift register and compared with the received character. A distance or difference in the number of bits is calculated and the character with the least distance is printed out. Referring to System 4, a condition was made to accept the message for less than 27 errors. In practice this is the sum of all the distance values from the code for the 20-character message. This value of 27 was fixed by observation of the records of one flight period and a better value could possibly be determined. As the experiment sent out a symmetrical message and the interference itself produces an all-0's or all-1's message, the errors are systematic. For a random message it may be possible to increase the value of the total message distance.

The distance of the received character from the code is a measure of its probability of being incorrect and the total distance of the message a measure of the interference, atmospheric noise or static. It will always be possible with the system to print out the message together with a confidence measure for each character.

It can be shown that the 5+10 code may be modified to produce a 5+5 code and a simple mode switch could be used to reduce the redundancy if the channels eventually became exclusive to data. This tends to favour the development of correlation decoding. Also the generation of the 5+10 code within the aircraft's encoder is no more complicated than with the 5+5.

A search has been made for suitable codes for 6 and 7 bit, so-called Standard Character Codes. Reference 4 gives many of these and no difficulty is found in selecting codes by a method of truncating or by selection of suitable subsets.

Interlacing complicates the equipment as the complete message must be stored, but inexpensive and reliable stores are currently available. Even if the interference was radically reduced, the static and multi-path interference would still tend to overload the codes. It is possible to do without the interlacing, but a number of incorrect characters will necessarily occur.

Interference has been dealt with in a number of ways within the four systems. The use of a f.s.k. system has meant that the receiver is captured and all-0's or all-1's has resulted. Other forms of modulation will produce different types of effects. System 1 owes its success to the identification of the interference with a 30-character alphabet and if the all-0's and the all-1's characters cannot be dispensed with, then the coded systems have certain advantages. Each character may be translated before assembling as a message block and re-translated back again as soon as the character digits are channelled out again at the receiver, prior to the normal decoding process. Thus, for the 5+10 code, change parity for every third digit, i.e. add modulo-2 001001001001001, for each code character at the transmitter and receiver. Inspection of the syndromes of the 5+5 code do show that some protection is obtained for an all-1's interference, but superior detection properties appear to be available if the two characters can be spared. As an alternative it may be possible to detect the interference within the demodulator circuits of the receiver and provide erasure symbols.

System 1 requires a small computer to do the decoding and hence would only be suitable for a two-way link employing a computer in the aircraft. If, however, SELCAL was used to call the aircraft and a computer was available on the ground it could be a workable system. Storage for computation and program is very modest and shared facilities would be possible with other traffic problems. Interlacing with character-coded systems to provide burst error correction is worthwhile, as this complexity reduces the chance of an error and will still be operative even if the interference is eliminated leaving static and multi-path interference. One disadvantage of interlacing, from the system flexibility point of view, is that the message must be formed into blocks of 300 or 200 digits and this upsets any extended message facility. A 5+10 or 5+5 coded message is suitable for a flexible length, but a big penalty is paid for longer messages in that they now straddle the interference bursts. All systems which add messages in an attempt to read through very bad patches require some form of computer, whereas System 4 using a 5+10 coded message is serial in nature and does not require a general-purpose computer. A greater capacity is obtained by the addition of successive messages, but the increased complexity is probably not worthwhile.

It is concluded that System 4, $20 \times (5+10)$ using interlacing, is likely to yield consistent results and the equipment can be designed to be economical in size and cost.

10. Acknowledgment

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Effects of Nuclear Explosions on the Ionosphere

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Summary: The ionization produced in the lower ionosphere by x-rays, β-particles from neutron decay and β and γ-radiation from fission debris from a nuclear burst is examined. The effects of this increased ionization on the propagation of radio frequency signals in the various bands is considered.

1. Introduction

A nuclear explosion is the source of a great quantity of radiation of various kinds, including electromagnetic radiation from γ-rays and x-rays through visible light to the infra-red, and particulate radiation in the form of β-rays and neutrons. If the detonation takes place deep in the atmosphere all these except the visible light are absorbed in the atmosphere within a few hundred feet. However, when the detonation takes place in the thin air of the upper atmosphere or in space there is little to absorb the radiation and it can travel for tens of thousands of miles.

When such radiation impinges on the Earth's atmosphere, it first encounters the very thin upper atmosphere where the probability of interaction with the atoms of the atmosphere is very small, but this probability increases rapidly as the radiation penetrates deeper into the air and at a critical height, depending on the penetrating power of the radiation, it will all be absorbed, the energy of the radiation being used up in ionizing the air. The mean energy needed to produce an ion pair in air is about 32 eV, and so some 30 000 ion pairs will be produced by each MeV of incident radiation. The dependence of the distribution in height on particle energy is shown in Fig. 3, in which all the curves are for 1 erg/cm^2 of incident β particles. A series of curves for monoenergetic particles is shown, together with the distribution to be expected from the same total energy when the range of energies is distributed as in the spectrum of β particles from the decay of fission fragments, and also for the energy spectrum corresponding to neutron decay. Both these cases are important in the present context.

2. Ionization Produced by Radiation

Of the various forms of radiation resulting from a nuclear explosion the following are absorbed with the production of ionization in the atmosphere: γ-rays, x-rays, ultra-violet light and β-particles. These have different penetrating powers and produce their ionization at different levels in the atmosphere. These ionized layers affect the propagation of radio waves in several ways depending on the height of the ionized layers and the frequency of the signals.

The temperature of the bomb material immediately after detonation is such that the thermal radiation is mainly in the form of x-rays, and these may carry as much as 75% of the energy of the explosion.

2.1. *γ-Rays*

The penetrating power of the γ-rays is such that they can penetrate from the top of the atmosphere to a height of some 30 km above the Earth's surface. Here they are absorbed and produce their ionization, but it will be seen from Fig. 6 that the electron collision frequency is very high at this level, with the result that free electrons are very rapidly attached to neutral particles, and so become ineffective in absorbing radio frequency energy.

We have to consider two sorts of γ-rays: the prompt γ-rays associated with fission and/or fusion processes at the instant of detonation and the delayed gammas emitted over a long period from the cloud of radioactive fission products. The prompt gammas are emitted in a fraction of a microsecond and, owing to the rapid attachment of the electrons, the ionization from this source lasts only for a few microseconds.

The cloud of fission fragments moves in a way depending on the height of detonation. At low altitudes the density of the air is such that the x-rays are all absorbed in a sphere of diameter small compared with the density scale height. Under these conditions the bubble of hot gases behaves like a hot air balloon. At a somewhat greater altitude where the x-rays can penetrate further (see Fig. 1) the penetration is greater in an upward direction, where the air is less dense and the denser air beneath the explosion is

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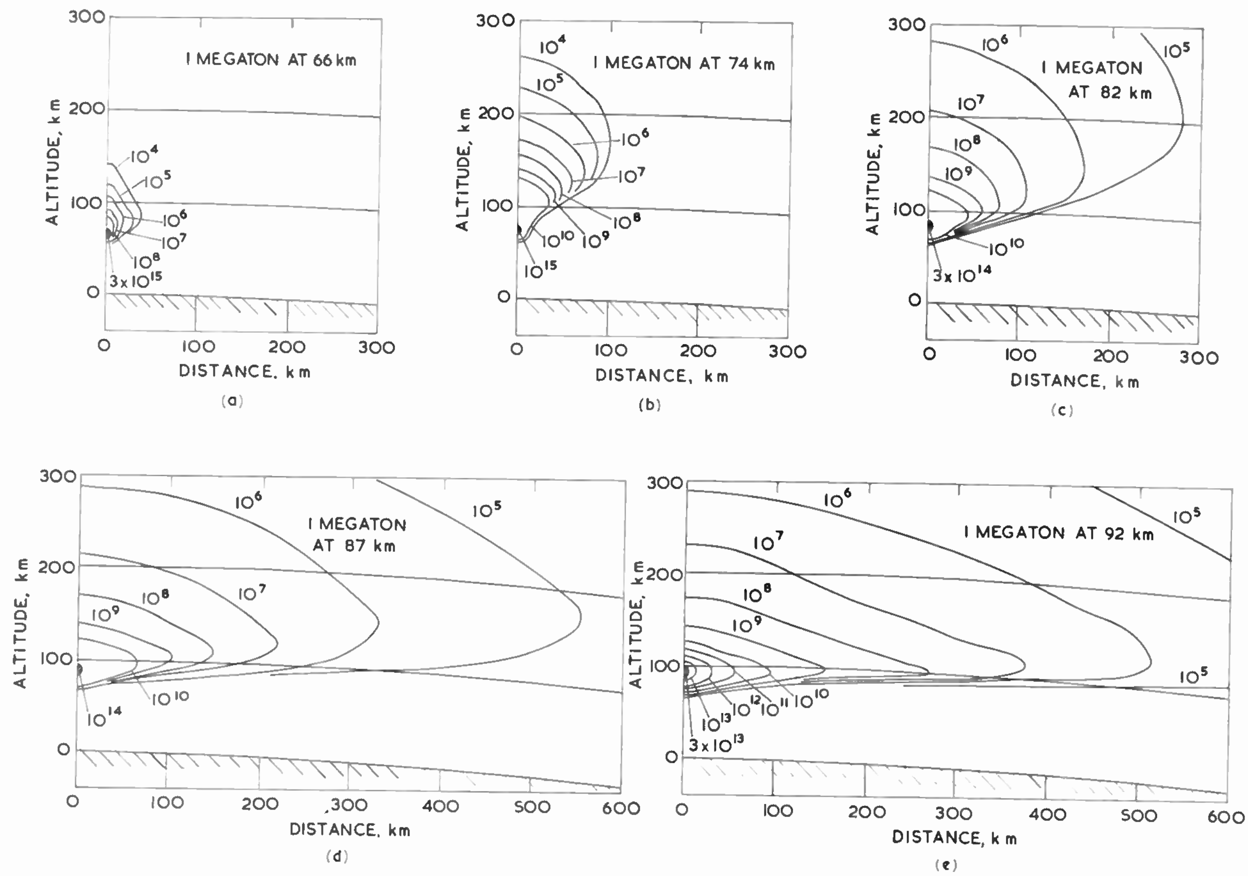

Fig. 1. Contours of electron density from prompt x-ray ionization.

heated more than that above it. This results in increase of pressure beneath the bomb and the debris is ballistically propelled upwards and may reach a much greater height than is possible from the hot air balloon effect.

Unless the detonation takes place at a very great distance from the Earth, the debris eventually settles down at an altitude of about 130 km, where it forms a thin layer of considerable area. Radiation from this layer, in the form of γ-rays and β-particles irradiates the air above and below the layer. The upward-going γ-rays easily pass through the thin air and produce negligible ionization. The downward-going rays are again absorbed at a height of 30 km, but here the irradiation is continuous, and the effect of the attachment of electrons is to establish a balance so that the rate of production of electrons by ionization is equal to the rate of removal by attachment. This results in the formation of an equilibrium layer of ionized air at this height which may exist for several days.

2.2. *x-Rays*

Since the thermal x-rays carry such a large proportion of the total energy, their effects are of major importance. As described in the previous section, for a detonation at low altitude the x-rays are absorbed in a short distance, giving a spherical mass of intensely hot and ionized air, which is visible on a radar screen, but which has little effect on radio propagation except for paths passing through the fireball, and then only for signals whose wavelength is short compared with the fireball diameter.

At altitudes between 70 and 90 km the horizontal spread of the ionized region increases enormously (Fig. 1), and at the same time the electron collision frequency is decreasing and so the recombination rate is less and the ionization lasts longer.

For the range of burst altitudes above 100 km, but where the atmospheric density is still appreciable, there are two regions of high ion density. One is the region immediately surrounding the burst, where the x-ray flux is sufficient to fully-ionize all the atoms. This process absorbs energy and reduces the flux, which is also decreasing by the inverse square law, and eventually a point is reached where the flux density is no longer sufficient to fully-ionize the air. In the region immediately below the burst this produces a region of almost constant ion density, the reduction in x-ray flux being offset by the increase in air density. Below 100 km, however, the rate at which the x-rays are absorbed with distance increases rapidly, resulting in a layer of high electron density with a sharply defined lower limit. The horizontal spread of the layer is defined by that part of the 100 km layer of the atmosphere which is visible from the burst point. It will be seen that as the burst height is increased to many Earth radii the affected area will increase to almost a complete hemisphere.

The contours of electron density due to x-ray irradiation shown in Fig. 1 are the instantaneous values. The processes of attachment to neutral atoms and recombinations between ions and electrons cause the electron density to decay. The processes are very complicated[1, 2] and the effects vary with height (depending on collision frequency and atmospheric constitution). During daylight photo-detachment of electrons which have become attached to neutral particles takes place and this results in the peak value of electron density some time after the event being lower in altitude than at night; in a similar way the natural D layer is at a lower altitude by day than by night.

At very high electron densities the rate of recombination is very high, but decreases at lower values. This means that a high yield device will produce a high initial electron density, but this will decrease more rapidly than that from a lower yield, so that after a few minutes there is little dependence on yield. An approximate indication of the way in which this sort of ionized layer decays is shown in Fig. 2, but this will be more complicated if a day/night transition occurs during the decay period.

2.3. *Neutrons*

Neutrons are emitted in great numbers over a range of energies during the nuclear reaction. They are very penetrating since, being uncharged, they can pass close to a nucleus without being deflected by the electric field and so pass on unless a direct hit is scored. Thus neutrons themselves cause little ionization, but they are radio-active, decaying with a half-life of thirteen minutes into a proton and an electron.

At the time of the explosion neutrons are emitted more or less isotropically and move off in straight lines. After 1 second neutrons of 10 MeV energy will have travelled to 28 000 miles, 1 MeV neutrons to

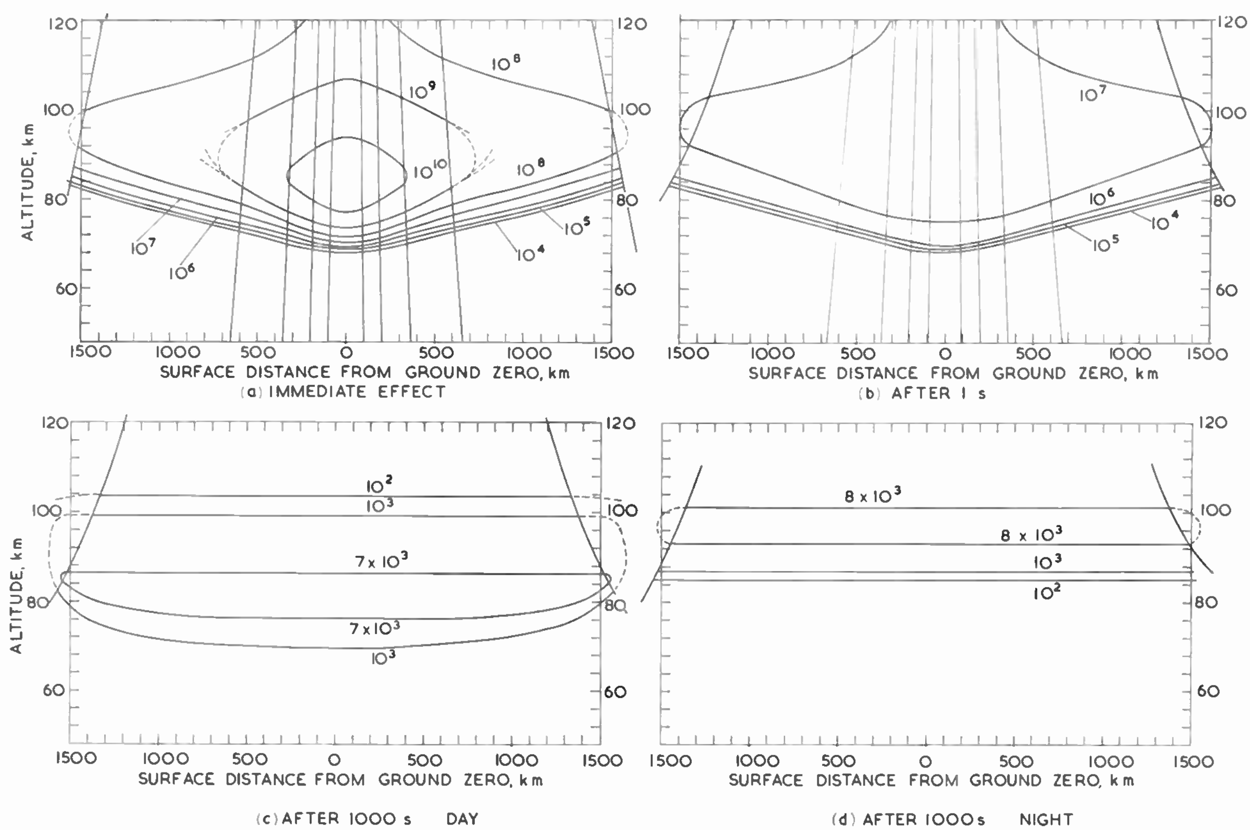

Fig. 2. Electron density contours for 1 megaton at 400 km altitude.

9000 miles and 100 keV neutrons to 2800 miles (Fig. 4). The probability of decay in any second when the half-life is thirteen minutes is approximately 1 in 1000, and so a thousandth of all the neutrons emitted will have decayed in this time.

When decay takes place the major part of the momentum will be carried by the proton, which will move on initially in the same general direction as the neutron from which it is derived. The electron may start off in any direction, but being in the Earth's magnetic field it is constrained to move in a circular path. The component of velocity along the field line will be unaffected, but the component perpendicular to the field will result in a circular motion, so that the resulting path will be helical. As the electron approaches the Earth the field strength increases and the turns of the helix become tighter and flatter, until at a critical value of field strength depending on the initial velocity and direction the pitch angle of the helix becomes zero and the particle is reflected and oscillates between this point and its magnetic conjugate. If the mirror point is above that at which an electron of this energy is absorbed (see Fig. 3), it will oscillate indefinitely, or until a chance collision alters its velocity and so its mirror point. Those electrons whose mirror point is lower in the atmosphere will be absorbed before being reflected and so will be lost, their energy being converted to ionization and the formation of a layer of ionized air.[3] The mechanism for trapping of charged particles in the geomagnetic field is similar to that for the Van Allen belts of radiation.

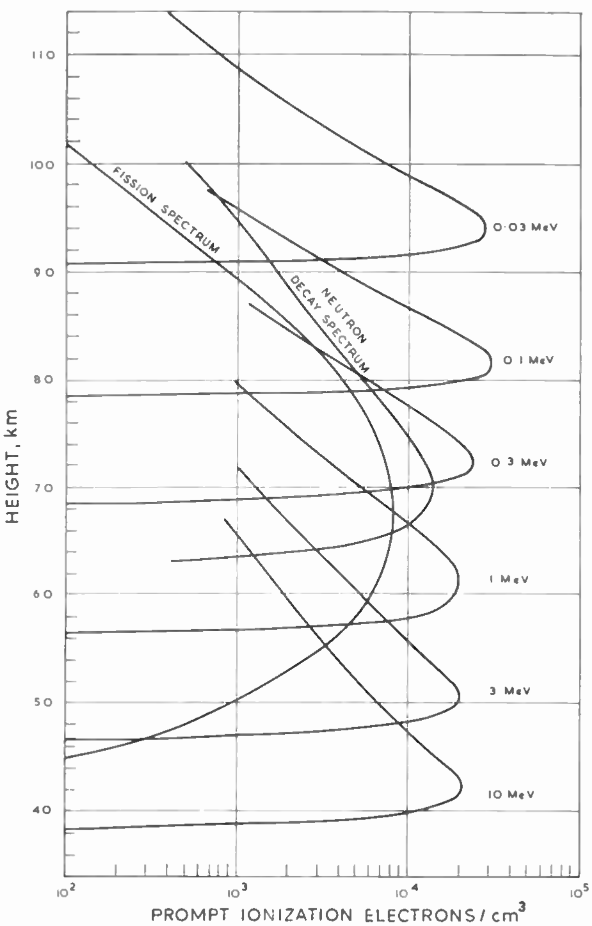

Fig. 3. Prompt electron density produced by 1 erg/cm² electrons incident vertically on the atmosphere.

The geometry of the situation is such that effects can be produced far beyond the horizon as seen from the burst point, and these effects can appear within a fraction of a second owing to the very high velocities of the neutrons and resulting electrons.

Neutrons in a cone tangential to the Earth's surface and having its apex at the burst point will be absorbed by the Earth, but others can travel to considerable distances (Fig. 4). Many of the higher energy neutrons will escape beyond the effects of the Earth's magnetic field before decaying. Of those which decay in the Earth's field some will be trapped with mirror points well above the atmosphere and produce no immediate effect in the atmosphere. However, as the electrons circle round the magnetic field line that part of the path lying closer to the Earth is in a stronger magnetic field than on the outer side, and so has a smaller radius of curvature. This results in the circular orbits being modified into a sort of epicycloid, and the whole trapped column of electrons moves in an easterly direction at a rate depending on the electron energy.[4] The Earth's magnetic field departs from the perfect dipole field, with the result that in places such as the South Atlantic magnetic anomaly the whole field structure approaches closer to the surface. This brings the mirror points of some of the electrons down into the atmosphere with resulting ionization, which it will be seen can occur on the opposite side of the Earth from the explosion, with a delay of minutes.

If we consider a particular line of force, part of which is visible from the burst point, we see that it will be approached first by the most energetic (faster) neutrons, and then in turn by the slower ones throughout the energy spectrum. The fast neutrons will pass through the vicinity of the line in a very short time and so will have a smaller probability of decay than those arriving later. The actual number of decays per second occurring at any given time is also directly proportional to the relative number of neutrons in a narrow band of a given energy. The energy spectrum will be different for different types of weapons and information on this subject is not readily obtainable.

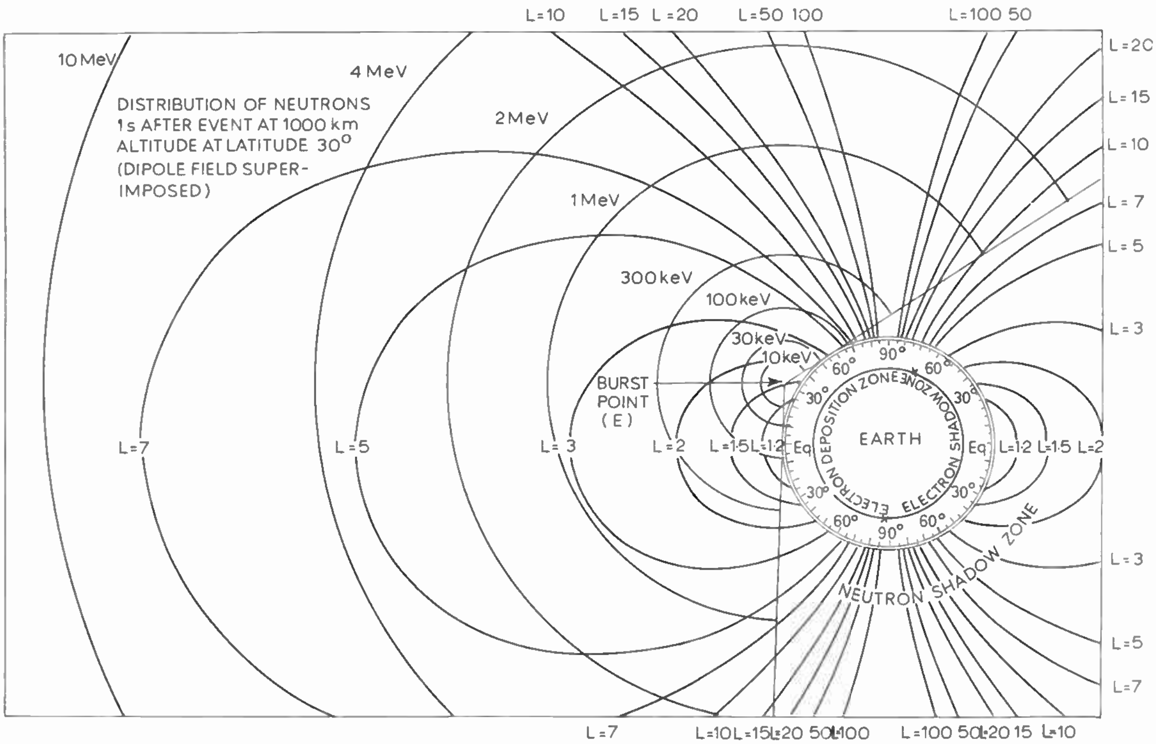

Fig. 4. Geometry of near space burst.

The energy spectrum of the electrons resulting from neutron decay extends from zero to 0·76 MeV with a peak at 0·4 MeV,[5] and these will be absorbed at different heights in the atmosphere as shown in Fig. 3. The peak absorption and hence maximum electron density occurs at a height of 70 km, which happens to coincide with the normal daylight height of the D layer. This reflects v.l.f. waves and so v.l.f. propagation is very sensitive to these disturbances.

2.4. *Radiation from Fission Products*

The cloud of fission products resulting from a nuclear explosion is intensely radioactive and emits γ-rays, β-particles and α-particles. The range of the latter is small and they do not affect the ionization pattern significantly. The other two produce characteristic ionization effects.

The effects of γ-rays have been considered above, and we have now to consider the effect of β-particles from the fission product cloud.

When the detonation takes place at a considerable height, but still inside the Earth's magnetic field, the electrons which constitute the β-particles behave similarly to those resulting from neutron decay, except that they originate in a relatively small area instead of from a dispersing cloud of neutrons.

The fission product cloud soon settles into a thin disk at a height of some 130 km and this increases slowly in diameter and so becomes less dense, but may take several days to disperse. From this disk electrons are emitted upwards and downwards. They all follow helical paths around the magnetic field lines, but the downward-going electrons reach the atmosphere in the same hemisphere as that in which the detonation takes place, whereas those travelling upwards follow the field lines to reach the atmosphere in the conjugate area. There are thus two roughly circular areas of ionization, and these are long-lasting as the bombardment of the atmosphere is continuous and equilibrium is established between production and removal of electrons resulting in a stable level of electron density. This will cover a range of altitudes corresponding to the range of electron energies in the fission spectrum as shown in Fig. 5. The distribution is different by day from that by night owing to the different recombination coefficients, notably the absence of photo-detachment at night.

As in the case of neutron decay electrons, some will be trapped and these will precess in an easterly direction, at different rates according to their energy distribution. The higher energy electrons will precess fastest and so will arrive first at a distant point. They will penetrate deeply into the atmosphere and produce their ionization at a low altitude (Fig. 3). Those following later will be less penetrating and so the effect at the distant point will be the production of an ionized layer which moves upwards, sweeping through regions where it affects different ranges of radio frequencies. The above effects, due to the initial burst of electrons, will behave as a pulse of short duration owing to the rapid radioactive decay of the debris. Later, when the decay time becomes comparable with the precession time, a quasi-equilibrium will be established. The effects will be greatest in two conjugate zones where the magnetic shell containing the debris cloud approaches the atmosphere.

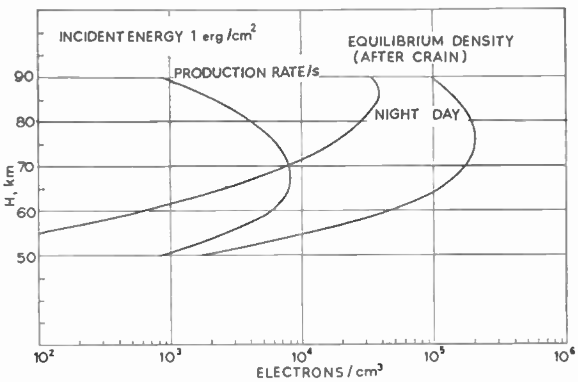

Fig. 5. Equilibrium electron density for fission product beta particles.

3. Effects of Ionized Layers on Radio Propagation

The effects of additional ionized layers and discrete bodies of ionized air will affect radio-frequency propagation in a complex manner, depending not only on the maximum electron densities produced, but their altitude and rate of increase with distance.

The principal effect is the attenuation of signals which pass through the ionized layers. For signals of frequency high compared to the gyro-frequency, and for non-deviative absorption, the attenuation in decibels per kilometre is given by[6]

$$\frac{4{\cdot}6\times 10^4 \nu N_e}{\nu^2+\omega^2}$$

Since the collision frequency ν is much greater at lower altitudes, the ν^2 term tends to swamp ω^2 and the attenuation simplifies to

$$\frac{4{\cdot}6\times 10^4 N_e}{\nu}$$

i.e. the attenuation is inversely proportional to ν, and independent of frequency. At very great altitudes ν becomes small and ν^2 can be neglected compared to ω^2 and the attenuation then becomes

$$\frac{4{\cdot}6\times 10^4 \nu N_e}{\omega^2}$$

i.e. it is proportional to ν and inversely proportional to f^2. In both cases the attenuation is proportional to N_e, the electron density. These relationships are illustrated in Fig. 6, which shows that for any frequency there is a height at which the attenuation is a maximum, and this occurs where $\nu = \omega$.

In addition to the absorptive effects of ionized layers other phenomena may occur. If the electron density produced by irradiation is sufficiently intense, so that the plasma frequency exceeds the signal frequency, a radio-frequency wave may be reflected and arrive back at the Earth's surface at a point where signals in this frequency range are not normally received, and communications may be enhanced for a time. The plasma frequency is given by[6]

$$f_c^2 = \frac{N_e}{1{\cdot}24\times 10^4}$$

where f_c is in Mc/s, i.e. the electron density required to reflect a signal varies as the square of the signal frequency, and so as the frequency is raised its power to penetrate the ionized layers increases rapidly. However, it will be seen from Figs. 1 and 2 that electron densities of well over $10^{10}/cm^3$ may be produced, and densities of $10^6/cm^3$ may persist for some time. These correspond to plasma frequencies of 900 Mc/s and 9 Mc/s respectively.

3.1. *V.H.F. and Higher Frequencies*

As shown above, the prompt effects may well produce local electron densities sufficient to reflect a radar beam, but the effect is likely to be transient. However, a layer with peak density 10^{10} electrons/cm^3 due to x-rays will produce an attenuation of some 3 dB each way in an x-band signal passing normally through it, and angular errors may be introduced owing to refraction in the layers, more particularly as the surface of the layers will not be parallel to the Earth's surface for bursts in or close to the atmosphere.

V.h.f. ground communications which normally rely on line-of-sight propagation will not be affected and ground-to-air communications at these frequencies will be largely unaffected. However, satellites used for communications must orbit at a height of over 300 km, and hence above the ionized layers due to x-rays and β-particle bombardment, and these channels will, therefore, be subject to attenuation where the propagation paths pass through the affected areas. Where such systems are used for long distance communication it may be that only one path from earth terminal to satellite or satellite to earth terminal will be affected, and so the attenuation will be halved. The 2300 Mc/s band will, of course, suffer much less degradation than the 136 Mc/s band.

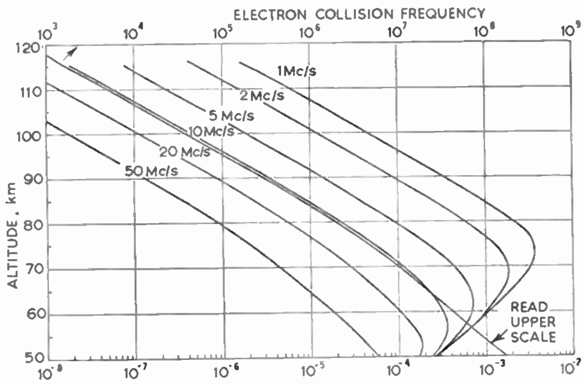

Fig. 6. Attenuation per km of r.f. signals per unit electron density.

3.2. *H.F. Band*

Since this band is used mainly for communication via ionospheric reflections, it will be more severely affected than the higher frequency bands.

The situation is in general similar to the daytime D-layer absorption but differs in its intensity and localization. Whereas the natural D-layer may have an electron density of $100/\text{cm}^3$, that due to a nuclear explosion may be many orders of magnitude greater. A density of $10^7/\text{cm}^3$ will be sufficient to prevent penetration by signals in the whole h.f. band. Whether or not such signals reach the ground after reflection depends on the distribution of ionization in the region below the layer of critical density. If the increase is very rapid, so that the reflecting layer is reached without traversing a great thickness of air of lower ionization, little absorption will take place and the signals may well be received by reflection at an appropriate distance. If the increase is more gradual, so much energy will be absorbed in the two-way traversal of air at lower ionization that very little will be received at the ground. Reference to Fig. 3 will show that layers due to monoenergetic particles have the steepest rate of increase as seen from the ground, followed by the electrons from neutron decay, and the electrons from fission fragment decay, since they cover a wide range of energies, tend to be spread over a range of altitudes and to have a less sharply defined lower edge.

Since the reflecting layers due to irradiation occur at heights below the E layer, a station which has been receiving via the F layer before the event will find itself cut off, and its range restricted to something less than the normal E-layer range. At the same time it may receive signals from stations which were previously in the skip distance.

Whether or not a particular propagation path will be seriously affected depends on the geometry of the ray path relative to the ionized areas. There will be four principal areas of increased ionization, and these may partially overlap. They are:

(*a*) The circular area of D-layer height directly illuminated by thermal x-rays. This will be very intense initially, but will be greatly reduced after a few tens of minutes (see Fig. 2).

(*b*) and (*c*) Two disks in magnetically conjugate areas irradiated by β-particles from the fission fragments before they are dispersed.

(*d*) A large area irradiated by γ-rays and β-particles from the fission product cloud after it has

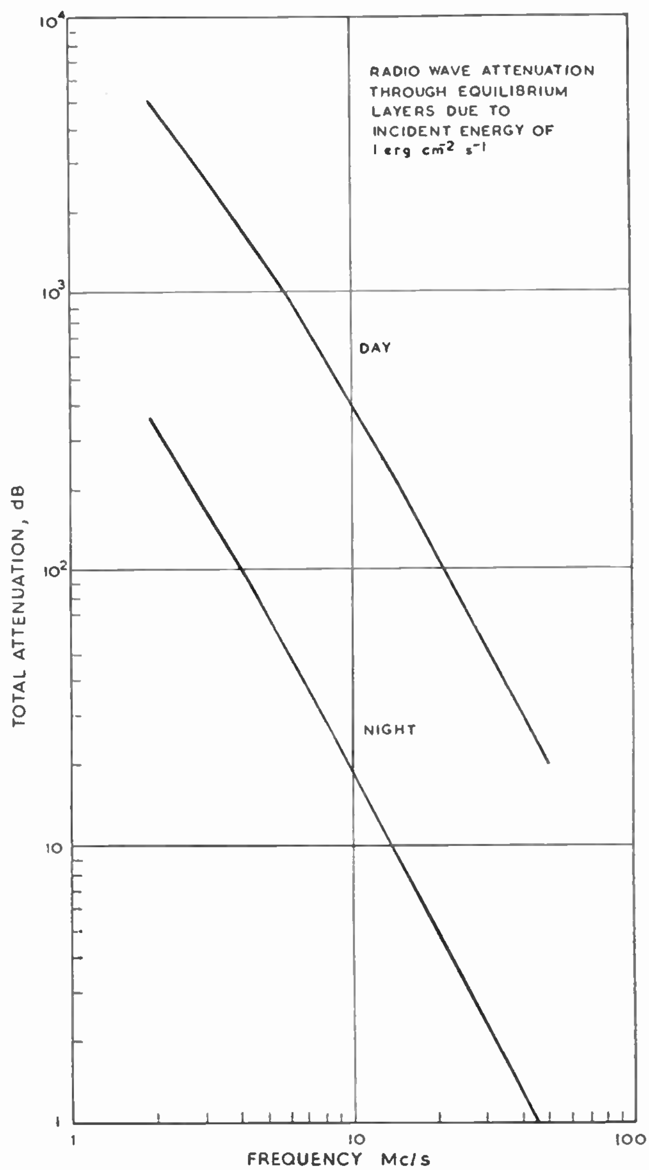

Fig. 7. Total attenuation of r.f. signals passing once through layers shown in Fig. 5.

spread out into a thin layer in the upper atmosphere.

Where the propagation path between transmitter and receiver intersects one of these regions in the course of one of its hops between Earth and F layer there will be considerable interference with communication and a complete blackout may occur lasting for a time depending on the type of ionized layer. Type (*a*) above lasts for the shortest time and type (*d*) the longest. Absorption curves corresponding to the conditions of Fig. 5 are shown in Fig. 7.

A further source of interference with h.f. communications results from the wave motions in the ionosphere caused by shock waves spreading out from an explosion in the upper atmosphere. There may be several such shocks corresponding to sound waves and magneto-hydrodynamic waves, and the effect of these is to disturb the smooth surface of the reflecting F layer at a distance from the explosion and so cause rapid fading and 'spread F' conditions.[8] These effects are noticeable over a very wide range and may last for up to twelve hours.

3.3. *Medium Frequencies*

Medium-wave transmissions are used principally for broadcasting, the ground wave being utilized, and this is not subject to interference from ionospheric changes. However, at night the normal D-layer intensity becomes low enough for these waves to penetrate without excessive attenuation and longer distance reception becomes possible.

The sudden interposition of an ionized layer of low intensity will cause a return to daylight conditions, in which all the clutter and noise from distant stations disappears and the local stations are received free from interference.

There may also be conditions where signals from other broadcasting stations too far distant for ground wave reception and suffering too much attenuation in the normal D-layer to reach a region from which they can be reflected may suddenly be presented with a sufficiently intense layer at D-layer height to cause reflection and consequent reception at a distant point. Thus conditions in this band may give an improved choice of signals at sufficient strength for useful reception.

3.4. *L.F. and V.L.F. Bands*

In the v.l.f. band the thickness of the ionized layers is comparable to the wavelengths of the signals, and so changes in electron density take place within a wavelength. Under these conditions the laws of geometric optics no longer apply and one cannot trace out ray paths in the same way as is done for the h.f. bands. It is necessary to consider the space between the conducting Earth and the conducting ionosphere as a waveguide.[9] The phase velocity of waves in the waveguide depends on the dimensions, and so on the height of the ionosphere above the Earth. This height is difficult to define as the ionosphere does not start suddenly, but the electron density increases gradually with height. Also at these frequencies the criterion for penetration is not as simple as at h.f. where frequencies above the plasma frequency penetrate and those below do not. Here the conditions which form the effective boundary of the waveguide depend not only on the electron density, but also on the rate of change of density with distance. The effective height of the normal D-layer, which forms the conducting layer at v.l.f. is about 72 km by day and 90 km by night. This causes a variation in the phase velocity between night and day conditions and so if the phase of the received signal is recorded at a distant station it will show systematic variations in phase between night and day.

The comparison of the phase of signals received from stations having very accurately controlled frequencies with those from local frequency standards is widely used as a means of standardizing frequencies, and many such phase comparison systems are in use.

Anything which alters the effective height of the D layer will produce anomalies on such equipment. One source of these anomalies during daylight hours is the occurrence of solar flares. These are accompanied by the emission of soft x-rays, and these are absorbed by the Earth's atmosphere with the production of ionization at D-layer height, and so causing phase changes on the v.l.f. records.

In a similar way a nuclear explosion either in the ionosphere or deep in space will produce x-rays and so will produce v.l.f. phase anomalies. These will differ in several ways from those produced by solar flares, the following being some of the most important:

Event	Time of occurrence	Rise-time of ionization	Area affected
solar flare	daytime only	minutes	sunlit hemisphere
nuclear explosion	any time	micro-seconds	small area for low altitude shot, almost a hemisphere for space shot

Since the boundary of the v.l.f. waveguide corresponds to regions where the electron density is low—say a few hundred per cubic centimetre—the phase comparison system is very sensitive to small changes in electron density and shows the greatest sensitivity to changes in density at the height where the effective boundary exists. This means that there is an optimum energy for incident particles, since the height at which particles cause ionization is a function of their energy (see Fig. 3). This is of importance where a mechanism exists for sorting electrons according to their energy, and this is the case for electrons trapped in the Earth's magnetic field. As explained in Sect. 2.3, the high energy electrons precess faster than the less energetic ones and arrive at a distant point earlier. However, these very energetic particles penetrate deeply and produce their ionization below the ionospheric boundary. Later the less energetic particles arrive, producing ions at the boundary where they have the greatest effect, and later still come those with very low energy producing their effect above the ionosphere and so producing little disturbance. Thus the peak change of phase corresponds not to the arrival of the most energetic electrons, but to those with the energy corresponding to the height of the conducting layer at the frequency under observation.

The fact that v.l.f. phase measurements are sensitive to only a few electrons per cm^3 enables us to use this method to detect mechanisms which are not easily demonstrated by other means. Among these mechanisms is the appearance of increased ionization at considerable distances from the burst within a few seconds of zero, due to neutron decay as described in Sect. 2.3 and illustrated in Fig. 4.

Here the $L = 7$ line, i.e. the magnetic line of force whose apex is at 7 Earth radii, is being intersected after 1 sec by 4 MeV neutrons at a distance of 5·5 Earth radii, 1 MeV neutrons at 3·3 radii, 300 MeV at 2 radii, etc. A proportion of each of these groups of neutrons will decay, yielding electrons all of which will be guided along the $L = 7$ line. Some will be trapped, but some will enter the atmosphere at about 70 degrees N and S magnetic latitude over a period of several seconds. The disturbance caused by such electrons has been described by several workers, and the neutron decay model was first put forward by Crain and Tamarkin.[3]

The radiation from debris also affects v.l.f. propagation. By providing a source of continuous radiation over a wide area the rather weak night-time D layer is reinforced, and the difference between day and night conditions reduced. It is well known that after the high altitude firing of nuclear devices the diurnal variation of phase of the received signal is markedly reduced for several days. Also, the layer of ionized air produced as a result of this irradiation is more sharply bounded than the natural D layer, with the result that attenuation in the Earth-ionosphere waveguide is reduced and stronger signals are recorded.

3.5. *E.L.F. Band*

If the waveguide mentioned above is considered over the whole surface of the globe, it will be seen to constitute a resonant cavity. Schumann[10] estimated the fundamental resonant frequency of this cavity at 10·6 c/s, and if allowance is made for the imperfect conductivity of the cavity walls a figure of 8·3 c/s is obtained, and has been measured by spectral analysis of thunderstorm atmospheric noise.[11] When a nuclear detonation takes place in the ionosphere the disturbance is so large that the ringing of the cavity can be seen above the noise background, and the frequency of fundamental resonance confirmed by this means.

4. Conclusions

It will be seen that some disturbance is caused over a very wide range of frequencies when a nuclear device is detonated in or near the upper atmosphere, and that these disturbances are due to a variety of causes. In assessing observed effects, it is often difficult to be sure of the exact inter-relation of cause and effect as many of the phenomena overlap in space and time, and the geometry of the situation is quite complicated.

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DISCUSSION

Under the chairmanship of Mr. A. G. Wray

Mr. C. Powell: The high-altitude explosion at Johnson Island on 9th July 1962 affected reception of the Newfoundland Dectra transmissions at the Kidsdale (Wigtownshire) and New Malden (Surrey) monitor stations. The frequency is 70·384 kc/s and the transmitter/receiver distances were approximately 2000 nautical miles. At both receivers, signal strength rose steadily from the time of the explosion at 0900 G.m.t. and reached a level some 10 dB above normal after 30 minutes.

This increased signal strength, which gave much improved performance in a Dectra-equipped aircraft operating in U.K. compared with previous daytime experiences persisted for two weeks at about the 10 dB level and had not completely decayed even after two months. Can Mr. Hill say whether similar long-term improvements in daytime reception were seen in the v.l.f. band?

Mr. F. L. Hill (*in reply*): The attenuation of signals received over long ionospheric paths at l.f. and v.l.f. depends on the sharpness of onset of ionization with height in the region where reflection takes place—the greater the rate of change of electron density, the lower will be the attenuation.

The lower boundary of the D layer is not very well defined and the presence of a layer of radioactive debris at E layer height irradiating the D layer with β particles results in a more sharply bounded layer with consequent reduced attenuation of l.f. and v.l.f. signals. The presence of this source of radiation also ensures that the conditions defining the position of the effective waveguide wall are more nearly constant and so the normal diurnal phase variation in received l.f. and v.l.f. signals is greatly reduced for several days after an event.

Dr. G. L. Hamburger: With reference to the earlier diagrams showing contours of constant electron density at various instants after the explosion, I would be intrigued to know how they were measured.

We read in the newspapers about 'clean' bombs purporting to cause less fall-out. Could Mr. Hill please explain what a 'clean' bomb is and in what way it would modify the effects on radio transmission as already discussed.

Mr. Hill (*in reply*): The electron density contours were derived from theoretical considerations. The x-ray flux is considered to be emitted instantaneously, and the absorption by air of varying density along the various ray paths and the resulting ionization is computed, allowing for curvature of the contours of air density.

A 'clean' bomb is one which produces its effects by radiation and blast with a minimum of radioactive debris. Such a weapon would produce x-rays with all the effects described in the paper and also the neutron and prompt β particle effects, but the delayed β and γ irradiation from the debris cloud would be greatly reduced.

Mr. W. T. Brown: Mr. Hill has referred to two features of γ-radiation—the short term effect, and what he called delayed effect. I understood him to say that the γ radiation built up an ionized layer which eventually reached a state of equilibrium.

I should imagine that this state of equilibrium cannot be maintained indefinitely and must break down. Can Mr. Hill suggest the causes for this breakdown/dispersal in general and in particular does he consider that photo-detachment plays an important part in the process?

Mr. Hill (*in reply*): The γ radiation consists of two components, the prompt γ radiation, emitted in the first micro-second after detonation, and delayed γ rays emitted from the cloud of radioactive debris.

The prompt γ rays produce a flash of ionization at a height of some 30 km, and here the collision rate is so high that electrons are very rapidly lost by attachment to neutral atoms or molecules.

However, the γ rays from the debris cloud produce ionization at a fixed rate. Over a short time the rate of production of free electrons will be equal to the rate at which they become attached, with a resulting quasi-equilibrium in electron density.

As the debris becomes dispersed by air currents and diffusion and as the radioactivity decays the rate of production of electrons is reduced and the equilibrium density will be correspondingly reduced.

The effects of photo-detachment are seen when equilibrium is established in conditions of darkness, and then at dawn many of the attached electrons are liberated by photo-detachment when the sunlight illuminates the layers and the increase in electron density has a marked effect on absorption of h.f. signals.

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The Broadband Dielectric Rod Aerial

By

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AND

D. J. WILLIAMS†

Summary: A new type of launching device has been tested with the dielectric rod aerial which removes the existing low-frequency waveguide cut-off limitation. As a result an extended range of dielectric rod diameters has been used, which are equivalent to an effective bandwidth of more than 3 : 1.

1. Introduction

The frequency range over which a given aerial will provide a satisfactory radiation pattern and power gain is the main criterion by which one is able to compare the performance of different aerials. While the impedance characteristics of a radiator are also important, they are not quite as significant in determining the practical operating bandwidth, since mismatch has to be very bad before it affects the power gain,[1] and it does not affect the radiation pattern.

Although the dielectric rod aerial was first investigated in 1938,[2] numerical references to a bandwidth for this aerial are rarely given, and the best which the authors have found has been proposed by Fradin.[3] He suggests that the ratio of upper to lower cut-off frequency for the aerial is 1·5, or the bandwidth is approximately ±25% of its centre frequency of operation. This represents an extremely good performance, and among uniform aerials is only exceeded by the helix, which can achieve a bandwidth of ±33% of its centre frequency for short lengths.[4]

In the case of the helical aerial, however, sufficient theoretical work has been done[4, 5] to establish the reasons for the existence of both the lower and upper frequency limits of the aerial. For the dielectric rod this is not the case, and indeed existing theory[2] leads to the conclusion that there is no lower cut-off frequency for it. The upper cut-off frequency on the other hand is well understood on the basis of linear array theory.

The purpose of the investigation to be described, therefore, was to find if an experimental lower cut-off frequency existed, and hence to determine the experimental bandwidth. Associated with this was an investigation into the power gain of the aerial.

2. Theory

There are already a number of theories[2, 6] which attempt to describe the mechanism of radiation from the dielectric rod aerial. The simplest[2] visualizes the rod as a linear radiator from which energy escapes continuously as the exciting wave travels along it. This would be expected to decrease the excitation along the rod but there is, of course, a compensating factor in that with endfire operation the escaping radiation will itself tend to maintain the excitation constant. In so far as this theory is valid, the radiation pattern will exhibit interference between the elemental radiators, and will thus be characterized by alternate maxima and minima, of which the latter will ideally be nulls. The positions of these nulls will, however, depend on the phase velocity of excitation along the rod.

Another theory,[6] in contradistinction to the above, assumes that the main body of radiation comes from a virtual aperture at the open end of the dielectric rod. From the expressions for the guiding fields which propagate along a lossless infinite rod Brown and Spector[6] have derived the radiation fields from this virtual aperture. Their results show two main points of significance. The first is that there are no side-lobes in the radiation pattern, but rather an exponential type decay from the main single lobe. To accommodate the experimental existence of sidelobes Brown and Spector assume also a small fraction (approximately 6%) of the total radiation occurring at the feed point. Interference between the virtual aperture and this feed point then produces the side-lobes. The second point of note in their results is that as the dielectric rod is reduced in diameter the radiation pattern from the virtual aperture gets narrower, e.g. for a rod diameter of $0{\cdot}282\lambda$ the half power points occur at angles of approximately ±5% from the endfire direction. As such narrow beams have not been observed in practice, Brown and Spector postulate that these results may apply only to very long rods in which the wide expanse of fields surrounding the rod may have been accommodated.

The present experiments do not differentiate conclusively between these two theories, but the first is at present preferred.

3. Aerial Construction

A diagram of the first type of aerial constructed is shown in Fig. 1. This excitation makes use of the metal cup and probe suggested by Kiely,[2] but the

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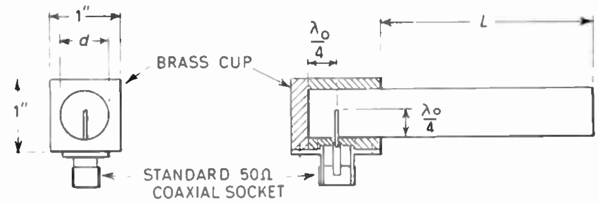

Fig. 1. Metal cup and probe excitation of dielectric rod aerial.

dielectric rod itself is in this case of constant diameter. This was done deliberately in order to reduce the number of variables in the investigation, and has been found to give satisfactory results by comparison with other travelling-wave endfire aerials. The length of the probe and the distance of the probe from the back plate were both made $\lambda_0/4$ at a frequency of 9·0 Gc/s,

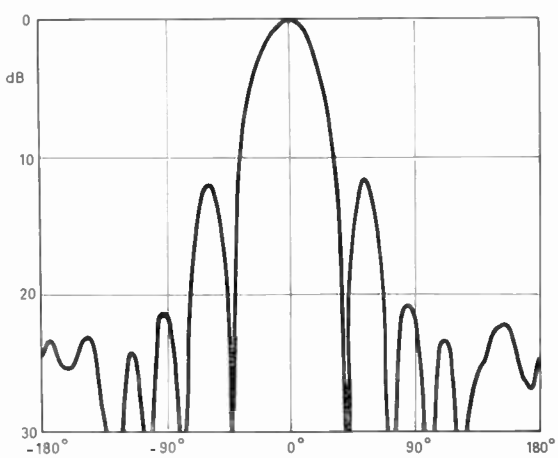

Fig. 3. H-plane radiation pattern for 3·6 in × ½ in rod at 9·0 Gc/s using metal cup and probe excitation.

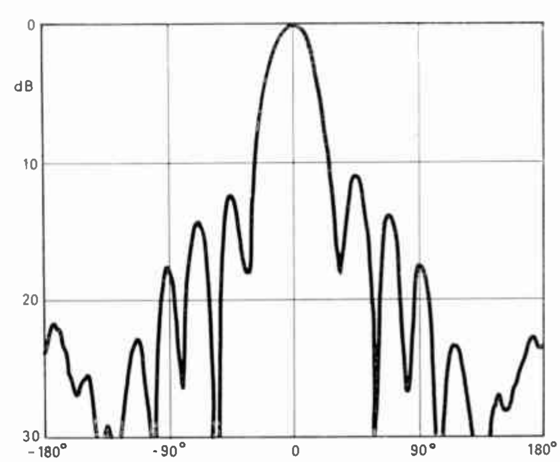

Fig. 4. H-plane radiation pattern for 3·6 in × ½ in rod at 9·0 Gc/s using angle and probe excitation.

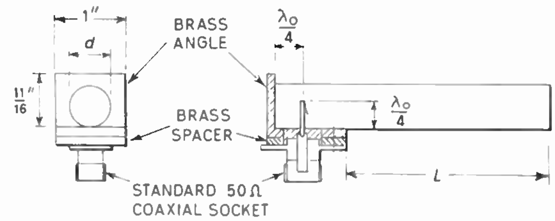

Fig. 2. Angle and probe excitation of dielectric rod aerial.

which was approximately midband in the frequency range of the radiation pattern testing equipment.

Three polystyrene rods of nominal diameter ⅜ in, ½ in and ⅝ in were tested initially using appropriate cup diameters. The rod diameters were found to be oversize in each case with tolerances of +5%, +8% and +3% respectively, but the cups were made to be tight fits over them. As the length of rod, L, external to the cup was another variable to be investigated, lengths of $L \rightarrow 8\lambda_0$ were prepared for each diameter.

For reasons which will be described in Section 4 it became necessary to devise another form of launching mechanism for the ⅜-in rod. Consequently an L-type of angle, together with the same probes and dielectric rods, was assembled as shown in Fig. 2. The launching mechanism in this case clearly resembles that which operates with the helical aerial. It has the advantage over the method shown in Fig. 1 that no propagation through a circular cylindrical waveguide is required.

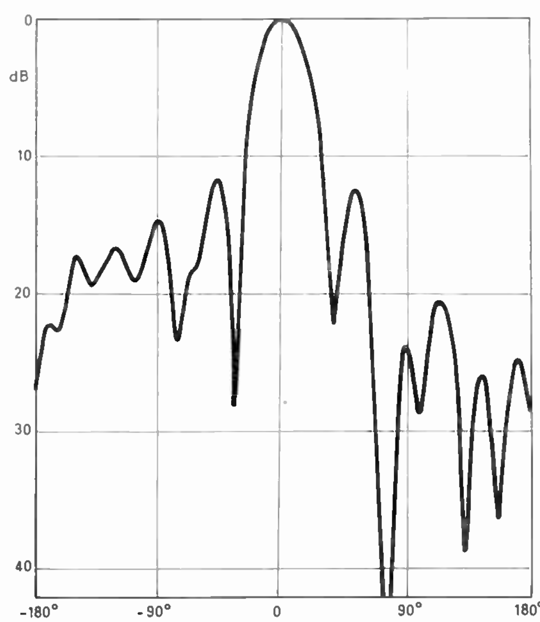

Fig. 5. E-plane radiation pattern for 3·6 in × ½ in rod at 9·0 Gc/s using angle and probe excitation.

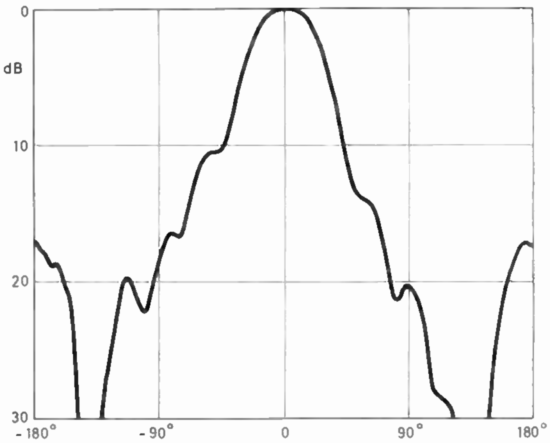

Fig. 6. Radiation pattern for 3·6 in × $\frac{3}{8}$ in rod at 7·5 Gc/s using angle and probe excitation.

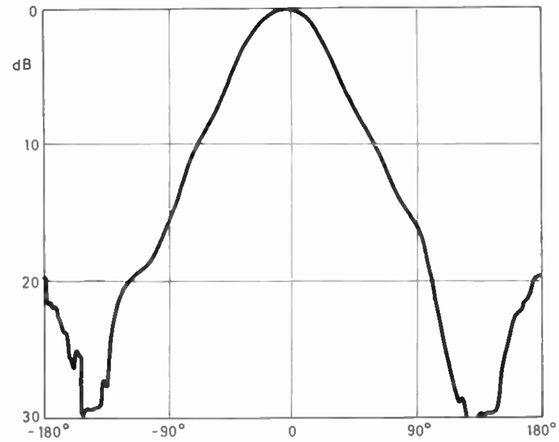

Fig. 9. Radiation pattern for 3·6 in × $\frac{1}{2}$ in rod at 7·5 Gc/s using angle and probe excitation.

4. Experimental Results

4.1. *Radiation Patterns*

The results obtained here for rod diameters of $\frac{1}{2}$ in and $\frac{5}{8}$ in using the feeding arrangement of Fig. 1 are represented by a typical example for a 3·6 in × $\frac{1}{2}$ in rod, as shown in Fig. 3. No useful radiation patterns could be obtained, however, for the $\frac{3}{8}$-in diameter rod, since the highest frequency available was 11·5 Gc/s and the cut-off frequency for the cylindrical cut guide was 11·7 Gc/s.

The feeding arrangement shown in Fig. 2 was therefore substituted and a comparison of the two methods of excitation for the same rod can be made by comparing Figs. 3 and 4, which show that both patterns are similar in shape, although the L-type angle and probe aerial has an extra side-lobe due to its extra unshielded length. The total physical length of the aerials, however, is the same in both cases. The pattern in the other plane using the L-type angle is shown in Fig. 5 and the greater asymmetry will be noted.

With this new angle feed radiation was obtained with the $\frac{3}{8}$-in rod and an H-plane pattern for a 3·6 in length is shown in Fig. 6 at 7·5 Gc/s. For other frequencies with this aerial the variation of side-lobe level and beamwidth as functions of frequency are shown in Figs. 7 and 8.

As no lower cut-off frequency was evident from any pattern using $\frac{3}{8}$ in diameter, for any length of rod,

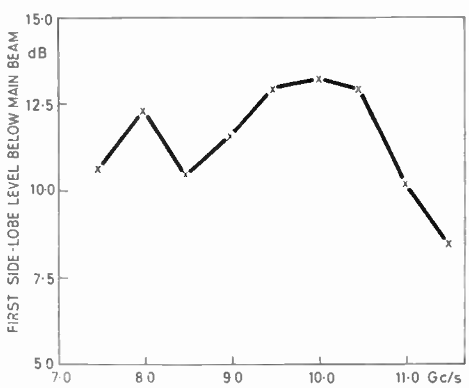

Fig. 7. Variation of first side-lobe level with frequency for 3·6 in × $\frac{3}{8}$ in dielectric rod using angle and probe excitation.

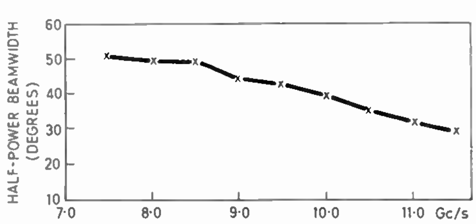

Fig. 8. Variation of half-power beamwidth with frequency for 3·6 in × $\frac{3}{8}$ in dielectric rod using angle and probe excitation.

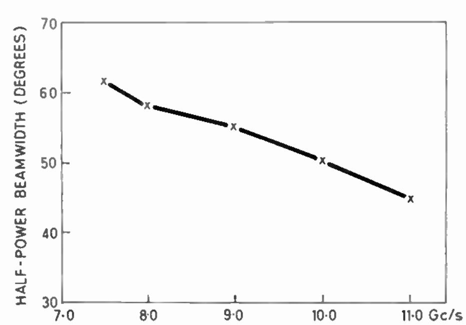

Fig. 10. Half-power beamwidth *v* frequency for 3·6 in × $\frac{1}{2}$ in rod with angle and probe excitation.

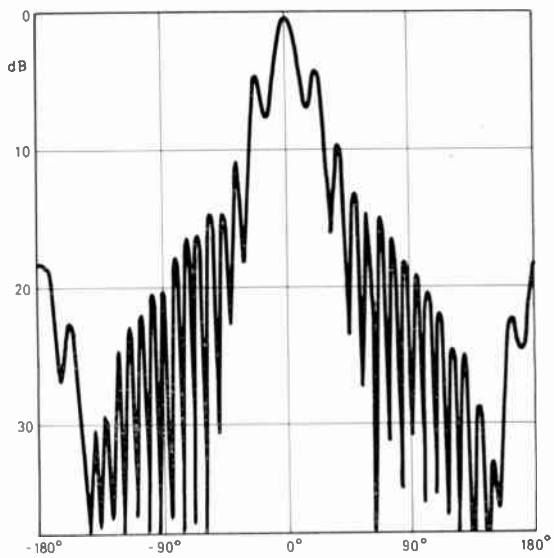

Fig. 11. Radiation pattern for 11·5 in × ⅝ in rod at 7·5 Gc/s with angle and probe excitation.

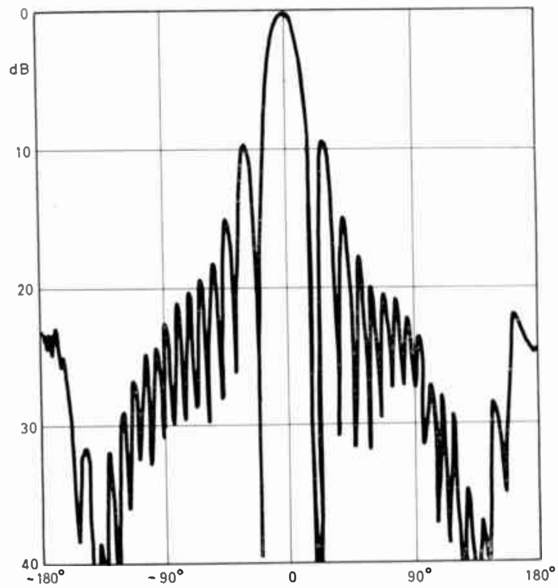

Fig. 12. Radiation pattern for 11·5 in × ½ in rod at 7·5 Gc/s with angle and probe excitation.

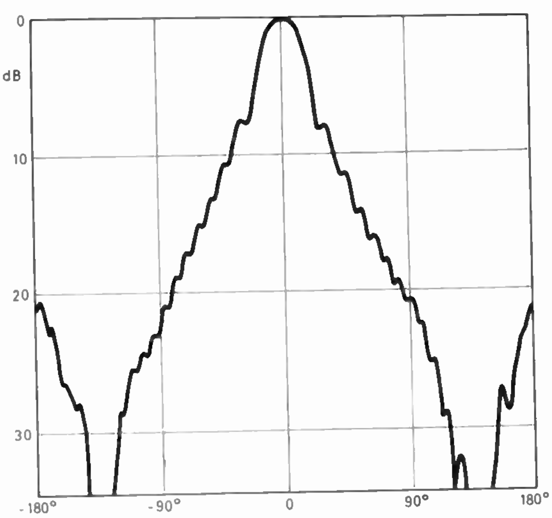

Fig. 13. Radiation pattern for 11·5 in × ⅜ in rod at 7·5 Gc/s with angle and probe excitation.

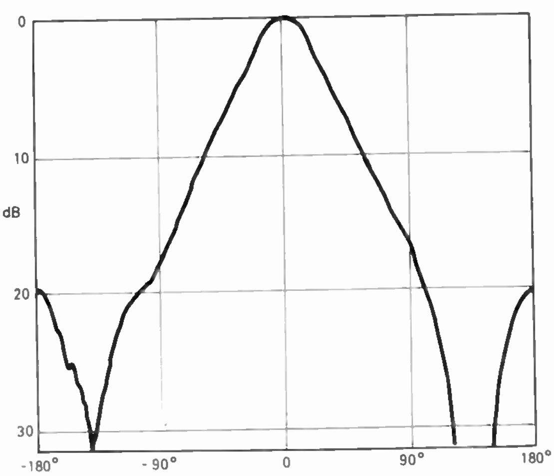

Fig. 14. Radiation pattern for 11·5 in × ¼ in rod at 7·5 Gc/s with angle and probe excitation.

it was decided to investigate the effect of diameter further by recording a series of patterns for a ¼-in diameter rod. The standard probe length of $\lambda_0/4$ was now greater than the rod diameter, but a suitable brass spacer was used so that the probe penetrated right through the ¼-in diameter rod but did not protrude on the other side.

A typical H-plane pattern for a 3·6 in × ¼ in rod at 7·5 Gc/s is shown in Fig. 9 where it is seen to take the shape of a wide cone with some back radiation. For other frequencies the results are summarized in Fig. 10. The side-lobes for these patterns merge into the main beam, especially at the lower frequency end of the range, and so side-lobe level cannot be measured in this case.

The onset of this single lobe effect with variation in diameter is shown in Figs. 11–14 for a single frequency. It may be postulated that as the rod diameter increases, thereby increasing the percentage of the total guided power which is carried inside the rod,[3] an interference effect between the elemental radiators produces a series of maxima and minima which is absent with the narrowest diameter rod. From the calculations given by Fradin[3] there is practically no power travelling inside the $\frac{1}{4}$-in rod and hence no interference would be expected. Alternatively the ripples may be considered to result from interference between the probe and rod end radiation, and for small diameter rods with consequently lower launching efficiency[7] of the surface wave, the net radiation will tend to that from the probe and angle alone. The radiation pattern for this probe and angle feed with no dielectric rod is shown in Fig. 15.

The results of all these experiments using rod diameters from $\frac{1}{4}$ in up to $\frac{5}{8}$ in show that endfire operation is possible at 7·5 Gc/s, i.e. when d/λ_0 for the $\frac{1}{4}$-in rod is 0·16. Hence applying this result to the $\frac{5}{8}$-in diameter rod indicates that operation of this kind is possible at 3·0 Gc/s. By separate experiments, using a 6-dB side-lobe level criterion, the upper frequency limit of the $2\lambda_0 \times \frac{5}{8}$ in rod has been found to be 9·6 Gc/s, indicating a bandwidth of over 3 : 1. The $\frac{1}{4}$-in diameter rod was the smallest commercially available and the bandwidth may be greater than this figure. The improvement which has been obtained in this way is entirely due to the new method of launching the wave along the dielectric rod.

A further series of readings was taken to show the effect of increasing the length of the $\frac{1}{4}$-in diameter aerial from λ_0 to 16 λ_0. The half-power beamwidths for these lengths and for the different diameters are summarized in Figs. 16 and 17.

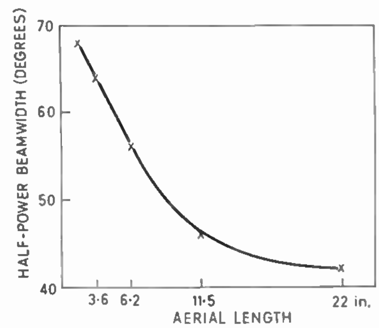

Fig. 16. Half-power beamwidth of $\frac{1}{4}$-in rod at 7·5 Gc/s as a function of rod length.

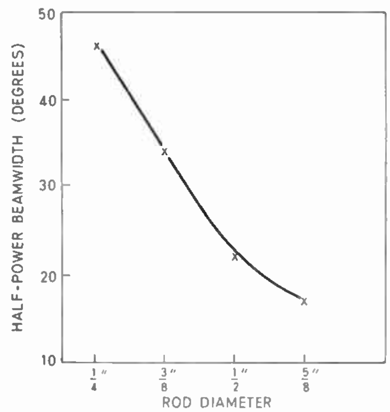

Fig. 17. Half-power beamwidth of 11·5-in rods at 7·5 Gc/s as a function of rod diameter.

4.2. *Power Gain Variation with Frequency for Rods of Different Diameters and Lengths*

The power gains of the different aerials were measured directly by comparison with a standard aerial of known gain. At each frequency the receiver input was matched to the 50-ohms transmission line with a v.s.w.r. better than 1·1. The results are shown graphically in Fig. 18 for the 11·5 in rods of the different diameters and a 22-in rod of $\frac{1}{4}$-in diameter, and in Fig. 19 for shorter rods of 3·6-in length. It will be noted that the upper cut-off frequency in terms of power gain is quite pronounced for the two larger diameters, but for the $\frac{1}{4}$-in diameter is outside the range of the equipment. The figures for the gain represent actual experimental values, without correction for mismatch at the aerial end.

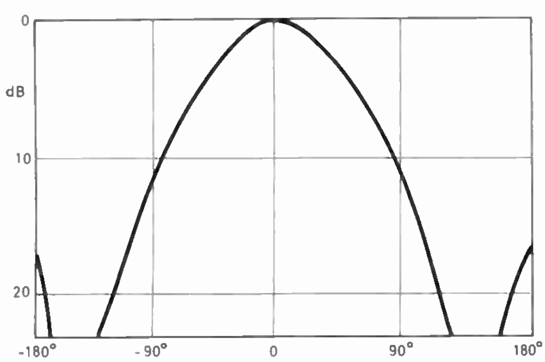

Fig. 15. Radiation pattern for L-angle and probe at 7·5 Gc/s.

4.3. *Standing Wave Measurements*

The degree of matching between the dielectric rod aerial and the 50-ohm feeder cable was measured using a standing wave indicator in the usual way. The variation of v.s.w.r. with frequency was observed for the same rods used in the previous power gain experiments, and also for the $\frac{5}{8}$-in and $\frac{1}{2}$-in diameter rods in the metal cup and probe configuration. It was found that for both methods of excitation, the v.s.w.r.

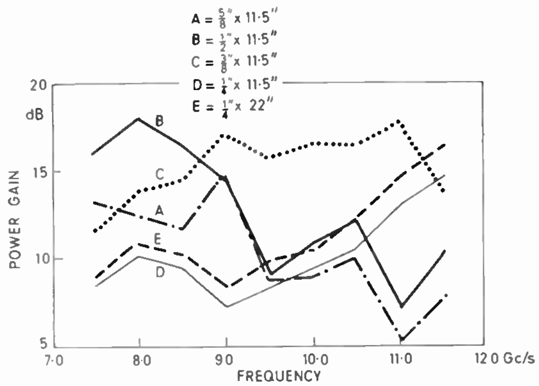

Fig. 18. Power gain variation with frequency for rods of ⅝ in → ¼ in diameter and length 11·5 in.

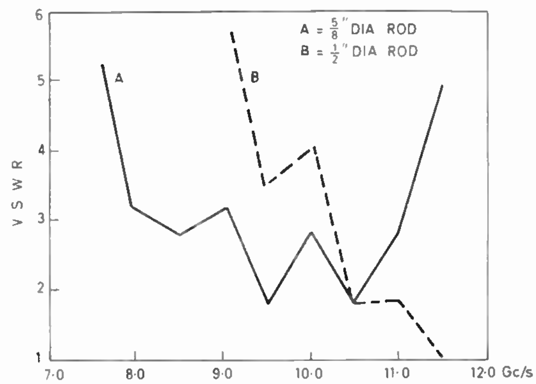

Fig. 20. V.s.w.r. as a function of frequency for metal cup and probe excitation.

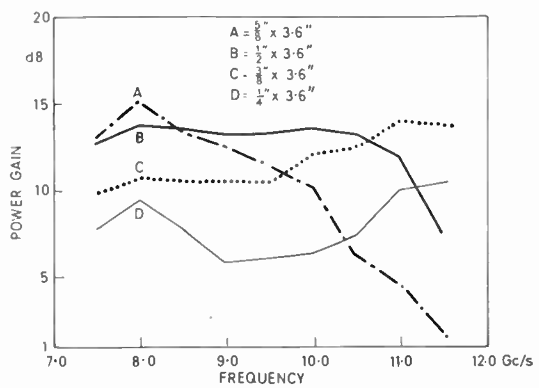

Fig. 19. Power gain variation with frequency for rods of ⅝ in → ¼ in diameter and length of 3·6 in.

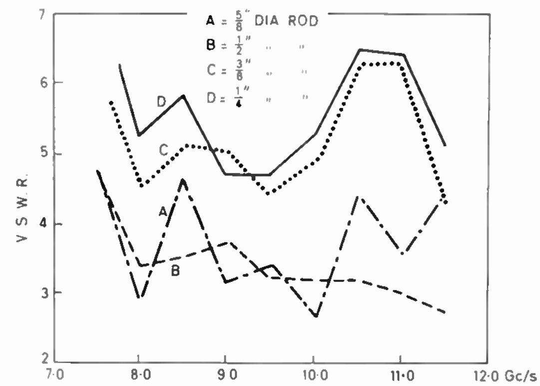

Fig. 21. V.s.w.r. as a function of frequency for angle and probe excitation.

varied very little with the length of the rod. The results as a function of frequency are shown in Fig. 20 for the cup and probe and Fig. 21 for the L-angle and probe methods respectively. In Fig. 20 the approaching effect of waveguide cut-off is clearly seen as the v.s.w.r. rises steeply. For the same diameters no such effect occurs for the angle and probe method in Fig. 21.

5. Conclusions

Using the L-type angle and probe excitation it has been possible to use dielectric rod aerials at X-band with diameters as low as ¼ in. This effectively multiplies the previously known bandwidth of the aerial by a factor of more than two.

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The Impact of Electronics on the Army's Repair Organization

By

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Summary: The aim of this paper is to trace the influence that electronics has had and is having on Army equipment, to highlight the problems of repair, the recruitment and training of engineers and technicians and finally to give some indication of future trends. The paper is in four parts—the period leading up to the Second World War, the war and the immediate post-war phase, the present day, and finally a look at what the future may hold.

Introduction

The impact of electronics on the army which fought the First World War was very slight indeed. This was the era of the spark transmitter, the crystal detector and the bright emitter. Whilst line communication and the Fullerphone—a device much ahead of its time—were used extensively, radio was little used and was mainly confined to the rear area. When it was used signalling was, of course, by Morse code.

Apart from this the equipment of the Army underwent a minor revolution during the course of the First World War and, when it ended, the fate of the horse was sealed and the Army irrevocably committed to mechanization, although this took some little time to accomplish. The first tanks were used in the Battle of the Somme in 1916 and, whilst they were only a limited success, they were sufficiently promising to justify a great deal of further development. There is little obvious connection between these early cumbersome tanks and the modern armoured fighting vehicle crammed with complex electronic equipment. The flying machine, too, had made its mark, but this particular brain child grew up and became too large for the Army alone and resulted in the birth of the Royal Air Force and the Fleet Air Arm through the medium of the Royal Flying Corps. Aircraft have only recently returned as an integral part of the Army.

During the war and for the period immediately afterwards, maintenance and repair of new weapons was accepted by the Arms responsible for their introduction. With the increasing mechanization of the Army, the need for rationalization was recognized and in 1926 the Engineering Branch of the Royal Army Ordnance Corps (which was already responsible for inspection and repair of armament) was formed and staffed with fully qualified engineers who took over the repair of armoured vehicles and some of the Army's mechanical transport.

It is of interest to note that on its formation the Engineering Branch of the Royal Army Ordnance Corps had a strength of 48 Ordnance Mechanical Engineers (O.M.E.) and 253 artificers. So far as can be traced, none of these was trained in electronics or radio, although five were Corporate Members of the Institution of Electrical Engineers. The main task of the R.A.O.C.(E) was mechanical engineering carried out by a simple Field Workshop organization, although in coast defence the complex mechanical fire control computer and power gun-laying equipment provided some interesting engineering problems of an electro-mechanical nature. The user arm was still responsible for a great deal of the day-to-day maintenance of equipment and called in Ordnance only when repairs beyond unit capacity were necessary. The rest of the work of the R.A.O.C. arose as the result of periodic inspection of unit equipment mandatory, for example, for artillery equipment after a certain number of rounds had been fired and before barrels which had fired their scheduled number of rounds could be disposed of. In fact, the inspection and 'sentencing' of ordnance was a large part of the task of the pre-war O.M.E. It may be of some interest to note that, in India at least, he needed to be able to ride a horse in order to do this!

The Second World War

At the time of the 1938 crisis the equipment of the Army showed little superficial change from that remaining after the First World War. Tracked vehicles had undergone a considerable amount of development, although those in service at this time were really what we would now call development models and were largely hand-made. This also applied to the Army's radio sets which were very bulky, laboratory-made models using techniques which had fallen well behind current commercial practice. Radar, developed as part of the air defence organization, had

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obvious implications in the Army's anti-aircraft defence, but was at this stage too secret for many people to know much about it.

An O.M.E.'s Wireless Course was started in the Military College of Science in 1936 and trained two O.M.E.s from the United Kingdom and one from the Dominions per year. A special wireless course to include radar or, as it was then called, R.D.F. (Radio

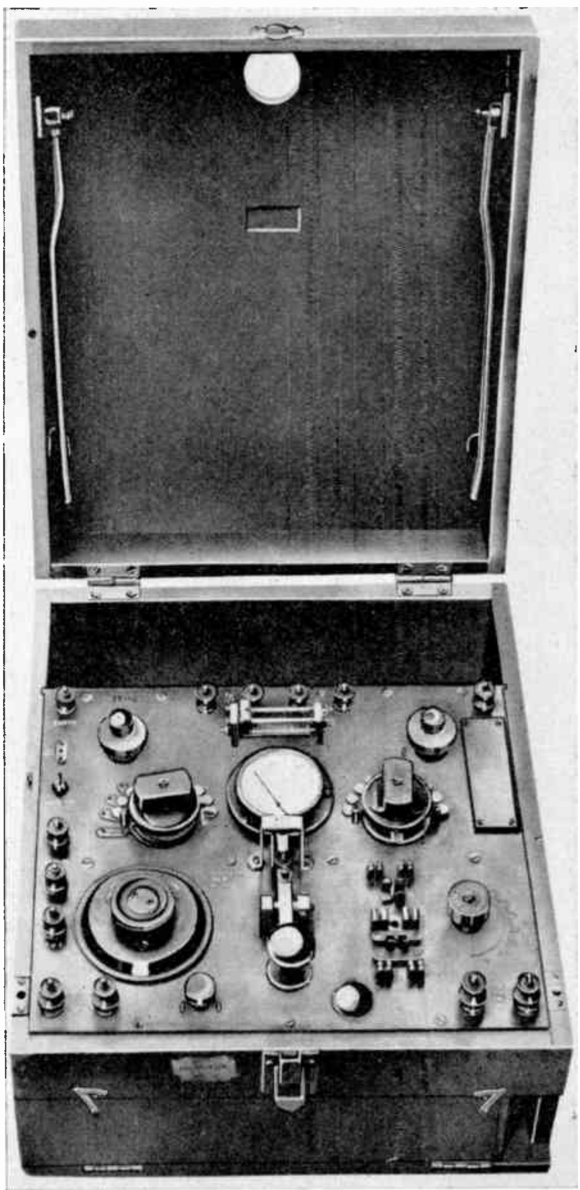


Fig. 1. C.W. Trench Set (1914–18).
In 1916 continuous wave (c.w.) sets were first seen in action. This four-valve transmitter-receiver was delicate and required a far higher operating skill. However, the advantages of its greater range, selectivity and small size were soon apparent. The hand generator provided h.t. for the valves.

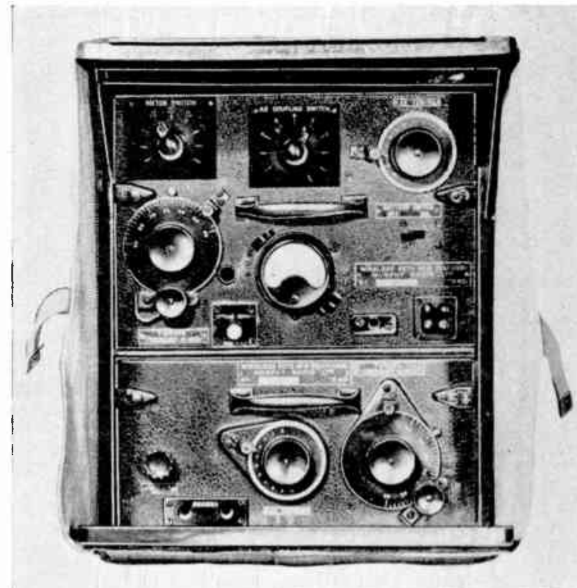


Fig. 2. Wireless Set No. 8 (1939–45).
This combined transmitter-receiver was the first of the so-called 'walkie-talkies'. It was issued to the Army in the years 1938–40 and was intended primarily for speech communication between battalion and company H.Q.s. The sender, receiver and batteries were housed in the one container which could be carried and operated by one man on the move.

Direction Finding) was planned in 1938. No. 1 Special Course started in July 1939 with a course strength of some five officers. By the spring of 1940 two courses had been completed and the third course was due to start—the duration had now been reduced from eighteen to nine months, but only a handful of officers had successfully completed the course.

It now became apparent that the repair services could not cope adequately with radar equipment in the Army and in the Air Defence of Great Britain (A.D.G.B.). In consequence, the Joubert Committee was formed and established that one of the causes was the serious shortage of electronic engineers and technicians. One of the means taken to remedy the situation was the establishment of the Army Radio School at Petersham near Richmond in 1940. This school was charged with the production, in the shortest possible time, of officers who could diagnose faults in and supervise repair of radar equipment. Some were commissioned, others remained civilians, all had had some University training, but not necessarily in disciplines connected with radio. Not a few subsequently found their way into the Royal Electrical and Mechanical Engineers and some are serving to this day. In retrospect it is obvious that this most unconventional procedure did much to retain radar in action on gunsites throughout the country and, through the frequent meetings at which field experience was fed back into the Army Radio School and thence to the Air Defence Research and Development Establishment, now part of the Royal Radar Establishment, did even more to influence research and development. Another offshoot of this organization was in operational research where the trained minds of statisticians and scientists were applied to problems of anti-aircraft defence and set the pattern for the present Army Operational Research Establishment, recently renamed the Defence Operational Analysis Establishment.

The Formation of the Royal Electrical and Mechanical Engineers

A critical situation arose due to the general shortage of skilled manpower. Conflicting requirements of war production and the maintenance and repair of equipment in the fighting services both made demands on the inadequate technical manpower of the nation. Those skilled men who did find their way into the Army were not always employed at their full potential. Some were enlisted in non-technical arms and others were employed in limited unit maintenance. To achieve the maximum economy in the technical manpower of the Army, the Beveridge Committee was set up in 1941 and led to the formation of the Royal Electrical and Mechanical Engineers in October 1942. The Corps was formed largely from the R.A.O.C. Engineering Branch reinforced by a few officers and soldiers of the Royal Engineers and the Royal Army Service Corps. Its ranks were swelled by incorporating the technical manpower dispersed throughout the Army in non-technical employment or in unit repair.

The new Corps was faced with a mammoth task imposed by the tremendous growth, since the outbreak of war, in the quantity and complexity of the equipment of the Army resulting from our own efforts and the advent of 'Lease-Lend'. To keep pace with its increasing responsibilities the Corps continued to grow throughout the war years until by 1945 it numbered 8000 officers, 150 000 soldiers and 100 000 civilians serving in all parts of the world.

That part of the new Corps which was concerned with electrical and electronic equipment developed rapidly during the war years and was responsible for many innovations which were subsequently adopted by the rest of the Corps. This was probably due to the rapid rate of evolution of electronics and the speed with which equipment and techniques became obsolescent. The majority of electronics engineers were new to the Army and had little respect for its traditions and were not afraid to make changes. They were regarded with some misgivings by their more senior mechanical engineering brethren with whom they could not easily communicate. The mounting load and the rate of development of electronic equipment demanded action and, in consequence, the very

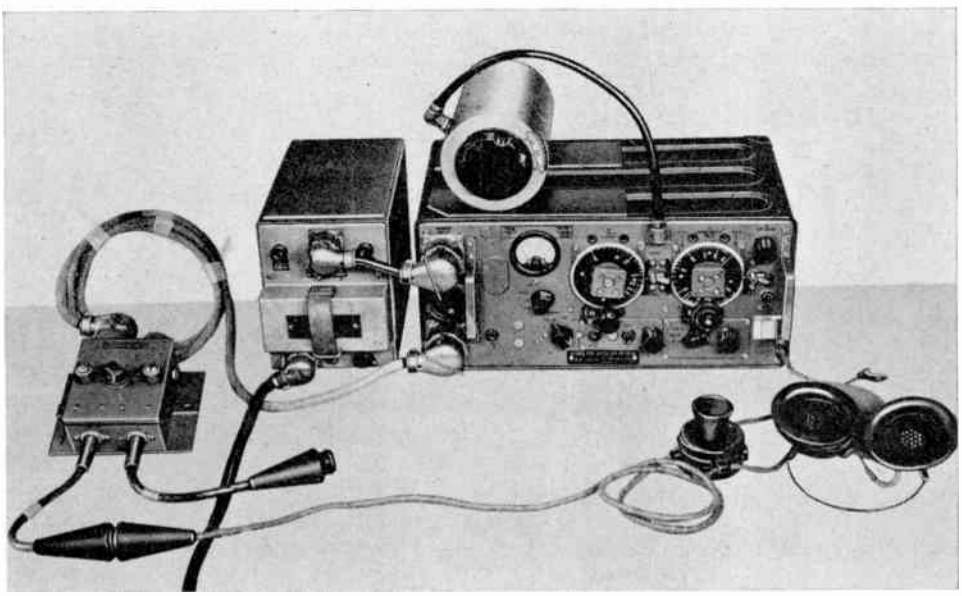


Fig. 3. Wireless Set No. 19 (1939–45).

Perhaps the best known set that came out of the last war, it was first issued in 1940 and many are still in use. It was designed for use in armoured fighting vehicles, but eventually became well known in all branches of the Army. The one chassis carried the main 'A' set, a short range 'B' set for working between tanks, and an intercom amplifier for communication within the tank.

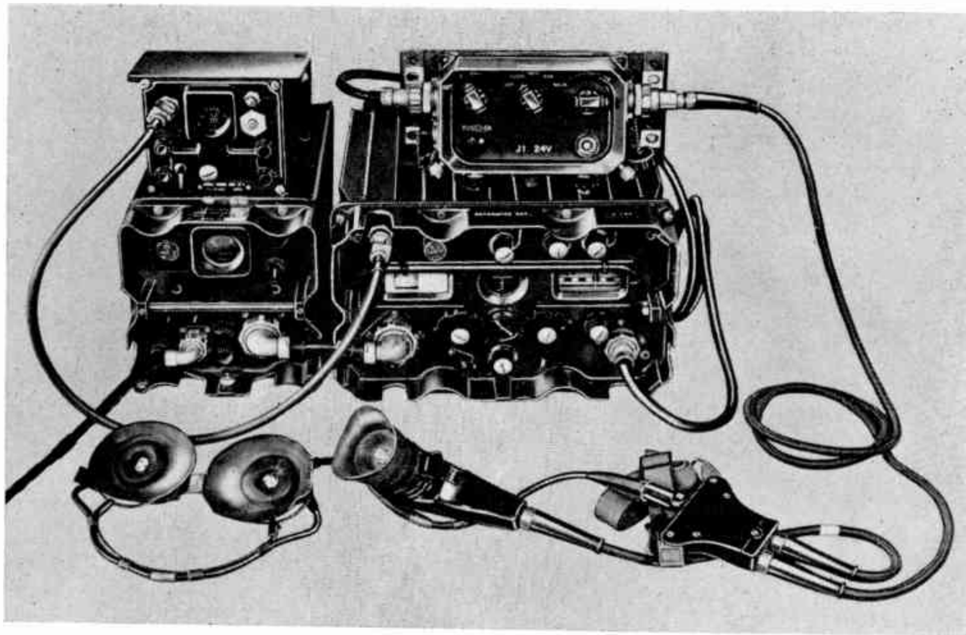


Fig. 4. Transmitter-Receiver Radio C.42 (1964).
This set was designed for installation in armoured fighting and other vehicles. It provides 481 speech channels in the v.h.f. band. First issued in 1963, it is fully sealed, tropicalized, parachutable and waterproof. In fact, it will float.

junior electronics engineers of the Corps exercised more authority than their age and service alone would justify.

The first purely electronic workshops were formed in 1942 to deal with the concentrations of radar equipment in Anti-Aircraft Command. Searchlight equipment was deployed in very large quantities, and some of these workshops were highly organized and undertook periodic servicing of searchlight radar on a production line basis using almost exclusively female labour provided by the W.R.A.C. (A.T.S.). One such workshop developed and set up a plant in 1942 to mould polythene plugs on the end of transmitter feeder cables utilizing only the talents which happened to be available in the workshop. Engineers with experience of moulding polythene will know that this technique is not without difficulties even today. Even less was known of the techniques of moulding these new plastics at that time and the production of a successful moulded plug free from voids with improvised equipment was no small achievement.

When a long-awaited delivery of a new and advanced radar from Canada was received it was found that the distance over which it could measure range accurately was too limited for the current tactical situation. It was necessary to double the range of accurate distance measurement and this required the manufacture of a large number of precision (1%) wirewound resistors. The best estimate that could be obtained from industry was quoted in years and consequently it was decided to undertake local manufacture. Existing resistors were stripped and rewound to double their original value, adjusted to tolerance and fitted to equipment deployed on gunsites throughout the country within a period of several months.

These are just two examples of the very many engineering activities performed by officers and technicians of the Corps during the war years. Time does not allow full justice to be done to their achievements, but they ranged from adapting anti-aircraft radar to detect mortars in France in 1944 to the development of what was probably the first British guided weapon (*Brakemine*), the story of which has been told elsewhere.†

The electronics side of the Corps took the lead in utilizing the most comprehensive and far-sighted system for the dissemination of technical information which had been developed as the primary means of communication within the Corps shortly after its formation. This system of "Electrical and Mechanical Engineering Regulations" (E.M.E.R.s) has proved to be equal to each new requirement and there is no doubt that the vast store of information which it

† J. R. C. Pedersen, "The earliest guided missile? The story of the *Brakemine*", *Journal of the R.E.M.E.*, **5**, No. 2, pp. 112–8, March 1960.

provided at all points where repair is undertaken has played no small part in the ability of the Corps to cope with its task.

A period of reorganization immediately followed the end of the war. Many of the 'temporary irregulars' who had contributed so much to the shape of the new Corps left the Service to return to their civilian occupations. Those who were left took stock and digested the lessons which the Corps had learned during its intensive initiation in all parts of the world.

Wartime experience and the situation which obtained in the immediate post-war phase confirmed the need to economize in the use of technical manpower. In a nation which had sacrificed everything to the war effort the need of the people for manufactured goods and the necessity to export in order to live demanded that industry should function at maximum capacity as soon as possible. On the other hand, it soon became apparent that the 'cold war' and the 'descent of the Iron Curtain' would make demands upon the Army far in excess of its normal peacetime responsibilities.

It also became apparent that the equipment of the Army would be substantially more complex than that of the war years. It is not surprising therefore that the need to economize in the technical manpower of the Army was reaffirmed in 1949 by the decision to implement a second phase in the formation of the Royal Electrical and Mechanical Engineers. This involved the transfer of almost all remaining unit tradesmen to the Corps and their re-allocation to units in the form of Regimental Workshops and Light Aid Detachments R.E.M.E.

Equipment Development

In new design a great deal of emphasis was placed on the ability of electronic equipment to withstand extreme environmental conditions. Many very bitter lessons had been learned during the war years and these tended to over-emphasize the weaknesses to which electronic equipment was prone. Bad packaging, mechanical weakness and susceptibility to electrical failure under humid tropical conditions were

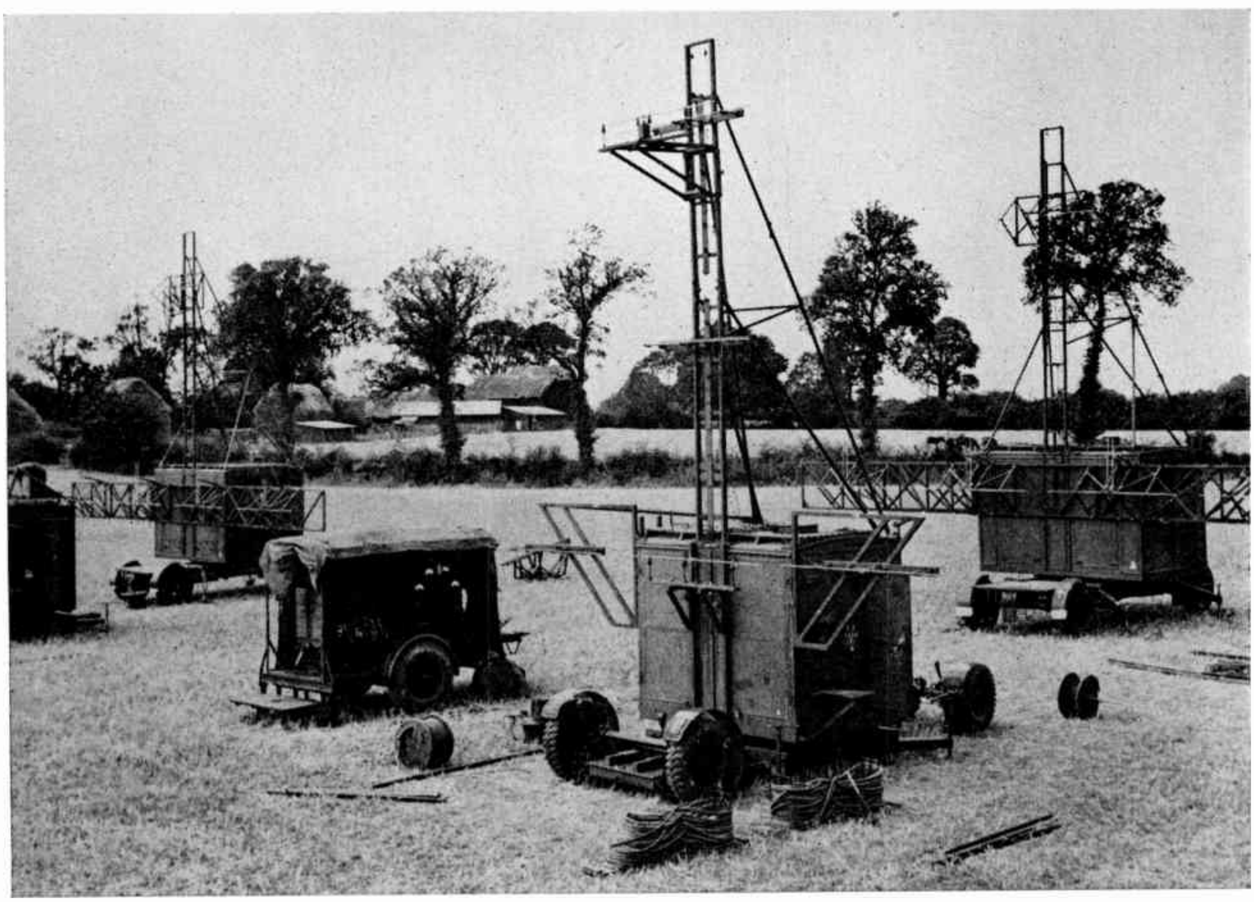


Fig. 5. Radar equipment of a mobile heavy A.A. regiment of Anti-Aircraft Command (1942). Picture shows receiver (Mark II) and generator in foreground and two transmitters (Mark II) in background.

all contributory factors and it was resolved that the post-war range of equipment would not suffer from these failings. In the process it is probable that we over-insured and created a new set of problems. For example, the wartime W.S. No. 19 could be repaired in little more time than that required to change a faulty valve or component. With the post-war 'pan-climatic' sealed equipment the operation took much longer. First the equipment had to be opened, involving the removal of many bolts retaining the sealing gland. The fault then had to be diagnosed and rectified. Subsequently the equipment had to be dried out in an oven, specification tested, and resealed. The efficiency of the seal required to be tested, a process occupying some hours. Thus what used to be a simple repair occupying 10–15 minutes now became an operation occupying several hours. This example serves to emphasize the need to strike a fine balance between reliability and ease of repair.

The difficulties experienced in the movement and concealment of the wartime equipment led to the development of a fire control radar so compact that life for the operator was very uncomfortable and the task of the repair man became extremely difficult.

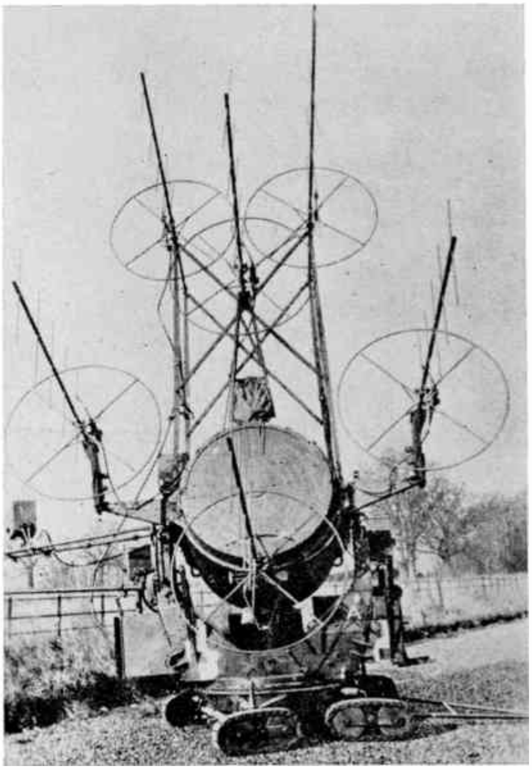


Fig. 6. A radar controlled searchlight equipment (1942), which was of great assistance to A.A. gunners and the R.A.F. in shooting down night bombers and which was extensively used during the flying bombs attack in 1944.

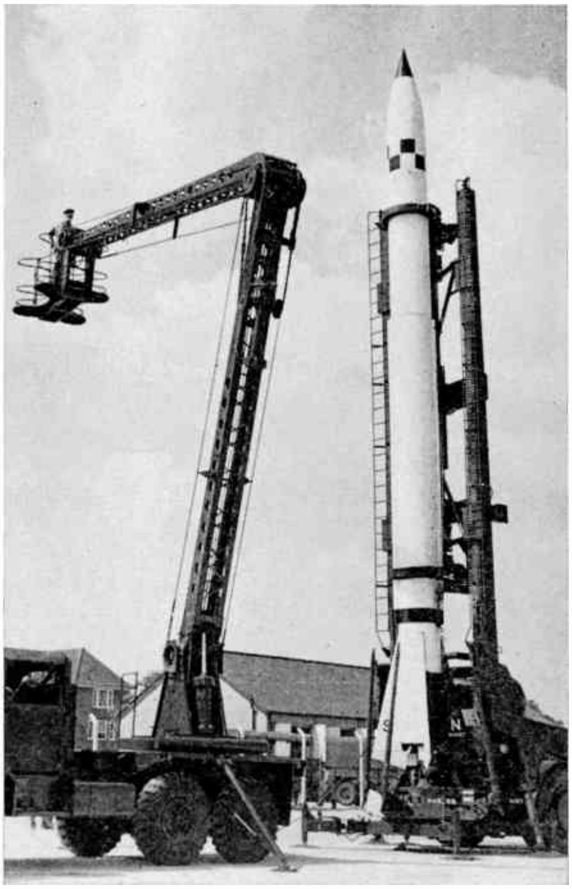


Fig. 7. The *Corporal* missile (1956).
Training in the servicing of missiles and missile equipment at the School of Electronic Engineering, R.E.M.E.

Tropical packaging was specified for the smaller equipments and all spare assemblies and components. This virtually assured the survival of equipment within the pack despite the best efforts of the railways and docks to destroy it by rough handling, and it guaranteed protection from the most extreme climates. Needless to say, the cost of such packaging is considerable and precludes anything but the smallest sample being opened for examination in store.

The Army in Nuclear War

Meanwhile the development of new weapons proceeded apace. The nuclear weapon was accorded pride of place on the battlefield and priority was given to the means of delivery by free flight rocket, guided missile, gun or aircraft. Other weapons were to be used to create the right situation in which to use the nuclear device and then to exploit the conditions created by its use. A great deal of emphasis was placed upon the collection of intelligence from the battlefield and its rapid processing and presentation by electronic means, although the equipment with which to do this was not yet available. Communications too assumed a new importance. Hopelessly outnumbered by the potential enemy, great emphasis was placed on superiority in weapons, especially armoured vehicles and armament. Flexibility, speed of response, accuracy, range and destructive power were of overriding importance—such considerations as reliability and ease of repair took second place.

In the effort to achieve these objectives, recourse had to be made to fully integrated electronic systems of control—there was no longer any attempt to provide alternative methods should the electronics fail—this was truly the emancipation of electronics as far as the Army was concerned. This was the era of the inertially stabilized tank gun, the surface-to-air and the surface-to-surface guided weapon and the anti-tank guided weapon.

The Provision of Tradesmen

During this period the Corps was dependent upon the National Service officer and soldier and a great deal of its regular manpower was tied up in the training organization, necessarily large to cope with the constant flow of trainees, most of whom after training had little more than a year or 18 months to serve. In common with the rest of the Army, the Corps found National Service to be a mixed blessing. It brought a great deal of first-class material into the Corps and some people liked it enough to stay, but the constant turnover in units and the very magnitude of the training problem proved demoralizing and caused some of the better regular soldiers and officers to leave the Service.

Fig. 9. Station Radio A13 (1964).
A modern h.f. manpack transmitter-receiver.

Fig. 8. *Thunderbird* surface to air guided missile (1960).
Officers receiving instruction on missile system, School of Electronic Engineering, R.E.M.E.

During National Service we had relied for electronic tradesmen on the man who had served an apprenticeship or who had several 'A' levels and was intending to make electronics his career. With the ending of National Service we could no longer rely on a sufficient supply of such men. We would have to train to the requisite standard of trade skill our share of the men who presented themselves at Recruiting Offices throughout the country, the majority of whom could be expected to have no more than an elementary education and no knowledge of electronics whatsoever!

Well before the end of National Service this problem was tackled by a team specially set up for the purpose—the Electronic Training Investigation Team and a course of 27 weeks' duration in basic electronics was devised which would enable the successful student to take a normal equipment course and so become a useful member of a repair team. The course is based on the principle of 'learning by doing'. In this system theory and the confirming practical work are so closely associated that classes take place in 'laboratory–lecture rooms'. The student is provided at his desk with all the necessary facilities and equipment to carry out the practical work and to prove for himself that the proposition which he has just seen demonstrated by the instructor is true.

To put this course into practice required the development of a comprehensive series of training aids, all of which were produced within the resources of the Corps. Instructors were provided with a console which enabled them to demonstrate circuit theory with the aid of functioning schematic diagrams equipped with large-scale indicating instruments and oscilloscopes.

To perform the experiment himself, the student had first to select a board by identifying the circuit diagram, select components from common component stores and plug them in over the appropriate circuit symbol. Thus, in proving the relationships implicit in, for example, Ohm's law, he would learn the symbol for a resistor and the resistor colour code at the same time.

This method, with some further development, is still the standard method of training technicians in basic electronics.

To fill the gap left by the National Service officer, a substantial number of whom were fully qualified electronic engineers, a post-graduate course in electronic engineering was developed within the R.E.M.E. training organization. The Officers' Long Electronic Engineering Course was designed to complete the education of a young regular officer who had read electrical engineering for his degree. However, the course was also successfully attended by many of the regular officers of the Corps who had mechanical engineering degrees, physics degrees or other qualifications.

The Present Time—The Organization and Operation of the Corps

Today it is recognized that the role of the Corps, expressed in simple management terms, is to promote and maintain a high equipment availability for operations and training at minimum cost in manpower and resources. This has implications far beyond the provision of an efficient repair system in the field.

A primary requirement in the achievement of high availability is to ensure that equipment is properly designed for its task; that it is reliable and can easily be repaired when it fails. Assistance in the achievement of these objectives is the responsibility of Technical Group R.E.M.E., a Major-General's command, working through specialist equipment branches, which include Maintenance Advisory Groups (M.A.G.) attached to design establishments and to firms engaged in development of new weapons and equipment. The need for M.A.G.s was foreseen in

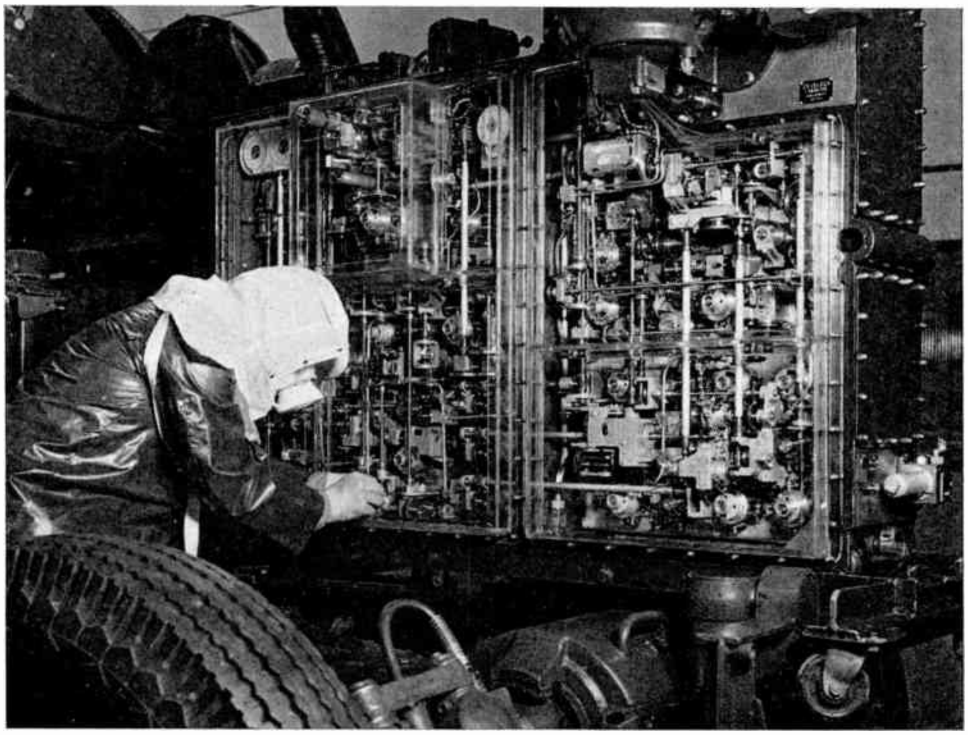


Fig. 10. A modern anti-aircraft fire control computer. Technician in protective clothing.

1941 and by 1942 Telecommunications Engineering Liaison Detachments, as they were then called, had been formed at the Signals Research and Development Establishment and at the Air Defence Research and Development Establishment. The function of these Groups is twofold—one to extract information from the development area so that maintenance manuals can be written, repair techniques developed and tools and test equipment provided; the other and probably more important one is to feed into the development area the fruits of field experience, preferred methods of repair and to develop design features intended to ease and simplify the repair task. With their fund of practical engineering experience M.A.G.s are quick to recognize those features of new design which may prove to be unreliable in the field. They take a keen interest in reliability assessments and seek to determine the maintenance and repair support which the equipment will require to retain operational viability.

The vital importance of this work which, if it is to succeed, requires the wholehearted co-operation of all authorities involved in the chain of procurement, is only now being fully realized. The promotion of reliability and ease of repair in new designs inevitably leads to increased cost and increased development time, since the process must include the manufacture and testing of development models (and any necessary redesign and retesting) on a sound statistical basis. The success or failure of this process becomes apparent only much later when substantial numbers of the new equipment are in the hands of troops and the cost of maintaining the required operational availability becomes known. The steady growth of the repair load suggests that this problem still awaits an effective solution! And this notwithstanding the tremendous efforts being made in design establishments and in industry to improve the operational reliability of equipment. As each improvement is made the effects of increased performance, complexity and numbers at risk more than compensate for the improvement in reliability. In the mechanical field probably the greatest problems arise in connection with Army aircraft. Light aircraft and new helicopters present a maintenance and repair load out of all proportion to the numbers in use.

The problem is more intractable with electronic equipment. The complexity of each succeeding generation of equipment, in terms of active and passive components, is at least an order greater than that of the preceding generation, thus cancelling out the effect of any improvement in component reliability which may have been achieved in the meantime. Increased complexity complicates the repair task since higher diagnostic skills and more sophisticated test equipment are called for. Greater repair skills are required as equipment becomes more compact and the spares problem increased with the range of component types employed.

Also with electronic equipment there is a far higher rate of growth and speed of evolution. There is now hardly a fighting soldier or a piece of military equipment which does not depend upon electronics for its efficient functioning. The infantry soldier already has his radio set and his infra-red sight and may soon have a radar which will warn him of enemy movement. Battlefield as well as air surveillance radars cover the operational area, radio-controlled drones fly above; the reconnaissance screen reports back by long-range radio—this and information from other sources processed by computer and is immediately available to determine the conduct of operations. In the infantry the anti-tank role is taken over from the gun by the anti-tank guided weapon; the tanks themselves have a quantity of electronic equipment, including inertially stabilized guns and inertially directed turrets, electronic rangefinders, infra-red, two radio sets and a host of other devices. A new and largely automatic communications system for the combat zone is planned. To the rear, vital areas are defended by tremendously complex air defence weapons systems.

As has been previously stated, the Corps seeks to ensure that equipment introduced into the Service is reliable and easily repaired. Once introduced it is the responsibility of the Corps to ensure that equipment is properly used and maintained. This is done through a system of routine inspections of equipment in store and in the hands of units, by the investigation of reported defects or malfunction, and the examination of equipment sent into workshops for repair (in future the data may be processed electronically!). Routine maintenance, tests and adjustments are specified for each equipment in the Technical Handbook, which is written and compiled by Technical Group R.E.M.E. during the development process. The medium of publication is E.M.E.R.s—Electrical and Mechanical Engineering Regulations. These regulations also specify the extent of repairs or adjustments which can be carried out in the unit or at any stage of repair as well as providing all necessary repair information.

The Repair System

Repairs are classified in three categories—Unit, Field and Base repair, according to the extent of the repair required and the time available. Thus the line of demarcation between these three categories may vary with the operational situation.

Unit Repair

Availability of equipment for operations is increased if repair is carried out close to the point of failure.

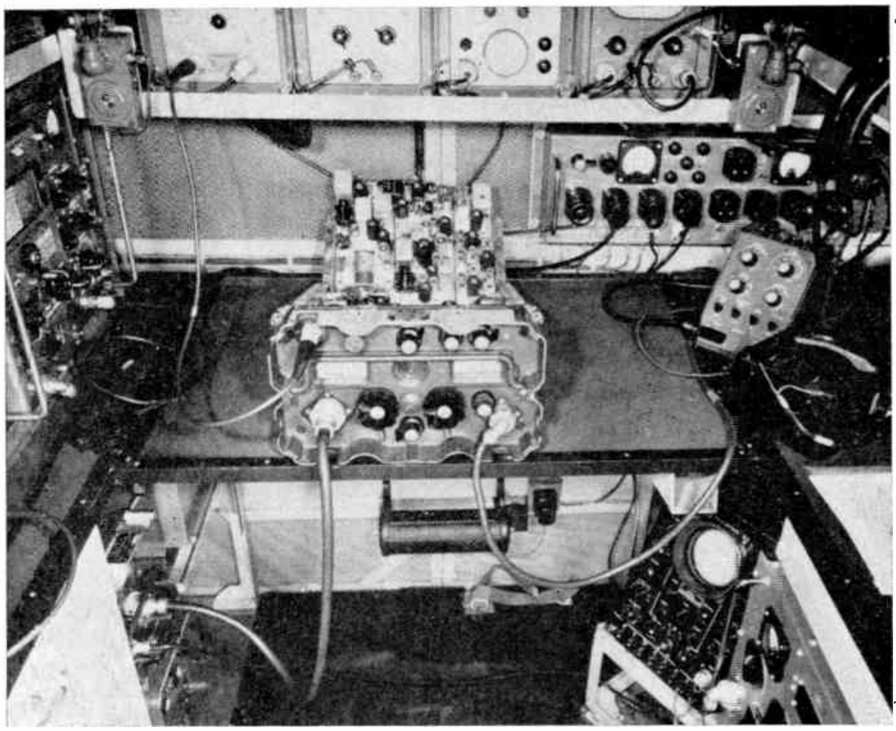


Fig. 11. The screened test compartment of a mobile repair vehicle.

This is achieved by providing small repair detachments, known as Light Aid Detachments (L.A.D.), as an integral part of user units. L.A.D.s range in size from one Electrical and Mechanical Engineer (E.M.E.) and twenty technicians and craftsmen to two E.M.E.s and eighty technicians and craftsmen. Units with very little technical equipment may have only a few attached R.E.M.E. tradesmen with hand tools; highly technical units such as Guided Weapon Regiments, Royal Artillery, have a Regimental Workshop which may have several E.M.E.s and 100 or more technicians and craftsmen.

In general, electronic technicians are not attached by themselves to units, but are provided in all L.A.D.s which deal with Armoured Fighting Vehicles. Electronic tradesmen predominate in the Regimental Workshop of Guided Weapon Regiments and Locating Regiments, Royal Artillery.

Repairs carried out by L.A.D.s and Regimental Workshops are limited in scope by the available time, tools and spares but, these considerations apart, the available effort must be applied to those equipments which can most readily be returned to operational effectiveness.

Field Repair

Repairs beyond the capacity of L.A.D.s and Unit Workshops are carried out by Field Workshops, allocated on a scale of one per brigade. These repair units differ in size and organization according to the composition of the brigade which they are supporting. An average complement is eight officers (E.M.E.s) and 200 technicians and tradesmen. On the principle of repair adjacent to the point of failure these units can send out detachments to repair battle damaged or broken-down equipment *in situ*. They are capable of exchanging an engine or other major assembly of a tank on the battlefield. Repairs which can be undertaken by these units are more comprehensive than those in L.A.D.s and unit workshops, but again they are limited by time, especially in a moving battle. All include a self-contained section capable of repairing all but the most highly specialized electronic equipment of the formation which they support.

Specialized electronic workshops are established adjacent to Corps and Army Headquarters to deal with the concentration of communications, radar and similar equipment which is found in these areas. Such workshops often provide a repair and calibration service for the electronic test equipment of other workshops in the Corps or Army area.

Army Air Corps units in the Corps or Army area are supported by Flight Workshops, R.E.M.E., for field repairs. More extensive repairs are carried out by the Royal Air Force. Each A.A.C. flight includes attached R.E.M.E. tradesmen for periodic inspection and servicing. Air technicians R.E.M.E. are provided in the L.A.D.s of units which operate their own aircraft.

Base Repair

In the Base area, Base Workshops concentrate on the repair of urgently-required equipment sent back from forward workshops or collected from the battlefield. The capacity of such workshops augmented by locally engaged civilians can be very substantial indeed. A certain amount of manufacture of items in short supply can be undertaken. Defect investigation and modification programmes are often carried out by these workshops.

In the United Kingdom there are several 'Central Workshops' employing 1000 to 1500 civilians and each specializing in extensive repair and overhaul of a limited range of equipment. These workshops are organized on mass production lines and are directly comparable with civilian industrial organizations of similar size. They are commanded by R.E.M.E. officers and staffed by military and civilian engineers and technicians.

Other specialist workshops support Port Operating Companies and undertake repair of the vessels of the water transport organization and the locomotives and rolling stock of the Royal Corps of Transport.

Command and Control

A senior officer of the Corps with a small staff which normally includes one or more electronic engineers is attached to Divisional Headquarters and superior formation headquarters. These officers act as engineering advisers and consultants to the Formation Commander and are responsible for the operational fitness of the equipment of the formation and the efficiency of R.E.M.E. services. They carry out routine inspection of equipment in the hands of troops using inspection teams drawn from the R.E.M.E. units under their command. They also carry out technical investigations and collect data from which the cost of maintenance of equipment can be evaluated.

The principle of repair adjacent to the point of failure requires the deployment of a substantial proportion of the resources of the Corps in the forward area (combat zone). The accommodation and working conditions in the forward area do not promote efficiency in the repair services from a production point of view. There are dangers, distractions, constant movement and occasionally the need to take a hand in the actual fighting. However, repair too far to the rear where working conditions are better and repair efficiency higher is no solution if savings are absorbed by the time and effort needed to move the casualty from the battlefield to the workshop and back again. Some of the factors involved are summarized in Table 1. The achievement of a proper balance between military requirements and repair efficiency is the constant preoccupation of all R.E.M.E. officers. A great deal of the engineering effort of the Corps is devoted to solving the many problems which arise in this connection, not the least of which is the design of specialist repair vehicles and test equipment.

The Role of the Army

In recent times the emphasis in the role of the Army has changed from the confrontation in Europe to so-called 'bush fire' and 'limited war' activities which may spring up unexpectedly in any part of the world. This type of internal security and counter-insurgency operation is not new to the Army, but it used to be undertaken, when the need arose, by the local garrison which was maintained for just this purpose. The need to economize in the size of garrisons abroad, now greatly reduced in number, the diversity of areas in which emergencies may arise, together with the ability to move large quantities of troops and equipment by air, have led to the creation of a 'Strategic

Table 1

Requirements for military efficiency	Requirements for technical efficiency
Mobility comparable with fighting units	Maximum stability
Light equipment that can be installed in vehicles	The most efficient equipment with less regard to size, weight and complexity
Ability to defend oneself	Minimum military distractions from the technical task
Ability to throw off detachments for special tasks	Maximum concentration of all resources
Ability to undertake any kind of work at short notice	A steady flow of work and a high degree of specialization
Ability to work in the open under any conditions of terrain and climate	Buildings, hard standing and adequate overhead cranes
Maximum emphasis on adaptability and craftsmanship	Emphasis on fixed procedures and semi-skilled work
Varying standards to meet operational requirements	Constant standards

Reserve' based in England from which garrisons abroad can be reinforced and assistance in support of the local power provided.

This type of operation requires a highly trained, highly mobile force capable of being air-lifted to the scene of operations and of being maintained from local stockpiles of supplies and equipment. Where local stockpiles do not exist the force must rely upon air supply until such time as supply by sea can be established. Since its creation, the Strategic Reserve has been continuously in action in places as far apart as Borneo, Malaysia, the Persian Gulf, Africa, Cyprus, etc. At times it has been so fully extended that reinforcement by withdrawal of units from B.A.O.R. had to be arranged.

Providing repair support for such an organization as the Strategic Reserve has presented the Corps with some very interesting engineering problems. Each force tends to be tailor-made for its task and usually contains a repair element whose size is determined by the optimum solution of a very complex equation. Factors in the equation include such intangibles as probable duration of operations, reliability of equipment in the local environment, relative weight of spare equipment or the corresponding repair capacity in terms of men and workshop equipment.

The requirements of the Strategic Reserve, diverse and exacting though they are, have all been met by adaptation of standard R.E.M.E. repair units and equipment. The repair philosophy of the Corps developed over its 20 years of existence has also proved equal to this task.

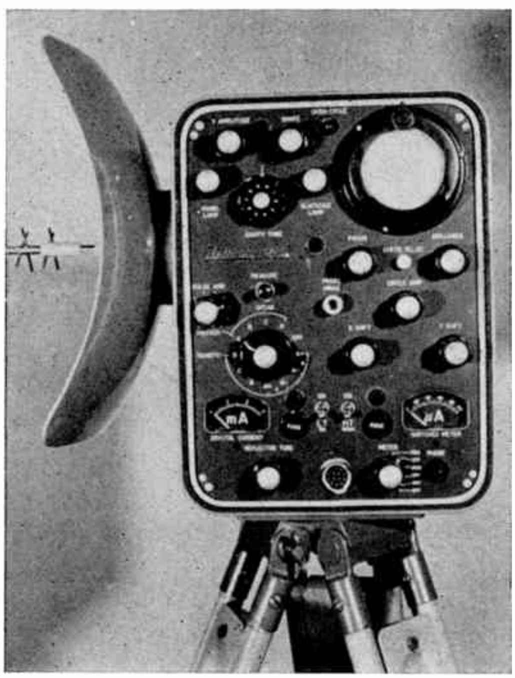


Fig. 12. The 'Tellurometer'. An accurate radar distance measuring device used in survey.

The Provision of Engineers, Technicians and Craftsmen

In the Services the size of the 'tail' or, more properly, the proportion of the uniformed strength employed in the logistic support units, is a matter of constant concern. This is particularly so at the present moment when the Ministry of Defence is carrying out a variety of studies designed to rationalize and reduce the size of the administrative support.

The Royal Electrical and Mechanical Engineers consists of 1200 officers, 15 000 soldiers and some 23 000 civilians world-wide (13 000 of whom are employed in the U.K.). It is inevitable that the Corps will be under even greater pressure to reduce its numbers or to accept a steadily increasing load without a corresponding increase in manpower. The only possible solution is to produce more reliable equipment which is also easier to repair and to devise better repair methods and more efficient management of the Corps resources. This in turn will make greater demands on the capability of our engineers and the versatility, flexibility and skill of our tradesmen.

The Training Organization

With the present pattern of military service, training the artisans, technicians and artificers of the Corps occupies a considerable number of the more experienced and able officers and senior ranks. Due to increased requirements in certain trades and the high rate of wastage of others to industry, we are currently training at the rate of 1600 military craftsmen and technicians a year plus 160 civilian craft and student apprentices. We train 260 electronic technicians annually the majority of whom, before they leave the service, qualify for entrance to the Society of Electronic and Radio Technicians by achieving Technician Class I standard or by taking the appropriate City and Guilds examinations. Others will take the Ordinary National Certificate during their basic training in the Army Apprentices Schools and will probably take the Higher National Certificate after further training.

It is of interest to note that at present some 400 men throughout the country annually qualify for the Final Certificates in Radio and Television Servicing of the City and Guilds and Radio Trades Examination Board and help to meet the needs of the domestic radio and television industry. The training achievement of R.E.M.E. of half as many more technicians is thus seen to be a valuable contribution to the nation's store of skilled manpower. In addition, we are producing almost 800 vehicle mechanics annually, which should go some way towards maintaining the nation's motor cars!

At present approximately 50% of tradesmen enter the Corps through Army Apprentices Schools on a three-year apprenticeship, shortly to be reduced to two years for the mechanical artisan trades. The balance of the requirement is met by direct recruitment of adults who are trained in one of the Corps' two major schools—the School of Electrical and Mechanical Engineering or the School of Electronic Engineering. These schools, which have a mixed military and civilian staff, are capable of taking adult recruits within certain standards of education and intelligence but with no previous trade training and turning them into qualified technicians and artisan tradesmen in 18 months. In these early days of the Industrial Training Act it may be of some interest to note these three ways of producing what is to all intents and purposes an identical product—the five years' formal apprenticeship for our civilian craft apprentices, two or three years for apprentices in the Army Apprentices Schools and 18 months for technicians and artisans produced by the adult schools! However, these results can only be achieved after careful selection of recruits for intelligence and ability to learn.

Once they have gained experience in the field both ex-apprentice and ex-adult trainees are eligible to return to the S.E.M.E. or S.E.E. for advanced training to fit them for Class I trade grading. After further experience and at age 23 and over the better men with proved qualities of leadership are selected by test, examination and selection board for the 'artificer course'—an 18-month course carrying the rank of staff-sergeant on successful completion. The artificer is the backbone of the Corps. He is the highest grade technician, the supervisor and junior manager. He rises by time promotion to WO II and by selection to WO I or to commissioned rank. Forty-three are now being commissioned annually.

Apart from those officers who are commissioned from artificers and certain short service commissions, all officers of the Corps are required to be chartered engineers. Most regular officers enter through Sandhurst and read for a degree at Cambridge or the Royal Military College of Science at Shrivenham. A number of University cadetships are awarded annually to students who have secured a place at University and are adjudged capable of becoming officers. These cadetships pay all expenses whilst at University. Direct entry commissions with appropriate antedates for seniority are available for those who enter after they have obtained a degree or equivalent qualification. Officers normally spend up to one year in industry and a similar time in attachments to units in the course of their training, which is so designed as to satisfy the requirements of the engineering institutions as well as meeting the Corps' requirements.

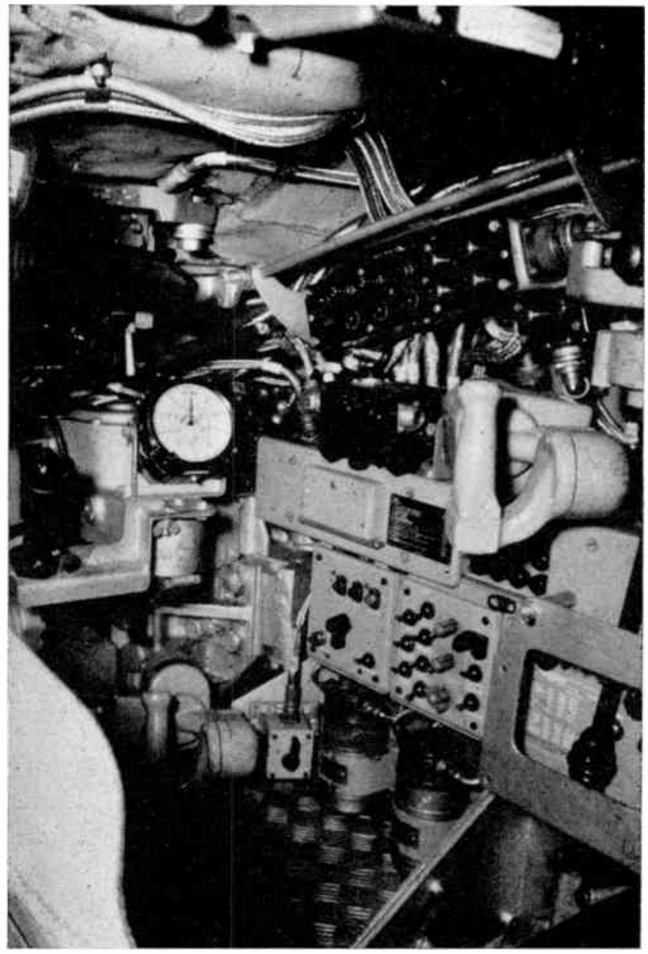


Fig. 13. The fighting compartment of a modern tank showing some of the electronic equipment.

In contrast to the early days when the majority of officers were trained as mechanical engineers, the Corps now requires 50% of its officers to read electrical engineering and to take a post-graduate course in electronics. Those who read mechanical engineering are required to take electrical engineering as a subject in the second year.

Post-graduate courses in the S.E.E. or in other Service schools are available in electronics and in aeronautical engineering. Further courses, including the first division of the new Army Staff course, which is a combined version of the old Staff course and the Technical Staff course, are open to qualified engineers and may lead to some of the highest posts in the Army, especially to those posts concerned with the development, procurement, inspection and testing of new equipment.

As in the past, officers' careers will be balanced between employment calling for a high degree of specialist training and posts demanding more orthodox military skills. However, the way is now open for an officer to pursue a more exclusively technical career than has been possible in the past without prejudice to his chances of promotion.

The Civilian Complement

The civilian officers of the Corps are recruited and trained by the Civil Service to standards set by the Civil Service Commission. The Corps plays its part in the training of engineer cadets and other types of potential engineers. A proportion of the officers of the Corps find employment as professional engineers in the ranks of the Civil Service on retirement.

Some 1700 members of the Technical Class of the Civil Service are employed by the Corps. They are recruited from suitably qualified craft and student apprentices and retiring artificers as well as from civilian life.

The Future

The almost exponential rise in the rate of technological development makes it probable that the next decade will see advances in the equipment of the Army comparable with those achieved in the last 30 years. If the growth in quantity of equipment as well as in complexity continues at the same rate, startling improvements in the standard of reliability and ease of repair are required or the Army will consist of nothing but R.E.M.E. and the equipment of the Army nothing but a repair load!

The greatest growth in quantity and in complexity will probably occur in electronic equipment. New techniques such as microminiaturization and the 'integrated' circuit are being relied upon to provide the solution to the reliability problem. These techniques may also simplify the repair and spares holding problems, since it is apparent that repair operations will be limited to replacing solid-state-circuit blocks containing very many active and passive circuit elements. We shall have come full circle when we have no more replaceable 'blocks' in our 1970 electronic equipment than we had valves and components in our 1942 one! Before we achieve this, however, we shall have some very complicated sums to do to prove that it is cheaper to discard an expensive solid-state block than it is to maintain a conventional microminiaturized assembly having replaceable components but which is perhaps less intrinsically reliable.

Whatever the form that equipment takes it will still fail and soldiers will break it! To maintain operational availability it will be necessary to repair it locally and speedily. To cope with the greater load without overloading the Army with repair services will mean greater reliability of equipment, greater productivity of the repair services and simplification of the repair processes (diagnosis, location and rectification of the fault).

An increasing rate of evolution of equipment makes it more than ever important to concentrate on fundamental engineering training for officers and technicians of the Corps. Training must ensure a thorough understanding of basic principles and must be sufficiently broad in scope to minimize the amount of retraining required when new equipment is introduced.

Conclusions

In the course of 50 years we have seen revolutionary changes take place in the equipment of the Army.

Electronics has developed within this time from something which was regarded as a useful aid if it worked but no great loss if it did not, to something which is an integral part of every weapons system and a vital part of the equipment of every fighting soldier or armoured fighting vehicle.

Whilst in the First World War battles were fought by the traditional infantry soldier equipped with little more than his rifle, bayonet and entrenching tool, now they are a complex operation, probably computer-aided and fought with tanks, guns, aircraft, guided weapons and infantry, fighting as one integrated entity with electronics providing the sensors, sight and hearing, the communications, the logic, the memory—in short, the whole nervous system.

In the last 23 years we have seen the creation of a specialized service whose task it is to maintain this vast amount of complex equipment in operational condition in peace and in war. It has been decided that the officers engaged in this task shall be chartered engineers and much thought has been given to their training. It is not feasible to practise specialization in repair in the forward area where the greater part of the task is carried out, and therefore officers attached to regiments or in charge of regimental or field workshops must be capable of dealing with equipment embracing a wide range of disciplines and techniques—mechanics, electrics, electronics, aeronautics, thermodynamics, hydraulics—both in a maintenance and repair capacity and as a consultant and adviser.

Unlike much of industry, we require our forward (and therefore junior) engineers to be general practitioners broadly trained in more than one discipline and capable of exercising sound engineering judgment over a very wide field indeed—resourceful, ingenious, determined, adaptable and with a natural capacity for taking the right decision in an emergency. They must be capable of improvisation and prepared to depart from the ideal engineering solution when dictated by operational requirements. In addition to their engineering qualifications, they must have well-developed qualities of leadership.

Whilst officers in training must obviously follow one main discipline, such training must be very widely based and should include an understanding of other disciplines and modern management techniques. The recent decision of the Engineering Institutions Joint Council in seeking agreement for a common Part I examination for its thirteen institutions would seem to be a welcome step in this direction.

The opportunity to specialize will come later when the officer will be required to participate in research and development actively or as an adviser, and to, weigh such conflicting requirements as reliability and ease of repair, decide future repair policies, spares scalings, etc. Later still each individual officer must decide if he wishes to pursue a general career or one of increasing specialization. In either event he will build on the sound foundation of his widely based training and experience.

One of the chief problems of the Corps is how to train officers to meet this exacting specification within reasonable time—at present training for the officer who enters via Sandhurst takes some seven years and practically deprives him of service with troops while he is young and junior enough to be allowed to make mistakes. Despite the very real need to reduce training time, it is obvious that the Corps will require officers who, apart from being fully trained engineers and professional soldiers, are also trained in management, cost accounting and new techniques as yet undetermined. In common with the rest of the country, the Corps is seeking more efficient means of training engineers to a standard dictated by the task they are required to perform.

Acknowledgment

Finally, I wish to acknowledge fully the very great help given to me in the preparation of this paper by Colonel J. Harris of my headquarters.

Manuscript first received by the Institution on 29th April 1965 and in final form on 3rd June 1965. (Paper No. 997.)

DISCUSSION

Under the chairmanship of the President, Colonel G. W. Raby, C.B.E.

Mr. A. St. Johnston: As an engineer concerned with the design side of industry, one of the questions I would like to ask General Atkinson is what price can be put upon reliability. The Army must have an unrivalled opportunity for generating not only statistics, but also the actual costs of maintenance in the field. Would you be able to feed back into industry the cost of doing certain things in maintenance in a particular way?

Major-General L. H. Atkinson (*in reply*): About eighteen months ago we started a scheme of feeding back information from the field and from static workshops. We arranged that every time a fitter in any capacity takes some tools or test equipment, spares, etc., it is recorded. Every time he does anything, the time he takes is recorded, the spares he uses, and of course the type number of the equipment. All this is fed back very quickly, and by the shortest possible means, to a data centre at Woolwich. This information is put on punched cards and analysed by computer. Complete information is thereby available as to how many times certain components fail in various equipment. We also know how long it takes to replace a component and as we know its cost and the cost of a man's time, we can determine the total cost of maintenance.

At last the Army is realizing what unreliability really costs the country and it represents a frighteningly large figure. This is why we are terribly keen on improving reliability, and not only because of the direct costs but also the locking up of manpower doing things which should not have to be done. This feed-back is giving us the information and I hope that it will be available to anyone who is making equipment for the Army in future.

Mr. E. C. Emerson: May I refer to the section on micro-electronics, where you suggest that you are using modules in future in integrated circuits, and so on. Can you indicate whether you have made any decisions on the possible size of these modules and/or the cost of them?

General Atkinson (*in reply*): I think the cost of repair obtained from our computer study will give some guidance on the economic factors. This will be available by the time integrated circuits have reached the development stage, and we shall then know the size and hence the cost of modules that we can afford to throw away.

Mr. J. R. F. de Klerk: I wonder what governs the rate of obsolescence of test equipment. I take as an instance the type 13A oscilloscope which is now being replaced by the CT46. What decides when the 13A becomes obsolete and what decides why it should be replaced by the CT46?

General Atkinson: This is a very big question which obviously depends on the equipment you have got to test: new equipments demand new test equipment, naturally. It is also based on the suitability of an equipment for worldwide use and its reliability in extreme climates. It depends also on the financial climate since we have to operate to a budget.

The President: I would like to ask a question myself if I may. How far is the Corps able to influence design, particularly in the standardization of parts that are to be used in new equipment? Are you able to talk with the manufacturers directly to make sure that the parts that are already used in other equipment can be standardized for use in new ones, so that you avoid a fresh stores problem?

General Atkinson: We have always supported the activities of the Radio Components Standardization Committee (R.C.S.C.) and have advocated the use of standard components wherever possible. However, the problem is more difficult due to the rate of evolution of the electronics art—today's standard component is not the same as the one in yesterday's equipment.

For a very long time now we have had Maintenance Advisory Groups in Design Establishments and at firms with important development contracts. These groups influence design by providing a feedback channel for information derived from field experience.

This link will be even more important in future for it is now apparent that the Ministry of Defence is taking an active interest in equipment reliability and is setting up machinery to deal with reliability questions. I believe that R.E.M.E. will have an important part to play in determining reliability targets and collecting performance data from equipment in service.

An Army Board paper on this subject is being prepared.

The President then asked whether General Atkinson had any particular points in mind which industry should strive to meet in the future in producing equipment for the Army.

General Atkinson replied that the prime need was for equipment of greater reliability which would also meet the varied environmental conditions under which it would have to operate. These conditions ranged from the heat and humidity of Borneo and Malaysia, to the intense heat and dust of Aden, not forgetting store houses which could reach extremely high temperatures. If it could not be extremely reliable then it must be easily repairable. Ways of achieving ease of repair by, for instance, replaceable modules, were under constant review.

A member of the audience: I think we all agree that credit must go to the Army and all the armed services for the way they have risen to this problem of reliability. The way in which all the Services can, I think, best co-operate with industry is by comprehensive defect analyses. Now you have indicated that only eighteen months ago you started to take steps in this direction. On the other hand, Sir, you have had the C42 vehicle-borne v.h.f. transmitter–receiver in service for ten years and you should have a wealth of data which, unfortunately, does not get back to industry in the flood that we would like it to, telling us what you have experienced in the field. It is not sufficient merely to collect defects, they must be analysed and the precise primary and secondary causes of failure sent to the manufacturer concerned. From then onwards it needs close integration between the Services and industry. I would like to say that the C42 does not include any particular reliability techniques. On the other hand, it is probably one of the most reliable wireless sets that industry has produced for mobile use. There is nothing clever about it, it is just good engineering, and I think like you that we can profit by your ten years' experience.

General Atkinson: I think what you have suggested is what we want, and it is long overdue. Now that we have got permission to buy the computer and we have already hired time on one, we can extract this information, and I hope we will be able to make it available to you. We are also beginning to make a start to write into our specifications what reliability is wanted. It is not easy to do this, but somebody has got to say "this wireless set must be made to operate for, it may be, 50 hours without a failure in various climates", "this radar equipment must go for 100 hours and require base overhaul every four weeks". I appreciate that it will only be possible for industry to develop equipment to meet our requirements if we produce full feedback of information from the field.

Another member of the audience: In industry there is a lot of information needed in the course of manufacture, but, unfortunately, it takes a long time to get it out of the system. Now you have mentioned data processing and I would say that you have essentially got the means whereby you could collate and compile this information, and feed it back to the design authorities concerned. The design authority wants the answer to a question within about half an hour or an hour. He doesn't want to have to wait six weeks; this is the situation as it stands.

Brigadier R. F. Shields: I would like to add one further point to this discussion. I was very much impressed by what the speaker has said but I would like to see more designers come over to Germany and see the equipment battered about every year on excercises. This would be a very interesting trip and, I think, instructive to designers.

Another Speaker: I would like to ask General Atkinson if he feels the Services are satisfied with the standard of technical manuals which are supplied with the equipment by industry to the Services. We have all seen the rather wonderful technical manuals which the Americans produce and by comparison those produced in Britain do not appear, to me at any rate, to be as good. On the other hand, it costs a lot of money to produce such elaborate manuals. Do you think you would rather have a higher standard of manual and pay a bit more for it, or do you think you are satisfied with what you have got?

[With the President's permission General Atkinson invited comments from R.E.M.E. officers present on this point.]

Colonel R. Knowles: I think we can say that generally the standards of commercial technical publications are most unsatisfactory. On the other hand, we do not have to rely on these as 99% of our electronic equipments are covered by publications which we write ourselves. So we haven't any practical experience of using these publications.

Another Speaker: As a corollary to the previous discussion, I would like to ask General Atkinson if it might not be a good idea in view of the expanding problems of R.E.M.E. and the manpower problems which are presented thereby, to consider whether it would be desirable or even feasible, for industry to take over the base workshop activity, particularly in this country?

General Atkinson: We do some base workshop repair by contract, but not very much. It is usually cheaper to do it ourselves, but I spend a large sum each year on various forms of contract repair.

Only recently we started a very complicated cost accounting scheme in one of our base workshops, prepared by a firm of management consultants, and we are finding out rapidly exactly what it does cost to overhaul a tank, a radar set, and so on. If it can be proved that it is any cheaper, we might well use contract repair to a greater extent. On the electronics side in general we have found that few firms want to do repair work.

Another Speaker: I think it is becoming increasingly obvious these days that with electronics progressing at the rate it is, it is possible to say that almost anything is capable of being made provided the cost and the time is available to do it; any piece of control equipment can be devised to do a certain job if it is really required. Who decides what is required in the future, and at what stage does your Corps come into it, and who specifies the reliability and service requirements?

General Atkinson: There is a branch of the Ministry of Defence which spends all its time looking into the future. It studies tactics, fire-control methods and so on and decides that there is a role for a certain equipment. The General Staff decide the type of equipment they want to fight a possible future war, and then lay down its military characteristics. It then goes to another body which does a feasibility study and during the feasibility study very often my Corps gets called in.

From then on it becomes a problem of deciding the optimum equipment that can be produced within the available time. Reliability, for example, must be balanced against cost of repair, cost of spares, etc., and my Corps comes in on all these questions.

Another Speaker: My experience is in one of the sister Services, where there is a rather disturbing trend in the attitude towards test equipment. This is becoming more expensive and more complicated than the main equipment it is trying to test.

I am wondering what is your Corps' attitude on test gear philosophy, bearing in mind that it is becoming more and more complicated?

General Atkinson: We are very concerned with this and we are doing a lot of work on automatic and even on multi-system automatic test equipment. What is really driving us to this extent is the enormous number of tests which have got to be carried out on a modern piece of equipment and done quickly. We are doing a lot of work on this and I think we shall certainly go for it, expensive as it is. It saves manpower and time and it might save some money in the long run.

Mr. J. L. Thompson: When I was associated with the making of defence equipment it was our experience that the spares invariably were ordered after production had started, with the result that they were never available at the most critical time. Quite often this didn't really matter, since the instruction booklets were not available until even later. I would like to ask you whether this sad state of affairs has now been rectified.

On the matter of reliability, have you considered following the American practice whereby they publish to the industry as a whole the mean failure rate (the mean time between failure) of equipment? Now within the industry, everybody knows who is making a particular equipment, and I have got a shrewd idea that reliability might improve quite considerably if these details were broadcast.

General Atkinson: Referring to your first question, when the equipment is ordered we do place an order for an initial supply of spares at the same time and everything is done to see that spares are in position in the unit when the equipment arrives. We also try and get our Electrical and Mechanical Engineering Regulations, which give all the details for repair, to be ready, if necessary in draft form, as soon as a unit receives its new equipment. It is not easy, but we do everything possible. We even would rather hold things up until the spares are ready.

We cannot make performance information generally available, for security reasons if no other, but I believe that something is being done by the Ministry of Aviation about publishing component reliability data.

Mr. R. V. Collins: I wonder whether, if when you are publishing this information, you will give us, perhaps, 400 copies to pass on to our component suppliers. We have to use what we can buy and we find a great deal of difference in the performance of prototypes and samples for laboratory use and production components.

I.E.R.E. GRADUATESHIP EXAMINATION, MAY 1965

PASS LISTS

The following candidates who sat the May 1965 examination at centres outside Great Britain and Ireland succeeded in the sections indicated. The examination, which was conducted at 74 centres throughout the world, attracted entries from 471 candidates. Of these 155 sat the examination at centres in Great Britain and Ireland and 173 sat the examination at centres overseas. The names of successful candidates resident in Great Britain and Ireland will be published in the next issue of the *Proceedings* of the I.E.R.E.

	Candidates appearing	*Pass*	*Fail*	*Refer*
Section A				
Great Britain	86	30	47	9
Overseas	97	19	71	7
Section B				
Great Britain	69	14	41	14
Overseas	76	12	56	8

OVERSEAS

The following candidates have now completed the Graduateship Examination and thus qualify for transfer or election to Graduate or a higher grade of membership.

BEDFORD, J. *Vancouver, Canada*
BHOJANI, N. P. (S), *Kampala, Uganda*
JAYAWARDHANA, S. C. (S), *Colombo*
KRIEGSMAN, A. H. (S), *Holland*
LEE, S. J. (S), *Singapore*
LOUIS, J. J. *Bangalore, India*
PANDE, G. B. *Lucknow, India*
RAMA-KUMAR, R. (S), *Bangalore, India*
SHAIKDAWOOD, A. *Madras*
SINGH, V. (S), *Bangalore, India*
VERMA, V. D. *Ernakulam, India*
WILLIAMS, J. W. *Auckland, N. Zealand*

The following candidates have now satisfied the requirements of Section A of the Graduateship Examination.

ANDREWS, A. *Hong Kong*
BENNY, W. R. (S), *Singapore*
BROWNING, G. B. *Bulawayo, Rhodesia*
CHATTERJEE, N. C. *Shillong, India*
FRIZZELL, B. E. *Canberra, Australia*
FUNG, S. C. *Hong Kong*
GANGADHARAN, S. *Delhi, India*
HALL, M. J. *Cape Town, S. Africa*
IGWEH, F. N. (S) *Lagos, Nigeria*
NARASIMHAN, K. L. *Hyderabad*
PECK, E. B. *Christchurch, N. Zealand*
RAO, K. N. *Mysore, India*
RAVINDRAN NAIR, K. *Hyderabad*
RODWELL, W. E. *Bermuda*
SANSOM, D. J. (S), *Salisbury, Rhodesia*
SHOME, S. *Germany*
SRICHANDRAN, C. K. (S), *Madras*
TAY, K. M. *Singapore*
WEARING, M. L. (S), *Montreal, Canada*

The following name was omitted from the list of candidates who qualified at the May 1964 examination, as published in *The Radio and Electronic Engineer*, page 292, October, 1964:

SHANKAR, H. *Calcutta.*

The question papers set in Section A of the November 1964 Graduateship Examination together with answers to numerical questions and examiners' comments will be published in the September/October issue of the *Proceedings* of the I.E.R.E. Parts 3 and 4 of Section B and Part 5 of Section B will be published in subsequent issues of *Proceedings.*

(S) denotes a Registered Student.

U.D.C.621.396.969.34

Enhancement of the Radar Echoing Area of Gliders at S- and X-Bands

By

R. S. ARBUTHNOT†

AND

S. R. BADCOE‡

Presented at a meeting of the Radar and Navigational Aids Group in London on 27th January 1965.

Summary: A review is given of a number of experiments which were conducted to improve the unreliable echoes given by gliders on air traffic control radars.

Typical values are given for the echoing areas of various gliders at X- and S-bands for different aspects as measured in flight.

Investigations into various possible methods of increasing these echoing areas are then described, and the results of flight trials carried out on gliders treated by two different techniques are shown.

One of these techniques, namely, fitting a light-weight cluster of corner reflectors into the fuselage, produced an adequate increase in echoing area, and it is concluded that though each type of glider would require its own particular design of corner cluster, the method should be generally feasible.

1. Introduction

Some three years ago the then Commanding Officer of Experimental Flying at the Royal Aircraft Establishment, Farnborough (Hants), asked whether anything could be done to enhance the radar echoing areas of gliders, as difficulties were being experienced in Air Traffic Control from time to time on account of the flying of gliders from Lasham airfield, which is only twelve miles from Farnborough. These gliders often flew at about the same altitudes as aircraft which had either just taken off from Farnborough or were about to land. When under adverse conditions of visibility such aircraft were being controlled or monitored on the airfield radars, gliders in the proximity of the aircraft could often not be seen on the radars, on account of their low echoing area, and this situation was liable to constitute a hazard.

Accordingly a programme of work was instituted to investigate possible methods of increasing glider echoes. The work was concerned with enhancement at S- and X-bands, since the airfield radars used at Farnborough to cover the area in which gliders were most likely to be found operated in these bands. As the work proceeded, it became apparent that S-band was of greater importance, since the X-band radar was not often employed on targets in excess of ten miles, and therefore in the later stages of the work priority was given to finding a solution at S-band.

Towards the end of the programme it was learned that the problem was a national one, particularly with regard to the real possibility of the penetration of gliders into controlled airspace within national radar coverage, and that echo enhancement was required, therefore, at wavelengths of 23 and 50 cm in addition to X- and S-bands. At this stage the Ministry of Aviation placed an extramural contract for investigation into ways of increasing glider echoes over the whole band 3–50 cm, and this work has now been in progress for some time.

This paper describes only the investigations completed at the Royal Aircraft Establishment.

2. Requirements of the Solution

From observations made on aircraft of known echoing area, it was deduced that an echoing area for gliders, at S- or X-band, of 4 square metres would be just adequate. This figure should, of course, be attained at all aspects at which gliders were likely to be seen, that is, from all directions around the glider, up to a radar beam elevation of say 10 deg.

It was important that the cost of any recommended practical solution to the problem should be low, as it would need to be applied to very many gliders, and an arbitrary limit of £5 was set.

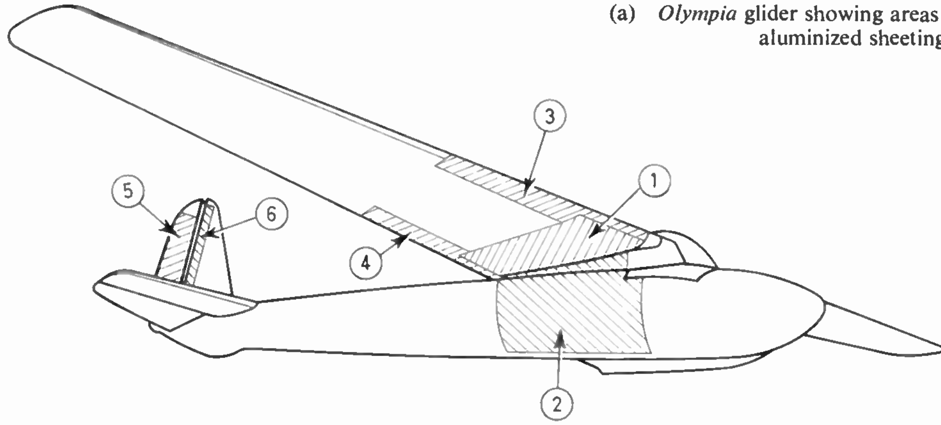
The solution would have to be capable of retrospective application and, finally, it would not have to impose an unacceptable performance penalty, due to excessive additional weight or for any other reason.

3. The Echoing Areas of Gliders

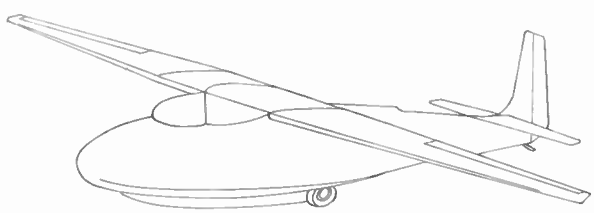
The first step in the study was to measure the echoing areas of typical gliders as a function of aspect at S- and X-bands. These measurements were carried out on real gliders in flight, using S- and

† Spembly Ltd., Chatham, Kent.

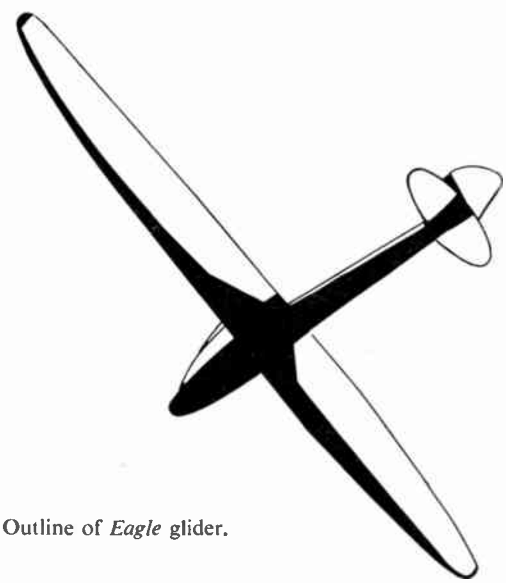
‡ Ministry of Aviation, Royal Aircraft Establishment, Farnborough, Hants.



(a) *Olympia* glider showing areas covered with aluminized sheeting.



(b) Outline of *Sky* glider.



(c) Outline of *Eagle* glider.

Fig. 1.

X-band lock-follow radars modified to give continuous recordings of echoing area in absolute terms after calibration with metal spheres of known echoing area.

Polar diagrams of echoing area were normally obtained by making observations on the glider orbiting a point some six miles distant from the radar. The diagrams for the gliders measured all followed the same general pattern, namely highest values at broadside aspects, smaller and roughly equal peaks at the head-on and tail-on aspects, and lower values still at the remaining aspects.

The results were very similar in the two bands, and varied only slightly with the elevation of the radar beam at low angles (up to 10 deg).

Typical peak values are given in Table 1.

Table 1

Typical glider echoing areas

Glider	Aspect		
	Broadside	Head-on	Tail-on
Olympia (Fig. 1 (a))	2·5 m^2	0·6 m^2	0·6 m^2
Sky (Fig. 1 (b))	5·0	1·0	0·8
Eagle (Fig. 1 (c))	5·0	2·5	2·5

Between the above peaks the echoing areas dropped to values ranging from 0·3 to 0·8 m^2.

4. Methods Investigated of Increasing Echoes

The following methods of echo enhancement were investigated:

(a) Covering some of the glider surface with aluminized terylene sheeting.

(b) Installing a Lüneberg lens, either internally or externally.

(c) Spraying the glider surface with a conducting paint.

(d) Installing a multi-corner reflector internally.

4.1. *Aluminized Sheeting*

Certain surfaces of an *Olympia* glider were covered with aluminized terylene sheeting as illustrated in Fig. 1(a), the total area of sheeting used being 74 ft^2 and the areas covered as follows:

(1) Undersurface of main planes, out to 2 ft from fuselage.

(2) Sides of fuselage adjacent to main planes.

(3) Leading edges of main plane out to 6 ft from fuselage.

(4) Trailing edges of main plane out to 6 ft from fuselage.

(5) Much of rudder surfaces.

(6) Trailing edge of fin.

The results obtained at X-band with the *Olympia* treated as above are shown in Table 2.

Table 2

Echoing area of *Olympia* glider part covered with aluminized sheeting

Glider	Aspect				
	Broadside	Head-on	Tail-on	Broadside/ Head	Broadside/ Tail
Untreated	2·5	0·6	0·6	0·3	0·3 m^2
Treated	12	2	2	0·5	1 m^2

The treated *Olympia* glider was not measured at S-band, but there is no reason to suppose that the results should be very different.

It was clear that even with the considerable area of sheeting employed, the increases in echoing area achieved were far too small, especially in the regions between broadside and head or tail. In addition, the view was expressed by glider pilots that gliding clubs would fight against the general application of this particular solution, as it would not be possible, having applied the sheeting, to achieve the highly polished smooth surfaces which are essential to high performance of the glider.

4.2. *Lüneberg Lens*

The use of a Lüneberg lens for echo enhancement was next considered.

A lens of 10 in (25·4 cm) diameter, weighing 7 lb (3·2 kg), was obtained with a metal band fitted as the reflecting surface to secure a 360 deg coverage in azimuth and ± 10 deg in elevation.

The maximum echoing area at X-band of this lens was found to be only 7 m^2, compared with a theoretically possible figure of 19 m^2. At S-band the echoing area would be about one-tenth of the X-band value.

Experts on glider design expressed the view that a 10-in lens would have to be mounted internally, since an external mounting, even if properly faired, would induce extra drag and invoke an unacceptable penalty in performance. An internal installation would reduce the effective lens echo on account of attenuation through the glider skin.

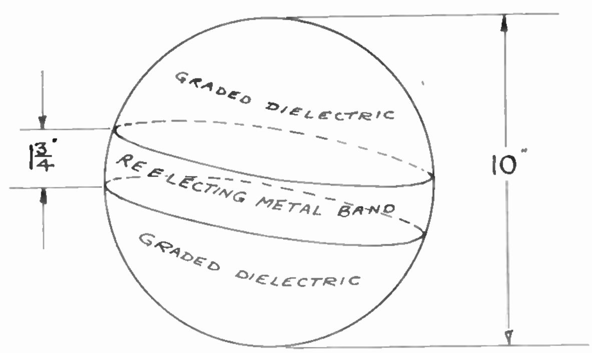


Fig. 2. A 10-in Lüneberg lens giving ± 10 deg coverage in elevation.

Thus although a 10-in lens might just provide sufficient echo at X-band, albeit over a restricted angle of elevation, the echo would be far too small at S-band. A larger lens would invoke an unacceptable weight penalty.

In view of these considerations, and also the probable excessive cost of a Lüneberg lens, this solution was discounted as a practical proposition.

4.3. *Conducting Paints*

The feasibility was investigated of spraying all or part of the glider surface with a conducting paint. It was thought that a metal-loaded paint might be made sufficiently conducting for this purpose. However, the binder in such paints is an insulating material, and normally if the metal content, e.g. aluminium or zinc, of a metal-loaded paint were to be so increased that the paint became conducting, it would no longer be stable and would be quite unsuitable for use on gliders.

The only known exception to this rule is the silver lacquer, Eccocoat CC-2, which has an organic resin base and is used as a conductive coating for, e.g. waveguides and radar dishes. However, ideally 1 lb of paint, costing £20, would be needed to cover 1 square yard, and the total surface area of an average size glider is of the order of 80 yd^2. Therefore, although it is possible that technically this paint would provide an acceptable solution, the cost would be far too high, even if only a fraction of the surface—say a quarter—were to be treated.

4.4. *Corner Reflector Assemblies*

Finally, the possibilities of corner-reflector installations in the fuselages of gliders were investigated. It was thought that such a solution might be feasible, since, for example, a single corner of 12-in side would theoretically exhibit a maximum echoing area at S-band of almost 4 m^2, the specified figure. Several corners would, of course, be required to provide adequate echoes at all azimuthal angles.

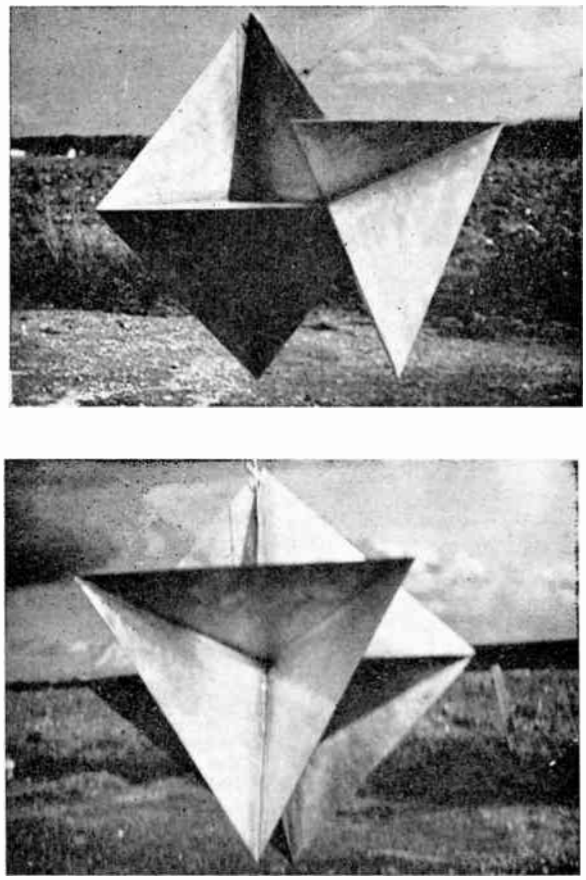


Fig. 3. Assembly of five 8-in corner reflectors.

4.4.1. Experimental installation in *Sky* glider

An experimental assembly consisting of five 8-in corner reflectors, designed to give a reasonable directivity pattern over an angle approaching 180 deg in azimuth was constructed. At X-band its echoing area was found to reach maxima of the order of 13 m^2 —rather higher than the theoretical value for a single corner. The assembly is shown in Fig. 3.

At about this time the rear fuselage of a *Sky* glider at Farnborough had been partly stripped for repairs, and advantage was taken to instal the corner reflector assembly inside the fuselage, facing aft. Since the resultant echoing area at S-band would clearly not be adequate, a similar 11-in cluster was also installed, again facing aft. In order to fit in the larger cluster, its base was rounded off to a radius of 8 in. At X-band, its mean echoing area over 180 deg in azimuth, at angles close to the horizontal, was about 10 m^2, peaking to 50 m^2. At S-band the mean echoing area was 3 to 4 m^2, peaking to 8 m^2.

The *Sky* glider, with corners installed, was measured in flight at both S- and X-bands as described in Sect. 3. The mean results obtained over several orbits at the aspects of interest from broadside to tail-on are given in Table 3.

Table 3

Mean echoing area of *Sky* glider fitted with 8 in and 11 in corner reflector assemblies

Band	Aspect		
	Broadside	Between tail-on and broadside	Tail-on
X	11 m^2	8 to 11	11
S	10 m^2	3 to 4	5

These results will be seen to be in good agreement with those obtained on the 11-in corner assembly and the enhancement in echo was of the order of the required value. This approach to the problem was promising. However, two of the larger corner clusters would be needed for all-round cover, one looking rearward and one forward. In most gliders such an installation would be impossible.

4.4.2. Experimental installation in *Eagle* glider

It was thought that equally good results might be obtained with a corner of simpler construction, comprising three rectangular plates mounted in mutually orthogonal planes, as depicted in Fig. 4. Such an assembly could be installed in the fuselage piece by piece, broken up as required to fit in the available space, and apertures or slots could easily be made if necessary to allow the passage of control cables.

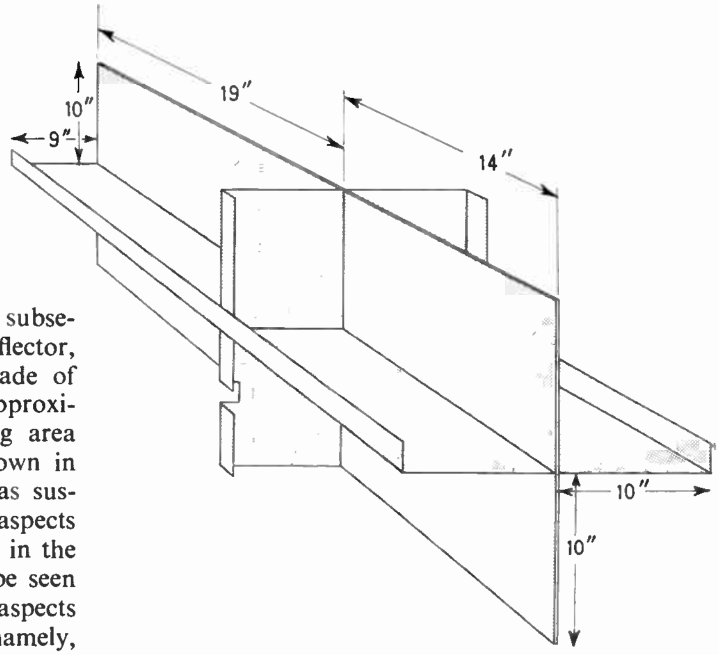


Fig. 4. Corner reflector assembly for *Eagle* glider.

An assembly of this type was constructed for subsequent installation in an *Eagle* glider. The reflector, with dimensions as shown in Fig. 4, was made of perforated aluminium sheet, and weighed approximately 1 lb. The results of S-band echoing area measurements on the corner by itself are shown in Fig. 5. In these measurements the corner was suspended in such a way as to present the same aspects to the radar as those presented when installed in the glider, with the glider in level flight. It will be seen that the best results were obtained at the aspects where echo enhancement is most needed, namely, between broadside and head-on and between broadside and tail-on.

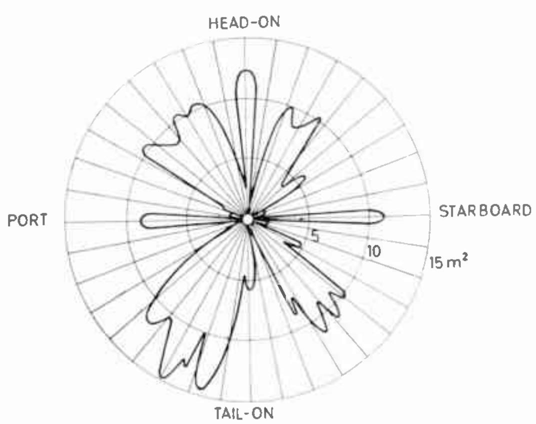


Fig. 5. S-band echoing area polar diagram of corner reflector assembly for *Eagle* glider.

The corner was then dismantled and re-assembled in the *Eagle* glider, as shown in Fig. 6, each component part being screwed to conveniently situated struts inside the fuselage. After assembly, the fibreglass skin of the glider was made good. The installation was carried out by a contractor, at a cost of about £35, including materials.

The echoing area of the glider was then measured in flight, as described in Sect. 3, and the results at S-band, together with those for an untreated *Eagle* glider, are shown in Fig. 7. It will be seen that the echoing area of the treated glider exceeded the target of 4 m^2 at almost all aspects, the lowest value being

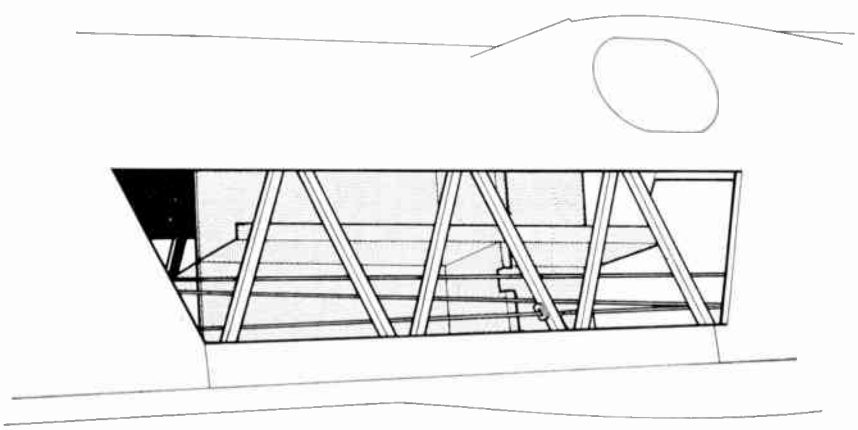


Fig. 6. Part of fuselage of *Eagle* glider, showing corner reflector assembly installed.

3 m^2. The echo enhancement was, therefore, considered adequate. The results at X-band were similar to those obtained at S-band. Although the echoing area of the corner assembly itself would be higher at X-band, presumably this was offset by increased attenuation through the skin of the fuselage.

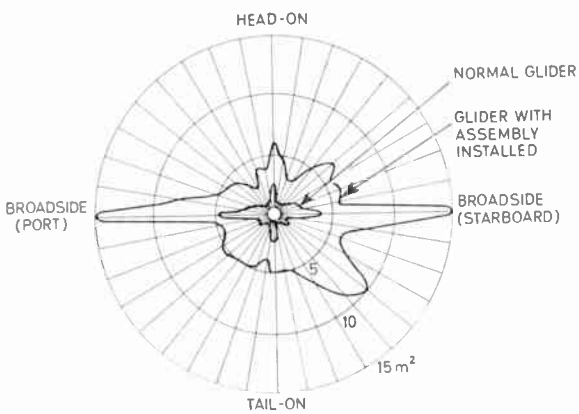


Fig. 7. S-band echoing area polar diagram of *Eagle* glider containing corner reflector assembly.

It would not be possible to fit the corner reflector of Fig. 4 into all types of glider. However, it is believed that a reflector of the same general shape, but with differing dimensions, could be fitted into any type of glider, to give the same order of magnitude of echo enhancement, the exact design varying from glider to glider. The contractor responsible for the *Eagle* installation considered that on a 'production' basis, i.e. treating many gliders, the cost per glider for a retrospective fit could be brought down to £15–£25, depending on the type. Though these figures exceed the original arbitrary limit of £5, it is thought that they would be acceptable. In the case of new gliders, where the installation would be carried out during their construction, the cost would be much lower, £4–£5 at most.

5. Conclusions

Of the various alternatives investigated, the only practical solution to the problem of echo enhancement at S- and X-bands was found to be that of fitting a light-weight assembly of corner reflectors in the rear fuselage. Adequate enhancement was achieved when one such assembly was installed in an *Eagle* glider, and it is believed that the method should be generally feasible with any type of glider.

The cost of this solution should be acceptable and, since the weight of each assembly would be of the order of only 1 lb (0·45 kg), the performance of the glider would be virtually unaffected.

Manuscript first received by the Institution on 18th January 1965. (Paper No. 998/RNA65).

STANDARD FREQUENCY TRANSMISSIONS

(Communication from the National Physical Laboratory)

Deviations, in parts in 10^{10}, from nominal frequency for July 1965

July 1965	GBR 16kc/s 24-hour mean centred on 0300 U.T.	MSF 60 kc/s 1430–1530 U.T.	Droitwich 200 kc/s 1000–1100 U.T.	July 1965	GBR 16 kc/s 24-hour mean centred on 0300 U.T.	MSF 60 kc/s 1430–1530 U.T.	Droitwich 200 kc/s 1000–1100 U.T.
1	− 149·1	− 149·8	+ 7	17	− 150·9	− 150·8	− 3
2	− 149·1	− 150·1	+ 7	18	− 150·6	—	− 1
3	− 150·3	− 149·7	+ 8	19	− 150·6	− 151·1	− 3
4	− 149·0	− 148·1	− 9	20	− 150·2	− 150·5	− 3
5	− 149·6	− 150·4	− 8	21	—	− 149·6	− 3
6	− 150·3	− 150·8	− 6	22	− 149·7	− 150·6	− 4
7	—	—	− 6	23	− 150·1	− 149·3	− 4
8	− 150·1	− 150·7	− 7	24	− 149·4	− 150·2	− 2
9	− 150·5	− 150·5	− 6	25	− 150·3	− 150·3	− 2
10	− 150·8	− 149·3	− 3	26	− 150·2	− 150·6	− 1
11	− 150·2	− 150·1	− 3	27	− 149·6	− 148·8	− 2
12	—	− 151·3	− 3	28	− 148·5	− 149·8	− 1
13	− 150·7	− 151·0	− 7	29	− 149·3	− 150·5	− 1
14	− 151·0	− 150·4	− 6	30	− 150·9	− 151·3	− 1
15	− 150·7	− 151·1	− 7	31	− 150·7	− 150·1	− 1
16	− 150·7	− 151·3	− 4				

Nominal frequency corresponds to a value of 9 192 631 770 c/s for the caesium F,m (4,0)–F,m (3,0) transition at zero field.

Note: The phase of the GBR/MSF time signals was retarded by 100 milliseconds at 0000 U.T. on 1st July 1965, and will be retarded by 100 milliseconds at 0000 U.T. on 1st September, 1965.