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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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The Presidential Address of Major-General Sir Leonard Atkinson, K.B.E., B.Sc., C.Eng., M.I.Mech.E., F.I.E.E., F.I.E.R.E.†

Delivered after the Annual General Meeting of the Institution on 5th December 1967

Resistance to change underlies many of the problems which have to be faced in our economic and working life. This attitude of mind is not only an obstacle to spending our working lives more efficiently and with greater economic advantage to all, but inhibits new thought and makes us unreceptive to the development of new ideas. Since the products of the engineer are largely responsible for improvement in the standard of living of all peoples, it is our duty to overcome resistance to technological innovation.

Because of the profound changes which technology has created in our social and economic structure there is a body of influential opinion which condemns further advances in technology and resists the changes which ensue from new scientific discoveries. One example is the criticism that has been levelled at space research without recognizing the 'fall out' benefits. Space communication can be developed to improve understanding between all peoples and remove barriers of misunderstanding. Only in this way can we increase international trade and improve the standard of living of all peoples.

Since the invention of the steam engine there have always been critics of technical advance. In our own field the development of wireless to radio and then into electronics was resisted for decades and only really prospered by the demands of ruthless war.

Obstacles to Progress

Resistance to change is invariably created because of misunderstanding and because, unfortunately, the engineer does not always adequately put over his case when endeavouring to introduce new scientific aids. So often a product is created to fulfil a function which many people regard as unessential although it may provide a more efficient way of doing things than by sheer manpower or brute force. The situation is then created where fear of temporary economic adjustment causes men to oppose new technological ideas and even to use political argument to reject means of creating cheaper production.

Part of the case for rejection of new ideas is due to the failure of the engineer in proving his case for technological innovation and also in failing to help both in education and retraining programmes.

This was indeed the background to the slow introduction of textile machinery. We have not advanced very much from this way of thinking when one realizes that today there is resistance to the use of the computer and electronic controls of all forms. Indeed this attitude is partly responsible for the slow spread of atomic power stations.

Whilst there is the odd manufacturer who resists change because he feels more sure of his prosperity by constantly churning out the same type of goods, I do not believe that this attitude is by any means typical of industry.

It scarcely applies to the electronics industry which, because of new scientific advances, is constantly meeting new challenges, but which is so often hamstrung because electronic ideas and products are all too slowly assimilated into other industries and government thinking. What industry suffers from most of all is lack of the climate of opinion which favours the adoption of new ideas and the creation of techniques more fitted to man's intelligence than the repetitive and boring tasks upon which so many men

† Harland Engineering Co. Ltd. and Simon Equipment Ltd.

are engaged. Lack of intellectual opportunity leads to unhappiness in work. This in turn leads to apathy towards responsibility and honest representation in political and economic affairs.

Is not this general attitude more responsible for the so-called 'brain drain' than lack of monetary reward? I believe that brains are like hearts—they go where they are appreciated.

Leadership is essential in all fields of human endeavour. It demands the ability to convey understanding not only of the immediate day-to-day tasks, but of the reasons for undertaking great projects of future importance. Lack of leadership accounts not only for the present muddled attitude of some of our young people, but also for our inability to convince young people of the desirability of cultivating their minds, whilst young, in preparation for a worthwhile career.

Restrictive Educational Policy

Frustration in the young is often created by the present mode of education. Wherein lies the excitement of acquiring classical knowledge?

In the past our higher educational system was primarily designed to provide men suitable for the large number of government and administrative posts that existed at home and overseas. It was considered that a classical education provided the best foundation. The situation today is very different. Many of our former overseas markets are no longer open only to us. Trade orders are so often tied to 'aid programmes' from countries larger and now richer than ourselves. Our once large overseas assets have now shrunk very considerably. If we are to survive and prosper we must reverse the accent on classical education and turn more to science and engineering, and provide men trained to invent and make goods of the highest standard at competitive prices.

The excitement of creating new tools, new machinery in this twentieth century—the technological century—can only be engendered by stimulating a love of mathematics and physics—not by revering Latin and Greek which, however commendable in humanistic studies, will never create a new bolt, screw, or transistor.

I would, however, plead that every engineer should study a *modern* language. The Council of Engineering Institutions could help by including a modern language as a compulsory subject in a C.E.I. examination. The twentieth century engineer is lost if he is not able to comprehend engineering specifications and requirements in at least one other language, such as French, German and, I am sure, Russian. In this age it has become increasingly important that engineers of all nationalities should be able to communicate clearly, and it is particularly important not only to the research and development engineer, but also to the engineer responsible for specifications and sales technique. We live by our industrial efficiency. Only by that efficiency can we afford classical studies—whether for diplomatic effort or for the occupation of the free time which technology makes possible.

As members of the great engineering profession, there is no doubt that we should do more to stimulate the minds of young people and attract them into the engineering profession by spending a little more of our time in indicating new fields of technological adventure.

The Young Engineer and his Future

On this theme I prefer not to take the traditional line of looking back to our magnificent achievements, but drawing on the influence which the radio and electronic engineer has had on the world during the last five decades to try and indicate some fields of endeavour, fulfilment of which will be a challenge to the younger engineer, and the benefits of which may affect all peoples.

On this premise I would like first to touch on the future of communications as it affects the ordinary man and woman. Are we really satisfied that we have reached the millennium in providing one or two black boxes of domestic equipment which for the ordinary person is the only audio or vision contact with the outside world—and indeed whether those few channels at present provided are really sufficient? It is not the purpose of this paper to debate the usefulness or otherwise of the programmes broadcast although it seems that the frequency spectrum is becoming crowded with similar noises! Certainly there is need to create new channels if we are to provide more broadcasting time for education and other matters.

In such a densely populated area as Great Britain—and in some other parts of the world—there is an urgent need to save all available frequencies for police, medical, aviation, defence and other essential services. Many of these needs cannot adequately be served by line communication. It is exciting, therefore, to learn that the National Electronics Council has stimulated interest in the possibility of a National Electronics Grid System and the tremendous economic advantages such a system offers to the country, apart from relieving congested wavebands.

This concept was the subject of an Address given by one of our Past Presidents, Admiral of the Fleet the Earl Mountbatten of Burma. As Chairman of the National Electronics Council, Lord Mountbatten has recently expressed the view that by using well established modern techniques, such as band-compression, pulse-code modulation and waveguides, a large capacity system of channels could be created. This would provide a channel for carrying existing and additional radio and television services together with telephone, computer access, and other business and industrial services. It could incorporate telemetering facilities and monitoring facilities for the electricity, gas, and water authorities; it could even be extended to the metering of domestic premises, so introducing considerable saving over the country by replacing the present system of personal inspection of meters.

As indicated in a recent issue of *N.E.C. Review*, the Post Office is working on this problem and, to some extent, can claim that the basis of an Electronic Grid already exists.

One hundred and fifty or more towns or cities are interconnected, not merely by telephone circuits, but by broadband multi-megahertz systems using the most advanced coaxial cable and microwave facilities. And these facilities, to an increasing extent, can carry the great variety of services that the community needs, ranging from slow control data, through telephony, to high-speed facsimile or television. In a further sense the switching and distribution networks are being developed, extended, and modernized by all the techniques available (e.g. microcircuitry, pulse code modulation, waveguides) that can contribute to business efficiency and productivity.

The capital expenditure required for covering the country will run into several hundred million pounds. A formidable sum, particularly at the present time, but the project will be spread over several years. Since costs are often the excuse for procrastination, we must hope that the separation of communication from postal services will enable the new Post Office Corporation to secure investment funds for this worthwhile project.

Apart from offering a great economic advantage to Great Britain and contributing to industrial efficiency, the project offers enormous scope for adventurous engineers.

The contribution of the electronics engineer to efficient production and the easement of human labour would in itself offer material far extending the generous time that members give to a Presidential Address. I am, however, endeavouring to illustrate the opportunities that are open to the young and adventurous engineer and will therefore content myself with two further examples outside the visual and audio means of communication.

Less than twenty years ago there were no such things as transistors. Ten years ago a transistor was regarded as a low frequency and low power device. Today they are commonplace and used in ever increasing numbers. Furthermore, the advent of new materials, in particular gallium arsenide, have made the future prospects—and applications—of solid-state devices, quite dazzling. It is possible now to envisage these devices dealing with frequencies up to 100 GHz—that is in millimetre waves—and with an ever increasing power handling capacity. One day they may well displace the magnetron and the klystron. The applications of thyristors to speed control of heavy rotating machinery are considerable and find an ever increasing application in industry where accurate speed control is required—for example in the paper, tyre and pump industries.

† 'Reorganisation of the Post Office', Cmnd. 3233 (H.M.S.O., March 1967).

Another relatively new development is the laser which already has applications in range finding, surveying, and short range but secure communication, not forgetting its use in cutting metal and in surgery. But the greatest potential in lasers may still lie in new communication techniques. As in the past, each generation believes that the ultimate in progress and invention has been reached; in fact what was wonderful a decade ago is commonplace or even out of date today. It would take an eminent seer to forecast the ultimate of thin-film electronics and microminiaturization! Surely these are exciting prospects indeed for any young man on the threshold of a career in electronic engineering.

Scientist or Engineer?

Compulsory direction into any field of activity is repugnant to us all. Nevertheless, in order to offer young people the chance of a worthwhile and lifetime career, more attention should be given to assessing the future potential of careers in all professions, including engineering. We are all aware of the dangers of overcrowding some professions and neglecting others, and of the consequent economic chaos which can arise in any country which does not produce a balanced professional community.

Unfortunately far too many young people are being advised to read such subjects as geography and economics—important as these are I find it hard to believe that there are enough commercial appointments available in this country to absorb the numbers that are today being trained for commercial, as distinct from engineering careers.

At the present time, we are experiencing in Great Britain a lamentable shortage of engineers. It is in the interests of our profession that we should do more to collaborate with teachers at all levels so that at very least our profession should attract the maximum number of young people. Moreover, it is essential that the opportunities be put over with an understanding of the background. All too often young people are being persuaded to regard themselves as budding scientists rather than as engineers, and still to regard the latter in a Victorian way as a dirty and second-class profession!

The truth is that scientists and engineers are complementary to each other; the economic fact must be faced that whilst a scientist may invent, an engineer is required to make, and that only by the wealth created by the engineer can money be afforded to help and encourage the pure scientist. It is also a hard economic fact that social improvement can only be brought about by the creation of wealth. The engineering profession makes a direct and major contribution to the creation of better economic conditions.

Perhaps we should learn from the recent decision to omit the word '*Research*' from the title of the National Electronics Research Council. In the words of the Minister of Technology: 'The rapid growth of the science and technology of electronics is one of the most striking phenomena of the present day. The continued application of electronics to more and more of the equipment we habitually use shows how our lives are being influenced to a growing extent by this new technique.'

The National Electronics Council is now more concerned with the impact of electronics on our national life, but its terms of reference still enable it to promote research *if research is necessary* to achieve the purpose of improving efficiency in any particular field.

Since the Institution is a founder member and a great supporter of N.E.C. we have now disbanded our Research Committee so that the Institution's efforts will also be more concentrated on engineering application and what I have described as 'making'. In this way we can make the maximum contribution to industrial development, co-operate fully with N.E.C. and yet have a suitable forum for the encouragement of essential research and development.

Retraining and Deployment

Thus I think we can all try to create an atmosphere where tradition and technical snobbery do not provide the background to the resistance to change. First I would mention the retraining of men who are in industries no longer offering good prospects in order to provide more manpower for an industry which has prospects for employment on a scale hitherto unknown.

In the engineering profession we have often complained that forward government planning in technology is done without the advice and help of the engineer. The exception to this rule has been in the direction and management of the Engineering Industry Training Board, for the Chairman of the Board is not only a Fellow, but a Vice-President of the Institution, and the President-elect of the Institution of Mechanical Engineers, Sir Arnold Lindley. I hope Sir Arnold will forgive me if I suggest the obvious—that the Engineering Industry Training Board should use the expertise not only of our Institutions, but of the large employers of labour, including the armed services, in tackling what I believe to be one of the country's most immediate problems—that of retraining men who possess old skills that are no longer required and affording them the opportunity of progressive employment in new technologies.

Secondly, I believe it is important that we should know whether the requirements of industry, government services, and the armed forces are being correctly assessed and whether proper use is being made of the existing professional manpower.

A recent study† concerning over 500 British Scientists who had gone to North America for reasons other than to earn more money revealed that by far the largest group went to obtain better professional opportunities.

Another survey‡ carried out on a thousand chartered engineers showed that 52% were employed on tasks not requiring the individual's abilities. They might well have been over-trained and under-employed!

I believe that large employers of professional manpower are at present tending to limit their own development because of a fetish in demanding out of all proportion to their requirements, an over-inflated demand for university graduates—not only university graduates, but university first-class honours graduates.

If we are not careful we shall be demanding in the future a major production of Major-Generals, and it will be outstanding to be employed as a private soldier!

For fear of being misunderstood I would like to express my view as applied to the professional life that I have led for over 30 years.

The armed forces have, of course, a wonderful career to offer to the young chartered engineer, but in spite of the difficulty of recruiting the right sort of man for a Service engineering life, have continued to recruit and train young men into three separate services. Indeed, one service, as far as engineering is concerned, recruits and trains into three separate corps!

All this should be viewed against the background that industry wants a growth rate of 24% per year in engineering graduates. Our training organizations are, I believe, only producing a growth rate of 14% and may not maintain that figure in the future.

As the armed forces run down to much smaller numbers and whilst agreeing that there are specialist roles to be played, I believe there must be some element of wasteful competition in recruiting men suitable for training as professional engineers within the armed services. Further, I feel that particularly in the realms of post-graduate technical training there is some duplication. This, I believe, could apply with even greater force to technicians.

† The Hatch/Rudd survey. See Appendix B, Section 2 of 'The Brain Drain: Report of the Working Group on Migration'. Cmnd. 3417 (H.M.S.O., October 1967).

‡ 'How members earn their living', *Chartered Mechanical Engineer*, **14**, p. 343, July 1967.

If the present trend of equipment development continues and equipment demarcation between the services, particularly as far as electronics are concerned, becomes less clearly defined, I believe there will be a case for securing integration or partial integration of the engineering services in the armed forces.

This will make for greater flexibility of employment, better and more economical use of the chartered engineer, particularly in the realms of the design, development and repair of equipment. In short I would support a proposal that we should consider the integration within the services of our requirement and use of engineers.

This is a natural corollary of the establishment of the Ministry of Defence and I believe that within the next decade recruitment to all three branches of the armed services could be to a single 'Engineering Service'. The requirement will be for men capable of being employed in one or more specializations, but as it happens they will be required to know more and more of the impact of electronics on engineering in general, for, as my predecessor Professor Emrys Williams said in his Presidential Address—'Electronics is the greatest intellectual "Nosy Parker" of all time!'

In the past few weeks we have had an instance of creating major industrial units simply because it has been thought that the creation of bigger units will enable the country to compete more efficiently with overseas competition. But the creation of larger units does not get down to the bedrock of making the most efficient use of present and future professional man-power.

Future Recruitment

Industry is at present hard pressed because of the lack of qualified manpower. Unless something is done now, it will be placed in an even more difficult position in a few years. Much depends, therefore, on the success of the recently created universities, polytechnics, and regional colleges of technology. I believe that the newer places of learning should concentrate on courses and degrees in engineering and technology rather than trying to emulate the pattern of degrees in general science which suited the country's needs when older universities were established.

For example, there should be variation in the type of engineering degrees; it should be possible to specialize in *engineering* management. Industrial administration is recognized as being one of the weak points in British industry, and the young man who is able to get a pass degree in the essential subjects of his engineering specialization, may turn out, if given the opportunity, to be a first-class manager instead of being a disappointed physicist or research worker.

Our Institution believes in the closest contact with polytechnics, regional colleges of technology and the universities, and I hope that during my Presidency we shall be able to encourage the development of degrees oriented toward engineering management.

Moreover, if the engineering industry is to be sustained in its effort to gain industrial superiority and the armed forces to be continually maintained in an up-to-date and efficient manner I would suggest that industry should get to know something of the underlying reasons and requirements of the government services and armed forces. It could learn much from the manner in which technical training is carried out, particularly electronics training, which is as sound and forward looking as any in the world. For instance, industry has still to realize fully the practice which has dominated the technological thinking of the services during the past two to three decades. I refer to the practice of sending suitable officers possessing the requisite qualifications on to specialized courses long after they are initially qualified.

By attending either technical or adminstrative courses throughout their careers, officers are not only kept up to date, but are able to benefit by learning to appreciate each other's problems and by the exchange of new ideas.

Leaving aside trade competition and realizing that much is already being attempted, I feel more should and could be done, as surely this whole idea of mutual exchange of knowledge could be of such enormous benefit to the engineering industry in which small and even quite large firms are so interdependent on each other.

Further, the armed forces might gain much by seeing how industry works and appreciate some of the problems of the export market.

When all is said and done one of the main reasons for the armed forces is to see that British trade can be carried on without interruption. It is perhaps as well if both sides study each other's problems and get the maximum benefit from each other.

Industry's answer, of course, particularly from the smaller firms, is that chartered engineers cannot be spared as their absence for even two or three weeks would disrupt the activities of the company. This attitude always seems strange to a serviceman, as for centuries any military organization has always had to be capable of carrying on if the top man was, for any reason, removed from his post.

Opportunity at All Levels

It is, of course, in all fields of new technology, where the shortage of chartered engineers is particularly felt. But, as I have already pointed out, this shortage is partly created by an insane love of technological snobbery, and the almost utter rejection of a principle of our national life which is 'Freedom of Opportunity'. This was better expressed by His Royal Highness the Duke of Edinburgh in his address last year to the Council of Engineering Institutions' Conference, when he stressed that professional engineers should never shut their own pearly gates to the late developer and the man who progressed in his profession by sheer hard work.

I believe it to be a major problem that many men are discontented because they have inadequate opportunity to express their ability, and to be employed up to the limit of their mental capacity.

Our Institution was one of the original founder Institutions of the C.E.I. and I think it a noble idea to bring together all disciplines to form a recognized professional activity—engineering. This idea is now being copied in many other parts of the world.

I feel however, that in achieving this very high ideal we are in danger of perpetuating the intellectual snobbery born in the Institutions many years ago. For a very long time engineering and scientific institutions have barred the technician from participating in their deliberations. Not only has this frustrated and discouraged the hardworking technician, but because every man has to find a means of self expression it has led to a proliferation of so-called engineering or scientific technical societies. We may well deny these people the freedom of opportunity within our Institutions, but we have not been able to, and I hope never will, deny them the freedom of opportunity to express themselves in other ways. The real problem is how we failed in our duty so as to make it necessary for these people to emigrate or to set about creating their own institutions and societies.

Several of my predecessors have expressed views on the moral responsibility of our Institution to encourage and help the senior technician. Without these men the electronics industry could not function, and certainly could not have grown in Great Britain. Professional engineers and technicians are interdependent and I am in complete agreement with my predecessors that we should ignore the technical snobbery of past generations by welcoming senior technicians to our meetings and letting the Institution become the forum for the necessary increase of opinion between engineers and senior technicians.

We have already taken the first legal steps to implement this point of view, and I may add that in the light of the country's manpower problem we very much hope that we shall also encourage a number of these senior technicians to continue their academic studies so that they may, in fact, qualify as Corporate Members of the Institution with the right to take part in our deliberations and counsel.

All this adds up, of course, to the fundamental question of whether in the armed services, in our public corporations, or in industry, we fully understand the economic and proper use of technical manpower.

I do not join those who think that all will be well in time. On the contrary, I think that time is now our enemy.

The Council of Engineering Institutions

I am honoured to be amongst those who helped to create the Council of Engineering Institutions, and have the privilege of being a member of the C.E.I. Board and serving on several of its Committees. I have therefore appreciated at first hand the problem that this Council has in acting as a central organization in the teaching and recruiting of engineers, publicity for engineering activities, and achieving common thought in a single examination. So much depends upon the goodwill of the fourteen Institutions who make up the C.E.I., and I am pleased to think that many of its initial problems have been solved by the understanding that it is the individual Institutions who can best influence the development of their own specializations.

To cite but one example. There would be a total loss to the engineering profession if the young man who wishes to specialize in electronics is forced to go through the preliminary training for a civil, electrical, or mechanical engineer before he is able to realize his wish to be introduced to electronics. Recognition of the individual role of the supporting Institutions means that there can be no intention whatsoever of the C.E.I. becoming a single Institution for Engineers of Great Britain but, to the contrary, it will marshal the common efforts of all fourteen Institutions to strengthening the engineering profession as a whole.

The roles of C.E.I. in controlling the central register for all engineers who have qualified for Corporate Membership of British Chartered Engineering Institutions and as being the media for expressing the viewpoint of British engineers to Government and overseas, are in themselves tremendous tasks and why we, as an Institution, are pledged to the support of C.E.I.

Returning, however, to our own country's needs, much has still to be done if we are to change the general attitude of our fellow countrymen towards our profession. Abroad, the engineer's worth has long been recognized—a fact which may well have contributed to the enormous technological progress that has been achieved in certain countries.

I have concentrated on manpower and training problems, because the creation of wealth is essentially the product of people. Raw material—of which Britain has so little—is useless unless brains are applied to its utilization.

The International Role of the Institution

I was a very junior member of the Institution's Education Committee when I learned of the Institution's intent to try and serve its members abroad more efficiently by creating Overseas Sections. This led to the creation of our Divisions and Sections overseas and, like most members, I have been delighted to learn that we have achieved further accord with our sister Institution, the I.E.E., by the agreement of the I.E.E. to share in the administrative facilities that we provide for our members in the great Indian sub-continent. This is a commendable start which I hope will be followed by other Institutions and ultimately lead to the happy co-existence of all Institutions and Societies in the British Commonwealth.

But this in itself is not enough and I hope very much during my Presidency to see an extension to our providing a broader approach between the professional engineers of the Commonwealth and Engineers of other nationalities which, in all conscience, has taken too long to develop. In short, I believe that one of the barriers to progress both in human understanding and in the employment of natural resources for the benefit of man is due to that of language. In the Institution, we are studying ways in which we can translate our proceedings and publications into other languages so that we may offer greater help and interest to engineers of other nationalities.

A start has already been made in our own Institution by the production of regular Bulletins within those Sections overseas which, as yet, are not able to justify production of their own *Proceedings* such as we publish in Britain and India. The first of these overseas news letters will be published in French at the end of this month.

In Appreciation

In attempting to cover such a wide field in the shortest possible time I may have sacrificed diplomacy for brevity. I have, however, welcomed the opportunity of putting forward some views as a basis for discussion and not in any way to give offence to others who have given much thought to education and training, industrial problems, and the future requirements of our armed services.

I began my address by referring to resistance to change. I think this can hardly be levelled at an Institution like our own where in 42 years we have made a number of changes to our Constitution, to our examination syllabus, to the conditions of election to membership. In fact we welcome change and I shall be grateful because it is perhaps one of the reasons why I have had the honour of being elected your 21st President. Even the list of Past Presidents shows how our Institution has welcomed change of thought. Our choice of Presidents has ranged from the Engineer to the Scientist, from the Professor to the Chief of the Defence Staff—all men who have made a most positive contribution to the development of our art, and I am especially conscious of the compliment now paid to my own profession and to the Corps of Royal Electrical and Mechanical Engineers.

We all tend to be dwarfed by the greatness of the past and I must admit to some qualm in inheriting the mantle which has been worn with such distinction by our Past Presidents. In the light of their example, however, I pledge myself to do all in my power to advance our profession of engineering and in particular the work of our Institution. I shall need the continued help of all members and I pray that the work of us all may justify our existence.

(*Address No. 38*)

INSTITUTION NOTICES

New Year Honours

The Council of the Institution has congratulated the following members whose names appear in Her Majesty's New Year Honours List for 1968.

Appointed Members of the Third Class of the Civil Division, or Companions, of the Most Honourable Order of the Bath (C.B.):

Captain Michael Hodges, O.B.E., R.N. (Retd.) (Fellow).

(Captain Hodges was until recently an Under Secretary in the Cabinet Office.)

Ieuan Maddock, O.B.E., F.R.S. (Fellow).

(Mr. Maddock is Controller of Industrial Technology in the Ministry of Technology.)

Promoted to Commander of the Civil Division of the Most Excellent Order of the British Empire (C.B.E.):

Edward Leslie Thomas Barton, O.B.E., E.R.D. (Fellow).

(Mr. Barton is Chief of Telecommunications (Civil Aviation) Board of Trade.)

Heriot-Watt University

Honorary Degrees were conferred by Sir Alec Douglas-Home, K.T., M.P., Chancellor of the Heriot-Watt University, Edinburgh, at a Congregation held on 3rd January 1968. Among those to be presented by the Dean of the Faculty of Engineering for the Honorary Degree of Doctor of Science were Admiral of the Fleet the Earl Mountbatten of Burma, K.G., F.R.S. (Charter President, I.E.R.E.) and Sir John Norman Toothill, C.B.E. (Companion, I.E.R.E.).

After the ceremony Lord Mountbatten formally opened the University's new 'Mountbatten Building' in the Grassmarket. This building houses the Department of Electrical and Electronic Engineering and several departments of the rapidly developing Faculty of Humanities.

The University was formerly the Heriot-Watt College, and was granted its Royal Charter in 1966.

Chartered Engineers' Registration Certificates

The Council of Engineering Institutions is now ready to accept applications for Certificates of Registration from registered Chartered Engineers who are members of the Institution of Electronic and Radio Engineers. The cost of the Certificate is £3 and a Registration Card, valid for three years, will accompany each Certificate. The Card will be renewable if desired for further three-year periods at a cost of £1 for each renewal. Application forms are available on request from the I.E.R.E., 8–9 Bedford Square, London, W.C.1, *not* from C.E.I. Remittances should be forwarded with the completed application forms.

This announcement, which is being made in accordance with a timed programme for issuing Certificates to Chartered Engineers of the fourteen Institutions, applies only to the I.E.R.E. Members of other Institutions who read this and are not also corporate members of the I.E.R.E. should await an announcement from their own Institutions before applying.

A Note for Engineers Travelling Abroad

There are members of the Institution working in almost every country throughout the World. Many members travel widely in the interests of their profession and such members can always be assured of a welcome from their colleagues in the countries which they visit.

Arrangements for meetings, whether formal or informal, between visiting members and local sections or other groups will gladly be initiated by the headquarters of the Institution or by secretaries of local sections or regional representatives. The presentation of a short informal paper is especially appreciated by members in countries where numbers are not yet large enough to support a Section.

Symposium on the *Ariel III* Satellite

Three of the papers presented at the above Symposium, which was held in London in October 1967, are printed in this issue of *The Radio and Electronic Engineer*. Further papers will appear in subsequent issues.

Reprints of these papers will be available, price 3s. 6d. each, and orders may now be sent to the Publications Department, I.E.R.E., 8–9 Bedford Square, London, W.C.1. The full list of papers is given in the reference section of the introductory paper, 'The *Ariel III* Satellite Project' (see page 17 in this issue.)

Institution Telephone Numbers

With the changeover to all-figure dialling in London, the Institution's telephone numbers are now: 01-636 1901 and 01-580 8443. The prefix 01 is to be used only for calls made from outside the London area.

U.D.C.621.37/9

The Electronics Industry: Looking Ahead with Hindsight

By

E. EASTWOOD,

C.B.E., Ph.D., C.Eng., F.I.E.E.†

Reprinted from the Proceedings of the Joint I.E.R.E.-I.E.E.-I.Prod.E. Conference on 'The Integration of Design and Production in the Electronics Industry' held at the University of Nottingham on 10th to 13th July 1967.

Summary: This opening address to the Conference points out that although progress in electronics since the end of World War II has been spectacular, its performance might have been even more impressive if a larger proportion of all the prophecies which were made of new devices, techniques, materials and functions had come to pass. Some of these hoped for developments are discussed and the reasons for their unfulfilled promise suggested.

Lessons learned from this study of the past include the importance of both technical timeliness and commercial timeliness and can be applied to present-day forecasts of probable developments. Guide-lines for the future include the digital concept rather than the analogue, parallelism rather than serialism; and the importance of achieving function without the limitations of circuits.

Introduction

This Conference on 'Integration of Design and Production in the Electronics Industry' is most timely because it has now become apparent to all that the era of electronics based on solid-state devices has truly arrived: no longer can transistors be buttoned on to equipment designed around thermionic tubes. The forward look in electronics has become dominant and perhaps, for this reason, it is not wholly inappropriate that a research man should be invited to give the opening address. But prophesying must always be leavened with the experience gained from hindsight, hence the title of this address.

I speak as a research man whose function it is to help to inform and guide management so that one decision of vital importance to the company might be correctly made. I refer to the choice of the right product, and the product chosen must be right in its performance, price, styling and makeability. Right, also, in its timeliness and suitability for the market—a market that may already be in existence or one which has been created by the device itself. The industrial research man, like his colleagues in development, design and production, lives in an atmosphere of time and cost, and the ultimate success of an electronics firm in the market place requires rightness also in the subsequent development and production of a well chosen product; this is only achieved by close harmonious working of all those who make up the electronic team.

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We have become used to rapid change in electronics, whether in devices, equipment, or in the operational functions they are intended to fulfil. In the form of radio, electronics was first applied to the solution of the communication problem, but in its later manifestations electronics is no longer limited to the transfer of information but also to its generation, processing, interpretation and display. So rapid has been the progress in electronics in the years since the war that we have come to accept with equanimity such advances as satellite communications, colour television, computer control of air traffic, road traffic and industrial processes generally. We almost cease to marvel that refinements in electronic measurement technique begin to make nanoseconds appear as gross intervals of time, while electronic measurements of other physical quantities have become equally refined.

Perhaps electronic engineers have every reason to be pleased with themselves, but complacency born of success is hazardous to continued health and growth, and so we would do well to remember that the real contribution of electronics towards uplifting substantially the total productivity of the country has yet to be made. Perhaps it will help to preserve humility if we remember that the first industrial revolution was based on mechanics and that mechanization has been the major reason for increase in productivity in both agriculture and the manufacturing industries since the war.

Many of us will remember that there was a great deal of electronics in being before World War II, based though it was on the thermionic tube. Thus, radio in the m.f. and h.f. bands was well established; television as a public service was initiated in 1936; radiograms were commonplace items of furniture in most homes. Radar was in being but was not publicized, communications by radio, line and cable were fully established. Even more significantly, the basic physics of the solid-state was well advanced. Certainly the electronics explosion which now faces us was not foreseen in those pre-transistor days, but good electronic engineering existed and was finding wide application in industry, also in comforting and assisting man in his daily life.

What is the reason for the transition from the pre-war era of modest electronic activity to the present phase of electronic dominance in so many fields? It is clear that the change in the electronic scene has been provoked by war and fear—World War II, Korea, Space and the Cold War have all provided their stimuli—but if I were asked to name three dominant factors that have contributed to the transition, I would give the following:

Firstly, the full understanding of the servo-control process and of the system concept of which it is part. There can be little doubt that the wartime need for control of radar aerials, anti-aircraft guns, bomb sights in aircraft, etc., prompted detailed study of the science of control.

Secondly, the development of electronic techniques deriving from the transistor, which was itself born from the radar crystal mixer. It is the emergence of the transistor and the microcircuit that have permitted the accumulation of electronic elements into complex electronic systems able to fulfil a multiplicity of functions—just as the association of biological cells in their differentiated form leads to the human body with all its capabilities.

Thirdly, the emergence of the high-speed digital computer. The mechanical computer and its electro-mechanical counterpart existed pre-war as did also various electrical analogue computer devices, but the creation of a digital electronic computer by F. C. Williams and others produced the essential nerve centre for the operation of the electronic control process in its widest aspect.

Higher productivity in industry can be achieved in various ways; the application of electronics is one such method, but I think it is true to say that the key to the second industrial revolution, or the automation age, which is now with us, is the science of control as it is now capable of being practised with the aid of the products of the new electronics, such as improved sensors, computers or visual displays. Notice that I place emphasis on the *functions* these equipments fulfil—a modern device is not to be regarded as a mere bundle of interconnected circuits; perhaps this is the most important guide-line to the electronics of the future.

It is this broad electronic systems market which we in the industry are endeavouring both to create and to satisfy—but is the rate of innovation matched to the market potential? Putting the question more crudely—have we got the correct balance and closeness of communication between research, development, design and production to ensure that our inventive output is exploited to the full in the markets of the world?

Innovation and the Future of the Electronics Industry

I suggest that we might now examine briefly this question of innovation and the future of the electronics industry in terms of some of the 'rightness criteria' mentioned earlier. We will all agree that it is easy to compile an impressive list of discoveries and inventions made during the last twenty years which were all relevant to the electronics of the day. Pride of place must be given to the point contact transistor of 1948 and its subsequent progeny—integrated circuits, m.o.s.t.'s, tunnel diodes, Gunn diodes, varactors, thyristors—a positive Pandora's box of solid-state devices! On the system side—the Doppler navigator, computers, tropospheric scatter and H_{01} communications, colour television, to mention but a few—with applied physics contributing its quota in masers, lasers, electroluminescence, fuel cells, ferrite devices, cryogenics, holography. All these advances have been important, but all have not been equally successful in securing the progress of the electronics industry.

Some of these innovations were made in response to a specific need, to solve a particular problem; more often they resulted from the interaction between the single creative mind and the corpus of basic scientific knowledge. Unfortunately, inventions cannot be made to order, and when made, they have to be assessed carefully to decide whether the investment demanded for their development and application is likely to result in commercial success. We would like to know if any broad principles exist which could conceivably guide such a selection. First, let us consider the rightness of timing.

Technical Timeliness

Timeliness is important in both the technological and commercial aspects. You will remember that Archimedes made the proud claim that he could lift the Earth by the use of the lever. Unfortunately the technology of the time was not able to provide him with either the fulcrum or the lever of sufficient length. Similarly, the materials science of classical times was not able to supply Icarus with a firm anchorage for his ornithoptic wings, with the result that he shed his wings after an impious flight too near the Sun, and the life of this early aviator was brought to a premature close.

I have already stressed the importance of the computer to the modern world, but the computer is not new. Arithmetic engines existed in the 18th century. The proposals put forward by Charles Babbage in 1822, however, first for his Difference Engine and later his Analytical Engine, were not for a mere arithmetic machine, since it contained all the logic functions of the modern computer, with store, 'mill' (arithmetic unit), control unit, print-out, etc. The input of the machine was intended to be carried out either by setting numbers on the storage wheels by hand or by means of punched cards derived from Jacquard's automatic loom. Babbage devoted the majority of his working life to the perfecting of his computing engine and he was well aware of the significance that his creation would have for the future development of science and technology. Thus wrote Babbage[1] to Brewster in 1822:

> 'Thus, you see, one of the first effects of machinery adapted to numbers has been to lead us to surmount new difficulties in analysis; and should it be carried to perfection, some of the most abstract parts of mathematical science will be called into practical utility . . . and if the absence of all encouragement to proceed with the mechanism I have contrived, shall prove that I have anticipated too far the period at which it shall become necessary, I will yet venture to predict that a time will arrive when the accumulating labour which arises from the arithmetical applications of mathematical formulae, acting as a constantly retarding force, shall ultimately impede the useful progress of the science.'

Babbage even succeeded in persuading the Government of the day to make a contribution of £17,000 on the grounds that his machine could contribute to the calculation of astronomical and navigational tables. Thoroughly modern also was his recognition of the importance of 'fall out' and the method of securing cross-fertilization of design and production, which is the subject being considered by the Conference to-day. Babbage[1] wrote:

> 'During the many years the construction of the Difference Engine was carried on, the following course was adopted. After each drawing had been made, a new enquiry was instituted to determine the mechanical means by which the several parts were to be formed. Frequently sketches, or new drawings, were made, for the purpose of constructing the tools or mechanical arrangements thus contrived. This process often elicited some simpler mode of construction, and thus the original contrivances were improved. In the mean time, many workmen of the highest skill were constantly employed in making the tools, and afterwards in using them for the construction of parts of the engine. The knowledge thus acquired by the workmen, matured in many cases by their own experience, and often perhaps improved by their own sagacity, was thus in time disseminated widely throughout other workshops. Several of the most enlightened employers and constructors of machinery, who have themselves contributed to its advance, have expressed to me their opinion that if the Calculating Engine itself had entirely failed, the money expended by Government in the attempt to make it, would be well repaid by the advancement it had caused in the art of mechanical construction.'

Although a portion of the Difference Engine which Babbage built still exists in the Science Museum, his project failed because it was too far in advance of the technological capabilities of the day. The whole of his logic had to be executed by means of gear wheels and levers and such mechanical elements could not be made accurately enough to achieve his total purpose.

Another invention whose technical timeliness was not suited to the technology of the day is that of pulse-code modulation (p.c.m.) by A. H. Reeves. This basic invention was made in 1938 while Reeves was working in the Paris laboratory of the I. T. & T. organization.[2] His was the concept of converting an analogue signal, such as speech, into a sequence of quantized sampling signals. This new system of information transmission was interference resistant and was clearly foreseen to have wide application in telephony. Nevertheless, it has taken the best part of 30 years for the prediction to be realized. It is really only with the invention of the transistor and the integrated circuit that the economic application of p.c.m. to commercial circuits has become possible, but it is now very clear that there is a bright commercial future for this method of communication.

Even radar may be held to have suffered from imperfect technical timing, in that Marconi and others could clearly foresee the possibility of reflecting radio waves from ships whose positions it was desired to determine, but the techniques of the day were not matched to the system requirement.

Commercial Timeliness

Commercial timeliness, of course, is equally important with technological timeliness and sometimes a brilliant invention fails to come to fruition because it is not timed to meet a market need. Such an example is provided by the work carried out some 10 years ago initially at the Bell Telephone Laboratories and subsequently in many laboratories all over the world on low-loss waveguide transmission for communication purposes. The general properties of the low-loss H_{01} mode of waveguide transmission had been known for many years and serious studies began some 20 years ago on the methods of utilizing this system of transmission in wideband communication circuits capable of handling 10,000 to 100,000 simultaneous telephone channels.[3] The crux of the problem was the design and manufacture of suitable waveguides; these were ultimately made from a helix of fine wire or, alternatively, a simple copper tube internally coated with a layer of dielectric. Several experimental communication projects using this waveguide are still being evaluated but the commercial incentive for the commercial exploitation of this system is not as pressing today as was once thought likely. The advent of satellite communication systems capable of fulfilling some of the same high capacity communication objectives has diverted attention from the H_{01} system. In addition, recent advances in laser optical generators suggest that other more economic wideband communication methods might ultimately be available. Thus, although the long-term need for increased communication facilities is still with us, H_{01} may not necessarily provide the most economic means of satisfying this requirement.

We have applied the criteria of timeliness to assess the suitability of an invention to the technology and to the market, but timeliness applies equally to the 'makeability' of the proposed device or equipment, which means that it should be matched to the production methods of the day, as the following familiar case history will illustrate. As the complexity of electronic equipment has increased during the last 20 years, so there has been growing recognition of the importance of the inter-connection problem. Probably the metal-sprayed circuit boards of J. A. Sargrove in 1946 were the earliest essay of industry to achieve integral wiring.[4] This was followed by the first printed boards which were a development intended to overcome the variability and unreliability produced by conventional wiring. This method also enabled the use of mechanical wiring techniques and consequently reduced costs. In parallel with this were many attempts at the mechanization of component handling, i.e. the bending of the component wires and their insertion in holes in the printed board. The printed board was definitely found to lead to better repeatability of performance, sometimes even better performance, and reduction in cost. Many problems encountered in the mechanization of the soldering processes were found and overcome. Unfortunately, the reliability of the components was not matched by that of the connections used to unite them. Modern multilayer boards carry on the battle, invoking the computer to aid the design and subject also to the rigorous discipline of automatic testing—a vital need in all branches of electronics. Under the impetus of the missile and avionics programme, a trend towards miniaturization, and later, micro-miniaturization, developed, the main objective being a substantial reduction in the size of sub-assemblies. This led to the several electronic packaging techniques, known as 'Cordwood' and 'Tinkertoy'. Later an extension of these techniques led to the famous micromodule programme of the U.S. Signal Corps.

In constructing a micromodule the required number of types of micro-elements were assembled by stacking them according to the desired circuit function, welding wire risers to the appropriate element ends; the assembly was tested and then encapsulated to provide a solid body 0·35 in square and varying in length according to its content. A great variety of micromodule elements were designed and produced. Resistor elements were made by vacuum deposition of nickel-chromium alloy on both sides of a high density alumina substrate. Multi-layered capacitive modules, which consisted of integrally fired sandwiches of dielectric and conductive electrodes, were also produced. Other microelements included transistors, semiconductor diodes, etc.

This concept was clearly a great advance on former techniques both in the standardization of parts, the reliability of the components and also in its obvious potential for automatic assembly. Towards the end of the programme, however, the great possibilities inherent in integrated circuits, in terms of the likely improvements in packaging density by two orders of magnitude, and, more importantly, the great potential for drastic cost reduction due to the application of bulk production techniques, whereby many tens of devices could be manufactured simultaneously on a single chip, led to the virtual abandonment of the project. It had become clear to the majority of workers in the field that the micromodule concept had been overtaken by a superior technique. Many good ideas which depend on difficult-to-master technologies may well be made obsolete by later developments long before they have become practical.

In an introductory paper such as this it is not possible to go into all the factors which can cause a technical environment to be favourable or unfavourable to the success of an invention, but passing mention should be made of the science of materials, since future developments for electronics are likely to be heavily dependent upon progress in this field. Studies now in progress on metal-oxide-silicon systems and silicon nitride spring immediately to mind. The science of materials as a discipline has largely been prompted by the progress in solid-state physics, which has been responsible for materials purer in content and more perfect in form than any substances previously known to man. The study of materials is vital to progress in microelectronics and even the potential importance of an invention such as the fuel cell will not be realized until there is an answer to the catalyst problem which can only come from the study of materials and the properties of surfaces.

Electronic engineers are masters of many crafts; chemistry and electrochemistry must now be included amongst their skills if they are to be the successful chemical sculptors of the functional devices of the future.

Rightness Criteria of the Future

Although I have not quoted sufficient examples to permit rightness criteria for the future to be extracted from them, I think there are one or two broad conclusions we can draw.

First, I would suggest that equipment and device proposals for the future are likely to be based on the digit concept. The generation and handling of information is the essence of electronics and the lesson of the past is that the method of treatment should be based upon the handling of digits rather than analogue wave-forms. I am not saying that linear circuits will disappear but I am saying that the quantization of information and its expression in terms of digits is likely to dominate electronic equipment in the future.

Second, I would proclaim my adherence to the principle of parallelism rather than serialism. In the development of digital computers and data processing and communication devices generally there has been continuous controversy concerning the relative merits of parallel and serial modes of operation. Parallelism in design requires greater amounts of equipment whereas serialism calls for higher speed in operation. However, it is clear that the computer is now suffering from the time delay of 1 foot per nanosecond which is imposed by the finite velocity of light. Nature contrives things differently and by using parallel feed of information into the brain and parallel processing, we find that many types of operation can proceed faster in the brain than in a computer, in spite of slow speeds of transmission of signals along nerve fibres and that the logical decisions themselves are comparatively slow. The principle of parallelism also lends itself readily to the inclusion of redundancy—which is one excellent way of ensuring reliability. Both these principles are practised in the brain, which, incidentally, seems to use ionics rather than bionics or electronics in order to achieve both conduction and insulation.

Parallelism as a principle applies also in production; the point-contact transistor did not lend itself so readily to mass production as does the modern integrated circuit, where large numbers of elements upon a single slice of silicon can be handled simultaneously. The electron beam method, which is being explored at the present time in various circuit fabrication methods, would seem to suffer from being in essence a serial device, whereas optical methods of mass production do possess the virtues of parallelism. In like manner, flow soldering is to be preferred to spot welding.

Even the electrical circuit itself, on which most of our technology is based, seems to suffer by leading inevitably to serialization of interconnection between the succession of circuits which make up a complex equipment. The various advances in active electronic devices from thermionic tube to the transistor to the micro-circuit, have permitted increased functional capability to be built into our equipment, but has demanded more and more elements to be connected together in order to achieve it and it is this mass of connections which limits, in the last resort, the reliability of the system as a whole. This is what is meant by the 'tyranny of numbers'—a descriptive phrase which can be applied to many pieces of modern electronic equipment. Even though the cost of transistors, for example, has been decreasing exponentially with time, the cost of encapsulation and of subsequently handling each component tends to remain the same, so that serialization of electronic equipment also brings with it high costs as well as inherent unreliability. This is because we are enslaved to the electronic circuit and liberation can probably only come by moving to a philosophy of design which emphasizes the function to be performed by an element.

It is true that the numbers barrier is being penetrated to some extent by current approaches to large-scale integration in which design is moving from the component level to the circuit level. With the better understanding and control of materials and processes, the numbers barrier will doubtless be pushed back still further, but it would appear that the law of diminishing returns will operate and so functional complexity will have reached a plateau by these techniques. What is needed is a form of molecular architecture that will permit function to be achieved without the limitations imposed by circuits as we now know them. J. A. Morton[5] is an ardent advocate of a research policy which looks for new energy–matter relations at the molecular level in order to achieve function as in the laser and maser. Examples of this approach have long been familiar in the piezoelectric and magnetostrictive resonators and delay lines which replace large numbers of lumped circuit elements and save size and cost as well as improving performance.

Conclusion

The examples I have given of some successful and unsuccessful ideas of the past years suggest that there are one or two guide-lines which can, at least, help us in the search for those forms of invention that will produce advance of the electronic industry. I would give pride of place to the concept of timeliness. The new idea, if it is to succeed, must have technical and commercial timeliness; in the technical sense it must not make demands that are too high to be met by available techniques; in a competitive world an excessively long lead time can nullify the effects of a good idea. This may mean that during the long development time that then ensues other and better ideas may come to the fore or the needs may change. Commercial timeliness means that the market is willing to receive the products derived from invention.

The probability of success of a timely invention is also enhanced if it satisfies some of the rightness criteria given above. Amongst these I would include the digital concept where information is handled in bits rather than in analogue form. The emphasis of parallelism over serialism in the information flow is a principle which also lends itself to the embodiment of a measure of redundancy which will aid the achievement of reliability.

Finally, it would seem desirable to stress the importance of function in any electronic configuration rather than the circuits by which it is achieved in order that we might ultimately release ourselves from the limitations of circuits and their interconnections.

It is said that the path of progress in pure science is strewn with dead or dying hypotheses. Their presence is indicative of man's use of experiment and the scientific method. Similarly, progress in technology is marked by inventions, some of which have never succeeded, but others have flourished and become the bright beacons which beckon us on. Perhaps, as engineers, we should comfort ourselves with the advice of Robert Louis Stevenson as expressed in his essay on El Dorado: 'To travel hopefully is better than to arrive and true success is to labour.'

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STANDARD FREQUENCY TRANSMISSIONS

(Communication from the National Physical Laboratory)

Deviations, in parts in 10^{10}, from nominal frequency for December 1967

December 1967	24-hour mean centred on 0300 U.T.			December 1967	24-hour mean centred on 0300 U.T.		
	GBR 16 kHz	MSF 60 kHz	Droitwich 200 kHz		GBR 16 kHz	MSF 60 kHz	Droitwich 200 kHz
1	−300·2	−0·1	+0·1	17	−300·0	0	+0·1
2	−300·0	−0·1	+0·1	18	−300·0	0	+0·1
3	−300·1	−0·1	+0·1	19	−300·0	−0·1	0
4	−300 0	−0·1	+0·1	20	−300·1	−0·1	+0·1
5	−300·0	−0·1	0	21	−300·1	−0·1	+0·1
6	−300·0	0	0	22	−300·0	−0·1	+0·1
7	−300·2	−0·1	0	23	−300·0	−0·1	0
8	−300·1	−0·1	0	24	−300·1	−0·2	0
9	−300·1	−0·2	0	25	−300·2	−0·1	0
10	−300·1	0	0	26	−300·2	−0·1	0
11	−300·2	−0·1	0	27	−300·1	−0·1	+0·1
12	−300·1	−0·1	+0·1	28	−300·2	−0·1	+0·1
13	−300·1	−0·1	+0·1	29	−300·0	0	+0·1
14	−300·0	0	+0·1	30	−300·0	−0·1	+0·1
15	−300·1	0	+0·1	31	−299·2	−0·1	+0·1
16	−300·0	0	+0·1				

Nominal frequency corresponds to a value of 9 192 631 770·0 Hz for the caesium F,m (4.0)–F,m (3.0) transition at zero field.

Notes: (1) All measurements were made in terms of H.P. Caesium Standard No. 134 which agrees with the NPL Caesium Standard to 1 part in 10^{11}.

(2) The offset value for 1968 will be −300 parts in 10^{10} from nominal frequency.

U.D.C. 629.19

The *Ariel III* Satellite Project

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Presented at a Symposium on 'The Ariel III Satellite' held in London on 13th October 1967

Summary: *Ariel III* carries equipment from five scientific groups in the U.K. to measure ionospheric and high atmosphere properties. The project management structure is described.

The spacecraft configuration evolved from two fundamental requirements—spin stabilization and power supply by solar cells. The evolution of the structure and sub-systems, together with the operation of various mechanisms, is outlined. The reliability, needed and achieved, of electronic ground equipment is stressed, and operations at the Western Test Range are discussed.

The choice of orbit was a compromise between several experimental requirements and the capability of the *Scout* launch vehicle. Data acquisition and processing are discussed.

1. Introduction

The present successful Anglo-American co-operative space research programme has developed from the offer of the United States in 1959 to launch, without charge, scientific instruments or complete spacecraft designed and made in other countries. The *UK-3* spacecraft, launched into orbit by a *Scout* rocket from the Western Test Range in California on 5th May 1967, was the third in the series of satellite launchings for the United Kingdom. Once in orbit the spacecraft was renamed *Ariel III* and it is now the first satellite in space to have been designed, manufactured and tested in Great Britain. Canada, Italy and France have also had their own satellites launched under similar co-operative agreements with America.[6]

The two earlier satellites in the Anglo-American programme, *Ariel I*[1,2,3] and *Ariel II*,[4,5] were launched successfully on 26th April 1962 and 27th March 1964, and for these the spacecraft were made in America to carry the British-built experiments.

The *Ariel III* satellite is now providing an earth-orbiting platform for measuring and transmitting back to Earth a number of physical parameters that cannot be deduced from ground observations. After the successful launch the satellite systems and the scientific payloads all operated correctly within their design specifications and vast quantities of data have been, and still are being received, processed and evaluated. These data when processed into digestible form will be made freely available to the world-wide scientific community by the publication of papers and the deposit of basic data with the N.A.S.A. Data Centre.

This paper outlines some of the many facets of the *Ariel III* satellite programme but omits any description of the electrical and communication systems in the spacecraft and of the individual scientific payloads, as these are described in detail in other papers presented at a symposium held in London in October 1967.[20-31]

2. Scientific Objectives

During 1962 the Royal Society British National Committee on Space Research invited scientific proposals from British Space Research Groups for inclusion in the proposed *UK-3* project. The final selection agreed with the American National Aeronautics and Space Administration involved experiments from five groups. The *Ariel I* and *II* satellites had each contained experiments from three Space Research Groups.

The payload objectives of each Space Research Group in *Ariel III* are detailed below together with an indication of the previous experience of the Group.

University of Birmingham, Department of Electron Physics:[27]

(i) Measurement of electron density.

(ii) Measurement of electron temperature.

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‡ Programme Manager—*Ariel III*, Science Research Council, London, W.C.1.

(Previous experiments in the *Ariel I* and *FR-1* satellites and also in the British, French and American Sounding Rocket programmes.)

Meteorological Office:[28]

(i) Measurement of the vertical distribution of molecular oxygen in the 100–200 km region.

(Previous experiments in the *Ariel II* satellite and in the British and E.S.R.O. *Skylark* Sounding Rocket programmes.)

University of Manchester, Jodrell Bank, Nuffield Radio Astronomy Laboratories:[29]

(i) Measurement of sky 'brightness' in the 2·0–4·7 MHz band.

(ii) Measurement with low resolution of the distribution of such radiation across the sky.

(iii) Measurement of such radiation originating within the ionosphere.

(Previous experiments in the *Ariel II* satellite and the British *Skylark* Sounding Rocket Programme.)

University of Sheffield, Department of Physics:[30]

(i) Measurement of the spatial and temporal characteristics of natural v.l.f. radiation.

(ii) Measurement of the field pattern of the GBR 16 kHz transmission.

(Previous experiments in the British and E.S.R.O. Sounding Rocket Programmes.)

Radio and Space Research Station of the Science Research Council:[31]

(i) Measurement of h.f. atmospheric noise to deduce the distribution of noise sources (lightning discharges) over the surface of the earth at different times of day and seasons of the year.

(ii) Measurement of the attitude of the spin-axis of the satellite.

(Previous experiments in the British and E.S.R.O. Sounding Rocket Programmes.)

3. Management of the Project

The division of responsibilities for the project between America and Britain was defined during 1962–63 in letters exchanged between the National Aeronautics and Space Administration (NASA)[6] and the Space Research Management Unit (S.R.M.U.), which was then part of the Office of the Minister for Science.

The agreements specified that America would supply the *Scout* rocket and the Range support for launching and also the separation and tie-down system between the fourth stage of the vehicle and the spacecraft. In addition, America accepted responsibility for providing the necessary tracking and data acquisition support after the launch of the spacecraft.

For the first time the United Kingdom accepted responsibility for the supply of the complete spacecraft and the provision and operation of the associated ground handling and check-out equipment at all stages of the project. As on the previous *Ariel* projects the United Kingdom remained responsible for the scientific payloads, the processing of the telemetry data and the publication of the scientific results.

The organizational structure of the project is outlined in Appendix 1. The Goddard Space Flight Center (G.S.F.C.) were assigned the overall management responsibility in the U.S.A. and in Britain the co-ordination of the project was the responsibility of the Space Research Management Unit (S.R.M.U.). There was a continual exchange of technical information. Ten months before despatch of the spacecraft to the launching site a design review lasting several days was carried out by an independent team from G.S.F.C. and seven months later a flight readiness review was carried out on a somewhat similar pattern.

The Ministry of Technology acted as the agents of the Science Research Council for all aspects of the work associated with the spacecraft, with the exception of the supply of the scientific payloads which was the responsibility of the individual space research groups. The Royal Aircraft Establishment, Space Department, were appointed as the research, development and design authority. The Ministry Headquarters negotiated and controlled the major contracts with Industry for the completion of the work and valuable support was provided by the Ministry Inspectorates.

It is accepted that one of the key problems of any scientific space research programme is to achieve adequate communication with the staff of the different groups constructing their payloads. It is vital that they fully understand the mechanical, electrical and data interfaces that have been set out for them and that their own special requirements are in turn fully appreciated by the spacecraft and systems engineers. In addition, it is important to make available to these groups specialist advice on such topics as the selection of components and procedures for environmental testing. The responsibility for achieving successful communication with the experimenters is one of the main roles of the S.R.M.U. in the British Scientific Space Research Programme and for *Ariel III* it was possible to appoint as experimenter co-ordinator a senior engineer from the S.R.M.U. who had similar experience on the earlier *Ariel II* programme. A description of the technical problems covered is given in a supporting paper.[20]

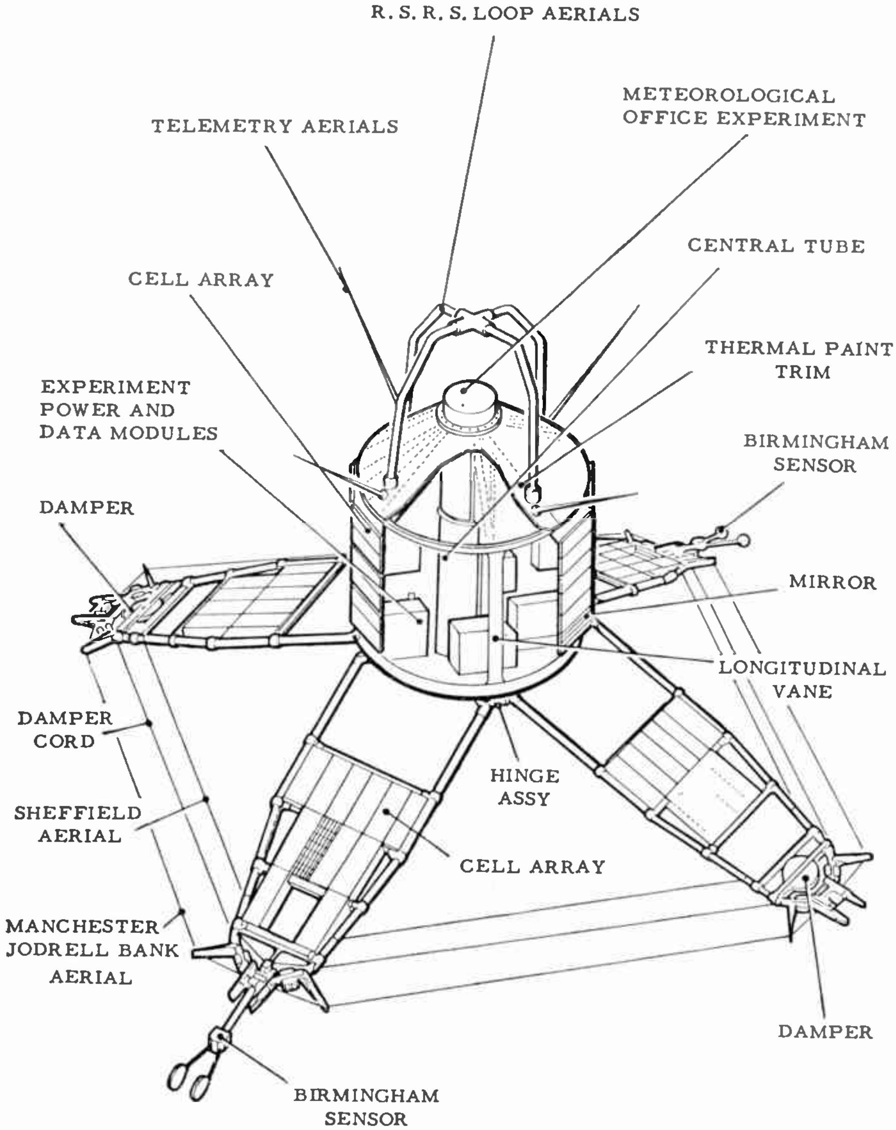

Fig. 1. Final configuration of *Ariel III.*

4. Spacecraft Evolution

4.1. *Configuration*

The shape of the spacecraft and the form of structure and equipment installation were designed to suit the requirements of the experiments while meeting the restraints of structural strength, thermal control, power supplies, communications, installation and access.[7,8] An early decision was made that the satellite should be stabilized only by spin and that its power supply should be derived from solar cells. The cylindrical body shape surmounted by a truncated cone was accordingly designed to give the optimum area for solar cell mounting, an adequate field of view for the Meteorological Office experiment, a simple thermal design and maximum use of available space inside the *Scout* rocket nose cone.

A primary purpose of two of the four booms is to support the electron temperature and density probes where body proximity effects are small. The booms are also essential, however, to ensure that the spin moment of inertia exceeds that around the other two axes; in this way the stability of the spinning satellite is assured. Advantage was taken of the booms to support the v.l.f. and radio astronomy loop aerials which are strung loosely around the extremities to become circular as the satellite rotates.

The booms also carry solar cell arrays on each face to supplement those on the body. In deriving the boom geometry it was important to optimize both the shape of the booms and their angular setting with respect to the satellite body in terms of minimum shadowing of the solar cell arrays by parts of the satellite. The technique adopted called for the photographing of a model and the analysis of shadow patterns in several hundred aspects.[9]

The final configuration (Fig. 1) was achieved some two years before expected launch.

4.2. *Structure*[10]

The body is about 33 in (84 cm) high by 28 in (71 cm) diameter and consists of a central torque tube whose lower end carries the flange which mated the spacecraft to the fourth stage adaptor. Four vanes riveted to the tube provide fixings for installed units. The body is closed top and bottom by a lightly constructed cone and diaphragm respectively. The cone was locally stiffened to carry the four telemetry aerials and the terrestrial noise crossed-loop aerial system. The underside of the diaphragm carried the umbilical and other electrical connectors.

The vanes were supported at their outer ends by upper and lower strong rings which provided handling and lifting points. The four boom hinge blocks were fixed to the lower strong ring. Four doors, carrying the body solar cell arrays, and giving access to the body, were fastened by screws to the strong rings and the vane edges.

The booms, each approximately 48 in (122 cm) long, consisted of a tubular frame with bracing members which acted also as the mountings for the double-sided solar cell trays. All four booms were geared to the body at the hinges to ensure simultaneous erection, following a suspected non-simultaneous erection of booms on *Ariel I*. At two boom ends were carried the electron density and temperature sensors on 12 in (30·5 cm) extensible arms, and on the other two the escapement mechanisms which controlled deployment rate (see Sect. 4.3).

It was decided at an early stage to minimize structural development by use of aircraft and guided weapons design and manufacturing techniques. The spacecraft was therefore constructed mainly of sheet and tube high-strength aluminium alloy with riveted joints. Where great rigidity and stiffness were needed, as at the equipment mounting vanes in the body, and the solar cell trays, resin-bonded aluminium honeycomb was used. The need to keep structure weight to a minimum strongly influenced the design at all stages.

The provision of a large mounting area on the vanes proved its worth at a stage of the project when the shape and size of installed units was changing rapidly.

To minimize eddy-currents, leading to perturbing magnetic torques, the upper cone was insulated from the remainder of the structure, except at one point. Whether or not this was sufficient may be resolved when current investigations into *Ariel III*'s spin-axis precession in orbit are concluded.

In stressing the structure, static loading safety factors of 1·125 to 1·25 were used and most components exhibited reserve factors of up to 2. However, the low mass of the structure led to quite low resonant frequencies (35 Hz in the case of the booms in launch configuration) and dynamic loadings were generally taken as design cases.

The mass properties of the whole spacecraft were predicted from the outset and the predictions updated as design, manufacture and test proceeded. At a later stage measurements were made to supplement the data. The properties of most interest were:

(a) Spacecraft mass: to keep it within launch vehicle payload limits.

(b) Dynamic balance in launch configuration, i.e. booms tied down: spacecraft must not unbalance fourth stage motor whose trajectory is spin-stabilized.

(c) Static and dynamic balances in orbit configuration, i.e. with booms erected: spacecraft must not cone or nutate outside narrow limits, otherwise aspect sensor and experiment data may be compromised.

(d) Moments of inertia about three principal axes: the ratio I_{spin}/I_{yaw} must not fall below unity or spacecraft will not maintain stable attitude.

Needless to say, these factors interact so that, for example, the necessary addition at one stage of ballast at the boom tips to maintain the inertia ratio (d) produced a critical all-up mass situation (a) and reduced the margin for adding balance weights to satisfy (b) and (c) to the closest degree.

Improvements in vehicle performance in the course of the project enabled the mass to be increased from a 150 lb (68 kg) target to an actual 197·7 lb (89·6 kg) at launch (Table 1). The increase was only held to this figure by reviewing the design at several stages to reduce weight.

Table 1

Orbital mass history—*Ariel III*

Date	Structure inter-connections, etc. (lb)†	Power supply and data sub-systems (lb)†	Experiment sub-systems (lb)†	Total (lb)†
January 1963	70	48	32	150‡
March 1964	82	80	48	210‡
June 1965	73	60	39	172‡
May 1966	82	63	33	178‡
December 1966	95	67	36	198

† 1 lb = 0·453 kg. ‡ Estimated.

4.3. *Mechanical Sub-systems*[11]

No mechanism was required to operate once the satellite was in orbit, but several sub-systems had to act in sequence during the orbit injection phase. Their operation was controlled by a timer mounted in the *Scout* adaptor section, designed and built by the Goddard Space Flight Center, which fired explosive devices to initiate the appropriate sequences.

After the first three stages of the *Scout* had burned and just before the third separated, the fourth stage with spacecraft attached was spun-up to about 160 rev/min to maintain its orientation while burning. After fourth stage-burn-out it was necessary to reduce the spin-rate. This was done in two stages:

(i) by yo-yo deployment[12] which reduced the rate to about 90 rev/min,

(ii) by boom erection, which brought the spin-rate down to the 30 rev/min required to maintain satellite attitude.

The yo-yo system, originally developed by NASA, consisted of two wires wrapped round the lower outer ring of the body with weights of about 2 oz (56 g) at their ends. On receipt of the timer impulse the weights were released to fly out under centrifugal force, unwrapping the wires as they went. The inner ends of the wires were free to separate from the spacecraft, so that angular momentum was discarded and the spin-rate reduced. Much development effort went into establishing the correct bob-weight/wire mass ratio so as to give uniform unfurling.

The boom ends were tied down around the fourth stage motor during launch. The tie-down cord was released after yo-yo de-spin and the booms rose under centrifugal force, to be locked into position by detents at the end of their travel. A major problem was the developments of satisfactory damper mechanisms to prevent structure damage as the booms reached their stops. Detailed consideration was given in turn to energy dissipating devices such as tension wires;[7] hydraulic and impact dampers[9] and escapement mechanisms.[10] The latter were adopted and two were fitted, one at each boom tip, paying out a Terylene cord at a controlled rate. Extensive trials in vacuum were needed to develop the correct materials for the gear train and bearings, unlubricated operation having been specified to ensure that no contamination of experiment sensors would occur.

The electron density and temperature probe arms were turned through 180° by springs as the booms erected.

The deployment of the Sheffield and Jodrell Bank loop aerials gave rise to much development. The difficulty here was that tangling of the loops in the early stages of the erection might prevent full deployment and cause damage. In the final system elastic straps retained the loops to pegs near the boom roots. As the booms erected the straps slipped off the pegs and the loops were flung out by centrifugal force between the partly opened booms. The success of this system was shown by means of high-speed films taken during test.

The final operation initiated by the timer was the separation of the satellite from the spent motor by means of springs in the adaptor section, to give a separation velocity of about 6 ft/s (2 m/s).

At a very late stage (in September 1966) it was decided to fit solar aspect mirrors to the body of the satellite. Six serrated mirrors in the form of plates equal in size to solar cell trays were mounted. Their settings were adjustable by means of spring-loaded screws and a collimation procedure enabled their angles to be set in relation to the spacecraft spin-axis.

4.4. *Electrical Sub-systems*

The electrical sub-systems of the satellite (Fig. 2), all of which are the subject of companion papers which follow this introduction,[21–24] are mentioned here for completeness. The power supplies, data handling and telemetry equipment designs were based on those established by NASA for *Ariel I* and *Ariel II*. Considerable development took place, however, in all areas both to meet the special requirements of *Ariel III* and to take advantage of improvements in the 'state of the art'.

The tape recorder may be singled out for special mention. The machine is an improved version of that designed by NASA for *Ariel II;* its development and construction by R.A.E. and A.W.R.E. imposed many novel problems. It was fitted inside the central torque tube to minimize angular acceleration effects.

4.5. *Interconnections*

To standardize manufacture, to simplify the task of integrating installed equipment on an extended time scale and to allow for the quick replacement of faulty sub-units, it was decided to make all electrical interconnections by means of a single cableform with plug/socket terminations. Initially, power supply leads were not screened and signal leads were. As integration proceeded the need to introduce electrostatic and magnetic screening around further leads and branches of the cableform appeared; the proprietary high-permeability wrap-on foils proved invaluable.

The wires were crimped to the connector pins. Quality was maintained by destructively testing one joint in every ten from each wireman. Continuous pin-to-socket retention tests were also carried out.

A high degree of redundancy was employed in both wires and pins. Shrinkable plastic sleeves protected the cable/connector joints and gave them mechanical

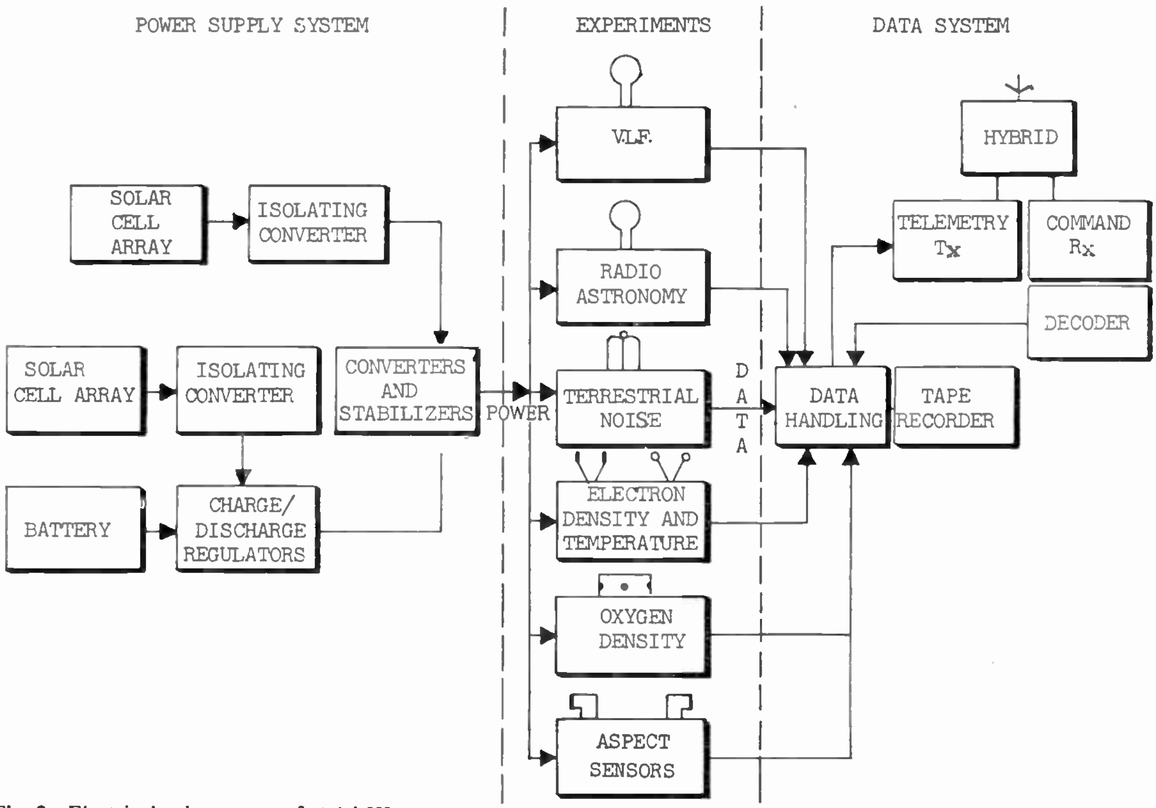

Fig. 2. Electrical sub-systems of *Ariel III*.

strength. These measures were successful in maintaining reliability except as regards certain coaxial connectors where many problems arose in the termination of wires and braids. Special modifications were devised for these cases.

4.6. *Mechanical Development Testing*

The mechanical development model (D1) was the first full-size satellite to be built. It was correct in all structural and mechanical features but embodied only dummy masses in place of the electrical units. It underwent a very full series of vibration tests up to and beyond prototype levels (i.e. 50% above flight level). Some failures were experienced leading to redesign of parts of the structure, after which the tests were successfully completed.[10, 13] An important output of the tests was data relating to the vibration environment at the equipment mounting points. This was made available to unit designers and experimenters to serve as the basis of their qualification specification.

The boom deployment system was evaluated on D1 using a spin machine which has been developed by B.A.C. Angular and linear acceleration tests were also performed to simulate vehicle motions. The D1 satellite proved invaluable for working up handling and mechanical test procedures and for packaging development.

4.7. *Electrical Compatibility*

The most intractable problem in developing *Ariel III* was the achievement of complete electrical compatibility between sub-systems. This arose from the wide frequency range and extreme sensitivity of the experiment receivers.[14]

The D2 development model was built to be electrically representative, both as regards structure and interconnections; it was used for compatibility tests, and later for initial solar illumination trials.

A later review paper will deal in detail with integration and compatibility.[25] It is worth noting that the experimenters ultimately reported receiver noise figures for satellite-mounted equipment equal to or better than those obtained in the laboratory.

4.8. *Life*

The design life of the satellite is one year in orbit. Reliability studies on the life expectancy of the whole satellite were somewhat inconclusive because failure data in the space environment were lacking, particularly in the case of electromechanical and structural parts.

A pair of end-of-life timers (Bulova electromagnetic) was fitted to meet C.C.I.R. regulations. They were timed to interrupt power to one of the two transmitters after two years. Until then, either transmitter may be selected for service by ground command. Transmission will be terminated when desired by switching to the 'dead' transmitter.

5. Spacecraft Manufacture and Test

5.1. *Manufacture*

In addition to the D1 and D2 models mentioned above three flight standard models were built. These were the prototype (P1) used for design qualification, the flight model (F1) and the flight spare (F2). Every care was taken to see that the three spacecraft were identical so that tests on the prototype would be valid for the flight models.

The experimenters undertook their own manufacture, generally with the aid of sub-contractors experienced in space experiment work. All other manufacture was undertaken by Ministry of Technology contractors who operated under the close supervision of the Director General of Inspection, Ministry of Technology, who created a special organization for the purpose of establishing and maintaining standards of quality.

All manufacturing organizations set up special clean areas for satellite work, generally supplied with temperature controlled and filtered air. Operators were selected and trained to undertake high quality work; the wearing of protective clothing was mandatory.

The basic finish of the outside of the spacecraft was gold to provide a conducting surface for ion-sweeping purposes in connection with the electron density experiment and to give suitable thermal characteristics. Achieving a uniform and blemish-free gold plated finish proved to be very difficult. Development tests had indicated that electro-deposited gold on a nickel substrate would be satisfactory, but it turned out that little experience existed in industry of techniques for plating areas of the order of several square feet to the required standard.

Another set of problems was met in applying the special black and white thermal control paints. The susceptibility of the painted and plated finishes to dirt and grease marks called for the development of protective masks and over-coats which were removed shortly before launch.

The fragility of the solar cell arrays also called for the provision of protective covers to minimize damage while the satellite was being handled and worked on.

As a final check that all inter-module wiring for the solar cell arrays had been correctly carried out, complete doors and booms were illuminated in a rig built for the purpose and voltage/current plots taken as the load was varied between zero and infinity.

5.2. *Test Procedure*

The progressive evaluation procedure was applied. In this, each minor unit must be qualified by tests at appropriate levels before it is added to the major assembly, which itself undergoes qualifications, culminating in tests of the complete spacecraft.

After development, two phases of test were distinguished: design qualification and flight acceptance.[15] In the former, weaknesses in the design were sought out by applying environments which were more severe than those expected during transportation, handling, launch and in orbit. The overtest in the case of mechanical environments was generally 50%. In climatic conditions a figure of 10 degC above maximum and below minimum predicted temperatures was usually applied.

Flight acceptance tests were carried out at the actual severities expected during launch and in orbit, so that not only the severity but also the range of tests was reduced. Great care was always taken not to overtest flight hardware.

Functional performance was required to be demonstrated before and after the environmental exposures. In some cases, such as thermal vacuum, the spacecraft was operated during the test. The prototype underwent approximately 300 hours of thermal vacuum cycling during which it was operated in all modes to simulate function while in orbit. The r.f. telemetry and command links were used in conjunction with ground checkout equipment to provide a running performance monitor.

A complete series of de-spin, boom deployment and separation tests was also carried out on the prototype at various spin rates to simulate failure conditions and to exercise back-up modes of operation.

The full range of tests is shown in Appendix 2.

A general reduction in fault incidence from test to test as the project advanced demonstrated that the required level of reliability was being achieved (Table 2).

Table 2

Ariel III fault incidence during test programmes

Test	Prototype	Flight 1	Flight 2
Integration	23	23	8
Vibration	14	5	1
Thermal vacuum	13	2	5
Total	50	30	14

5.3. *Miscellaneous Tests*

5.3.1. Magnetic moment measurements

It was calculated that a permanent magnetic moment around the satellite spin axis greater than 300 dyne cm per gauss would result in an undesirably high spin axis precession rate. Measurements of permanent and induced moment made in the special rig constructed at R.A.E. for the purpose gave initial figures of the order of several thousand dynes cm per gauss. 'Deperming' with an alternating field of 25 gauss peak was only partly successful in reducing the moment, and it was decided to fit nulling permanent magnets along the spin-axes of the F1 and F2 models (Table 3).

Table 3

Reduction in magnetic moment—F2 model

Space	Total permanent field strength (gauss cm^3)	Induced field strengths (gauss cm^3) at 0·48 oersted X-axis	Y-axis	Z-axis
As received	5570	770	830	900
After demagnetizing at 50 Hz to ±25 gauss	640	870	970	1160
After demagnetizing and adding nulling magnet along Z-axis	520	940	950	1200

5.3.2. Vehicle compatibility—fit

The P1 model was transported to the Ling-Temco-Vought works at Dallas, Texas, where it was fitted to the fourth stage motor and the heat-shield attached. No fouls were found in spite of the very close clearances which existed between *Ariel III* and its vehicle. A heat-shield ejection test was then carried out.

5.3.3. Vehicle compatibility—radio frequency interference

The spacecraft was operated in all modes when fitted to the rocket, primarily to ensure that the payload would not interfere with any of the vehicle firing and guidance circuits. The possible effect of vehicle signals on the spacecraft during the launch phase was also recorded.

5.3.4. Tracking network compatibility

At the Goddard Space Flight Center, Maryland, P1 transmitted telemetry signals to local STADAN receivers and also received commands from a typical transmitter. The field strengths at the STADAN receiving aerial and at the satellite command receiver at extreme range were simulated as accurately as possible.

5.3.5. Solar spin

The final test carried out at Goddard was the operation of P1 under real solar illumination while spinning at the orbital rate of 30 rev/min. This was done on a rig whose solar aspect could be altered. The purpose of the test was to prove that the power regulating and control system would not be adversely affected by any spin modulation impressed on the solar cell arrays. The test was completely successful.

6. Ground Support Equipment

6.1. *Ground Check-out Equipment*[16]

The check-out equipment was designed to support satellite tests proceeding simultaneously in several areas, as well as to provide the necessary test facility during range preparation and final countdown. Not only was it arranged to supply external power to the satellite but it was also capable of receiving spacecraft signals either by line or r.f. link, decommutating the data channels and displaying them in a variety of ways for quick-look purposes. The equipment also enabled permanent records of satellite behaviour to be made on paper and magnetic tape.

Two identical sets of equipment were provided, each consisting of a trailer housing the data recording facilities and heavier items, and a three-rack mobile equipment operating close to the satellite and providing a diagnostic and display service. Several panels from the mobile equipment were installed in the blockhouse consoles at the range to control spacecraft operation at the launch pad.

The reliability of the ground check-out equipment was such that no test or launch operation over a period of two years suffered significant delay by reason of a ground support fault.

6.2. *Handling Equipment and Packaging*

A great number of stands, trolleys, lifting beams, containers and other devices were made to enable the satellite to be supported in a variety of ways for assembly, test and transport.

Although *Ariel III* was a difficult handling proposition by reason of its awkward shape, very little damage was in fact done to satellites in handling; this was achieved by strict adherence to drills on the part of the highly trained mechanical group.

6.3. *Mechanical Test Gear*

A variety of special-purpose test gear was constructed, including:

(*a*) A spin and deployment rig incorporating gravity negating springs to simulate the erection of the booms in zero-*g* conditions.

(*b*) A rotator for positioning the spacecraft in any aspect to the Sun for solar illumination tests.

(*c*) A yo-yo deployment test rig on which the de-spin mechanism could be explosively released in the open air and system operation monitored by means of high-speed cinematography.

7. Launch Operations

7.1. *Launch Vehicle*

The *Scout* launch vehicle consisted of four solid-fuel stages having the characteristics shown in Appendix 3. The first three stages were programmed to achieve the desired orbital height and inclination, and spacecraft orientation. After a coasting period the fourth stage was fired to boost the spacecraft to orbital velocity, stability being maintained by spinning up to 160 rev/min under the thrust of four tangentially-mounted motors.

The choice of height for heat-shield ejection was a compromise of some delicacy. If too low, the payload may suffer aerodynamic heating, if too high, orbit height will be sacrificed. The *Ariel III* heat-shield was jettisoned at 300 000 ft (91 km).

The sequence of vehicle events for the *Ariel III* launch is shown in Appendix 3.

7.2. *Range Preparation*

Most of the work in the initial phase was done in the large NASA spacecraft assembly building at the Western Test Range. Ground check-out equipment was installed there and the P1 satellite used to prove it, so as not to risk flight satellites on untried test equipment or movements. A good deal of time was devoted to integrating the spacecraft and vehicle countdown procedures, both of which had been prepared in detail beforehand. The F1 and F2 models were thoroughly tested using the local screened room and then minutely cleaned and inspected.

Two weeks before launch the F1 spacecraft was finally weighed under close supervision of the vehicle authorities and mated to the fourth stage motor and flight adaptor already mounted on the table of the Gisholt spin balancing machine. The boom tie-down cord and support cradles were fitted and the assembly underwent dynamic balancing. Little adjustment was, in fact, needed to the spacecraft following its balancing operations in the U.K. A dummy heat-shield, flushed with nitrogen, was fitted to the assembly to protect it against atmospheric contamination, as it was moved to the *Scout* launch pad.

Immediately before the upper half of the heat-shield was assembled, the electron temperature spheres were replaced with specially cleaned ones and the oxygen density ionization chamber protective covers removed. The heat-shield was purged with clean dry nitrogen until launch.

Two days before launch all operations were practised, including the erection of the launcher from its horizontal to its vertical position. The exercise proved useful in enabling interfering signals received by the satellite to be identified to vehicle sources.

7.3. *Countdown*

The disposition of personnel is shown in Fig. 3. Technical control of both spacecraft and vehicle operations took place in the blockhouse but overall control was vested in the U.K. and U.S.A. representatives at the Mission Director Center. The intercommunication network enabled experimenters and design consultants to discuss a situation with any or all stations. Print-outs of satellite data received by r.f. link from the pad were made continuously available to them from Trailer 1. Trailer 2 provided a quick-look service to the spacecraft controller.

The countdown (Appendix 3) commenced at 03.00 hours and terminated at lift-off at 09.00 hours Pacific Daylight Time on 5th May 1967. It was carried out exactly as planned.

7.4. *Post Launch*

The NASA telemetry station at the Range tracked the satellite past third-stage burn-out, and a down-range ship recorded signal strength during injection. By studying the spin-rate derived from radiation diagram inequalities it was hoped to diagnose any fault occurring in the de-spin and boom erection sequence. The spin-rate of the satellite was soon seen to be near its predicted value of 30 rev/min, however, and all systems were working. Local radar observations showed that the track and velocity of the vehicle to horizon were correct.

Confirmation of these facts was obtained when *Ariel III* signals were received and replay was successfully commanded during the 3rd and 4th orbits passing the Winkfield, Berkshire, tracking station.

8. Orbit

The orbit that can be achieved with a launch vehicle of known performance is dependent on the weight of the spacecraft, the permissible flight paths at different ranges and the day and time of the launch. For *Ariel III* the final 'orbit requirement' was a much-argued compromise between the conflicting desires of some of the experimenters. As the requirement evolved during the project NASA agreed to move the launch from Wallops Island on the east coast of America to the Western Test Range in California. This change enabled the inclination of the orbit to be increased from 58° to 80° so that the satellite could collect data over the magnetic poles during a period of increasing solar activity. The difference between the final requirement and the orbit achieved is shown in Table 4 together with an indication of how the main orbit parameters have changed with time.

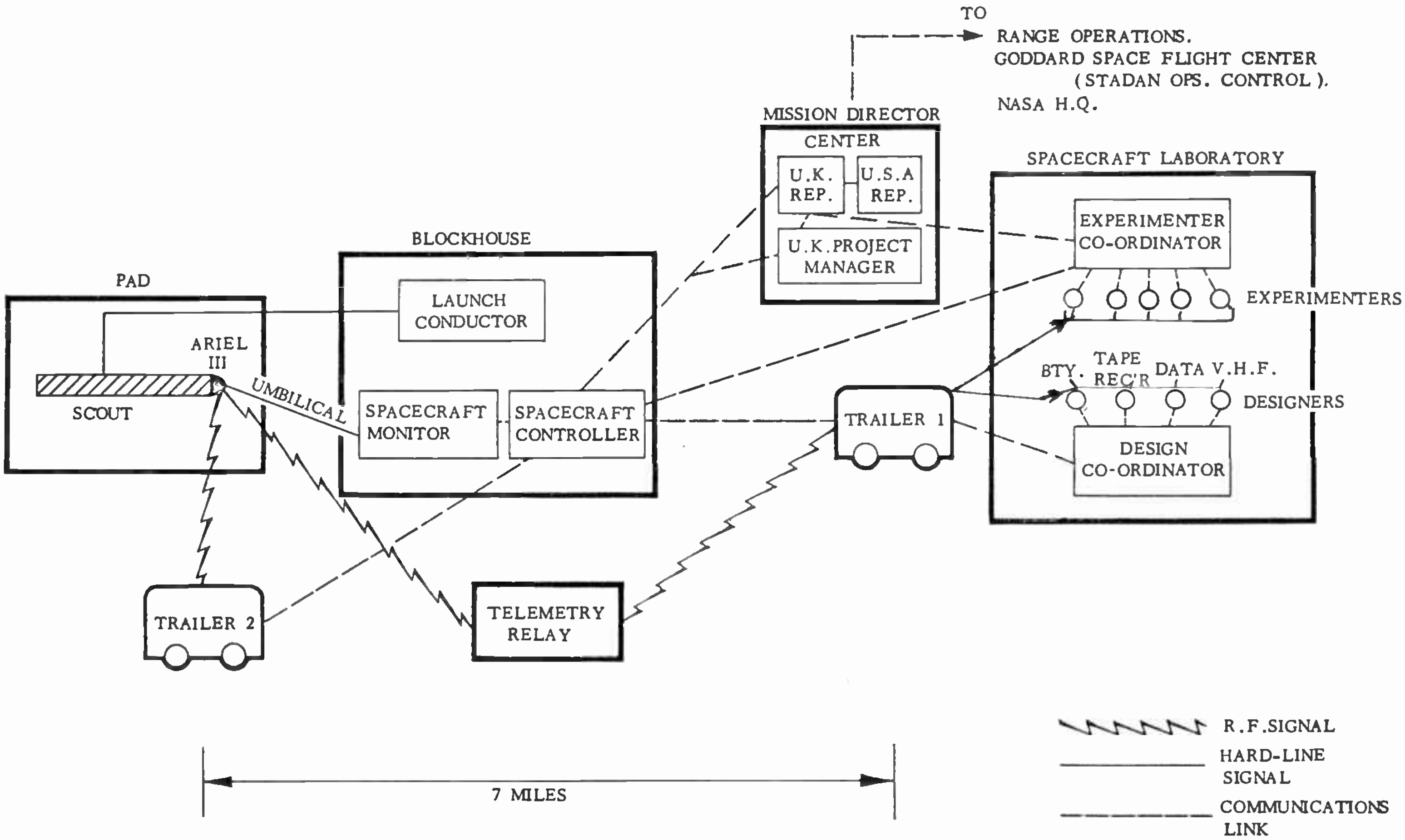

Fig. 3. Control during countdown.

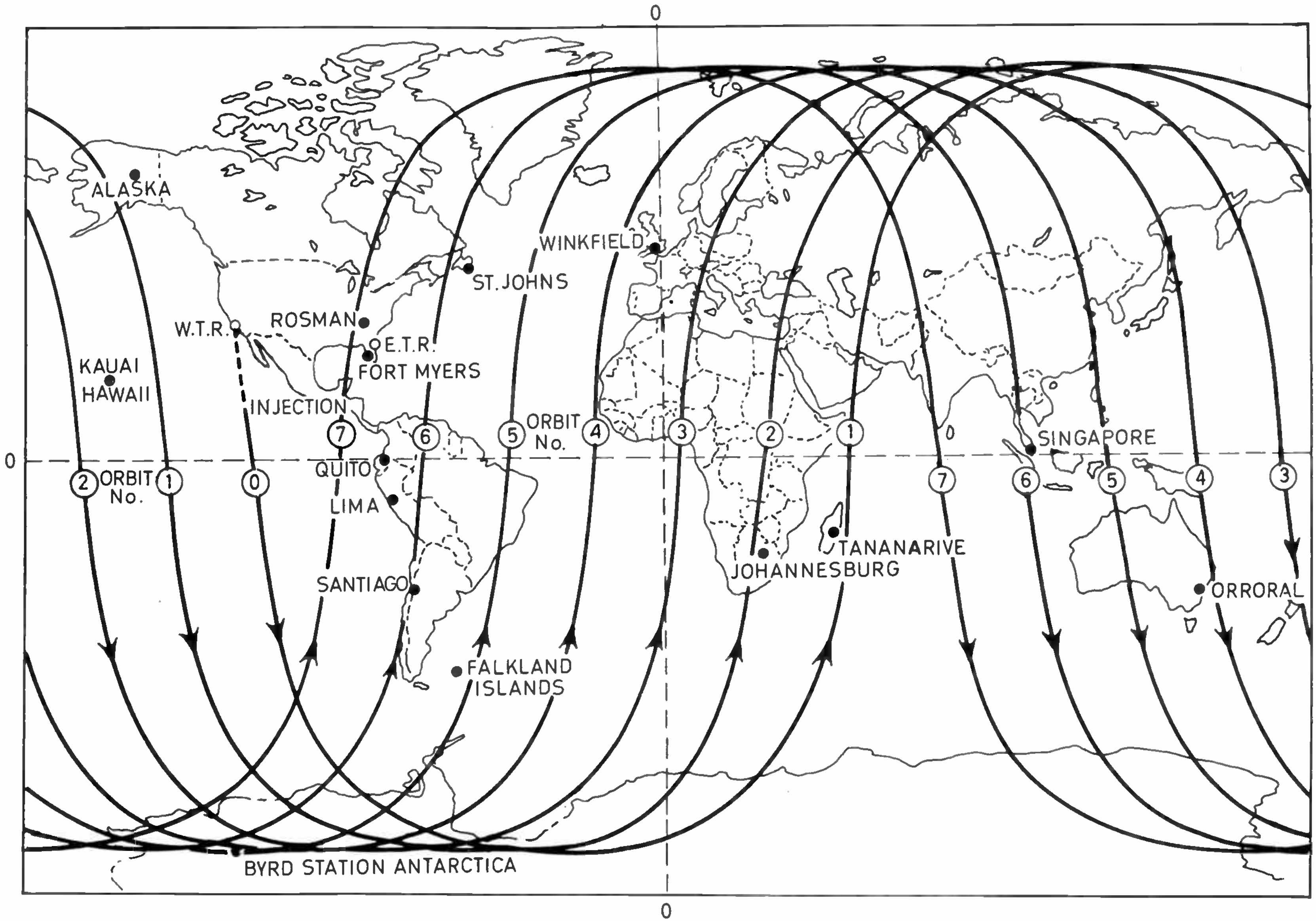

Fig. 4. *Ariel III* sub-satellite plot.

Table 4
Ariel III orbit data

	Final requirement	Orbit achieved	Orbit on 15th September 1967
Time of launch (hour G.M.T.)	1600 to 1630	1600	—
Date of launch	5th May 1967	5th May 1967	—
Height of apogee (km)	550	600·42	592·28
Height of perigee (km)	550	494·47	491·78
Inclination (degrees)	80 ± 1	080·181	080·184
Angle between satellite spin-axis and Sun line (degrees)	90 ± 10	90	>136°
Period (minutes)	—	95·599	95·486
Spin rate (rev/min)	30 ± 6	30·8	22

The orbital plane regresses at approximately 1·3 degrees per day due to the oblateness of the Earth and the Earth moves approximately 1 degree per day with respect to the Sun. These motions are in opposite directions so that the orbital plane moves at about 2·3 degrees per day with respect to the Sun line. In terms of local solar time at a specific location this means that an identical overhead pass would be 10 minutes earlier each day and hence full 24 hour coverage of a location takes about 2½ months. The movement of the satellite over the surface of the Earth is illustrated in Fig. 4. which gives the sub-satellite plot for the first seven orbits after launch.

When the angle between the orbital plane and the Sun line exceeds about 70 degrees the satellite will be in continuous sunlight. The *Ariel III* orbit entered this 'all Sun' condition on its seventh day in orbit and remained in it for a period of 19 days, some 300 earth orbits. After this, the period the satellite was in the Earth's shadow during each orbit slowly increased to a maximum of 35 minutes during the last few days in June.

To maintain inertial stability about the spacecraft spin axis a final spin rate after boom deployment of 30 rev/min was selected and this also provided an acceptable scanning rate for the Meteorological experiment. The spin rate is now decaying in orbit at a somewhat faster rate than anticipated.

9. Tracking and Data Acquisition

The moment the launch vehicle lifts from its launcher the whole balance of effort on a satellite project undergoes a major change. The staff who have been working, possibly for years, on the design, testing and final checkout of the spacecraft have completed their task, and, given satisfactory performance from the launching vehicle, the responsibility for the continuing success of the project moves over to those responsible for the tracking and the reception of the transmitted data from the satellite.

For *Ariel III* this task is being undertaken by the Satellite Tracking and Data Acquisition Network (STADAN) of NASA which is controlled from an Operations Center in the Goddard Space Flight Center (G.S.F.C.). The twelve stations of the STADAN network (Fig. 4) are being supplemented for *Ariel III* by the R.S.R.S. stations at Singapore and Port Stanley, Falkland Island and for several weeks after the launch the Stanford University station at Byrd in the Antarctic also co-operated by arrangement with the U.S. National Science Foundation. The tracking system uses an interferometer in which directional information is obtained from measurements of the phase difference between the satellite signals received on a spaced aerial system.[17]

Prior to the launch the nominated G.S.F.C. Tracking Data Manager produced for these stations an Operations Plan giving detailed information about the project and the method of implementing the tracking and data acquisition requirements. The criteria for data acquisition were provided by the U.K. and this was interpreted into detailed instructions in the Operations Plan.

Several days before launch each station was provided with predictions based on the nominal pre-launch orbit so that they knew when and where to 'look' for the satellite. These predictions enabled the early passes of the satellite to be acquired by the stations scheduled for the task. After launch, as orbit parameters are computed from the tracking data sent by the stations to G.S.F.C., the predictions are updated by sending amendments back to the stations.

The whole system worked outstandingly well and the daily coverage exceeded expectations. During the first three months after launch the average number of satellite passes recorded each day was 37 and during some 17 of these passes the tape recorder 'replay' command was sent. This means that on each day there was nearly total coverage of all orbits at the low-speed data rate obtained from the on-board tape recorder and approximately 6–7 hours of high-speed data obtained from the satellite when it was within reception of the different stations.

The replay commands are sent one minute before the closest approach of the satellite to the station and the low-speed data stored on the tape recorder take just under two minutes to be played at 48 times its recording speed. The station magnetic tape for such

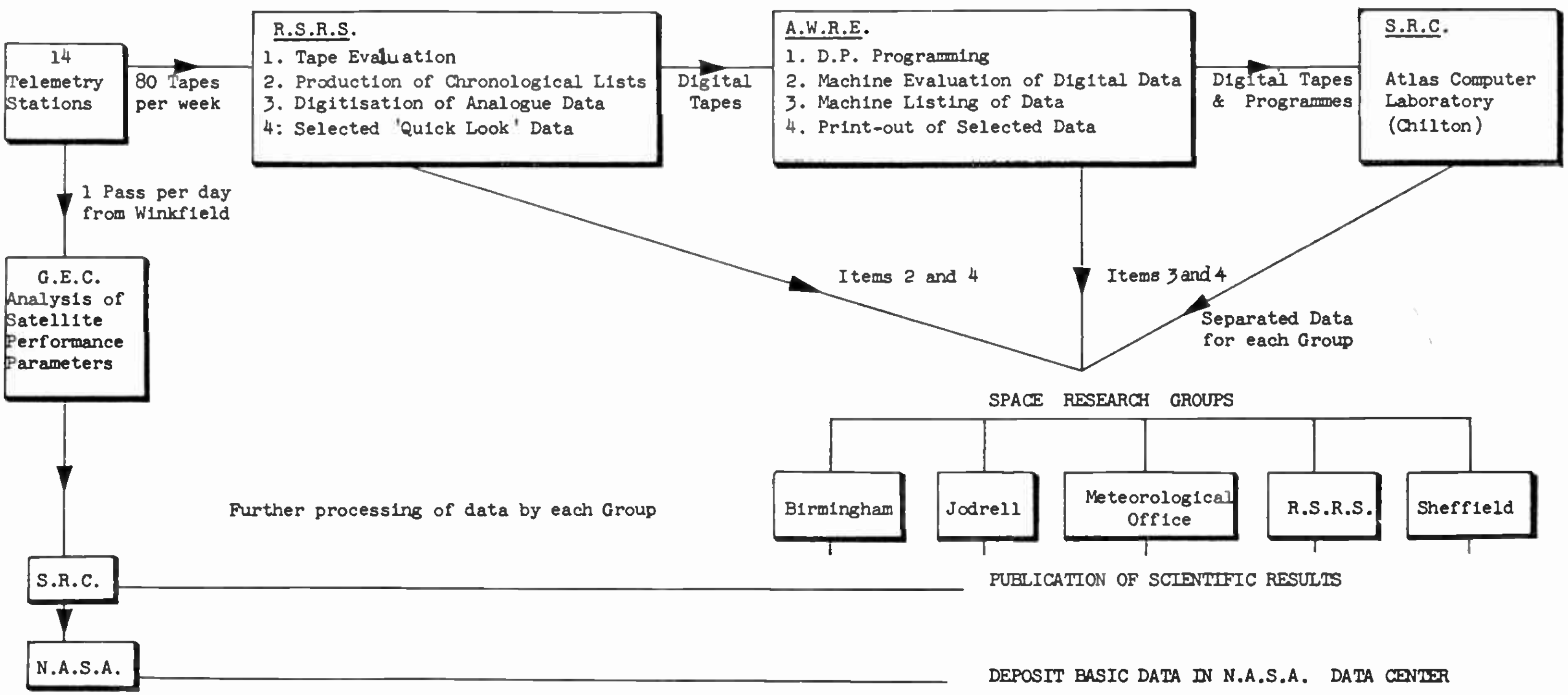

Fig. 5. *Ariel III* data processing.

a pass thus holds high-speed data with a period in the middle of low-speed data. Each station tape is used to hold data received from three or four passes before it is sent to R.S.R.S. for the first stages of the data processing system.

10. Data Processing

The success of any scientific space project is judged by the new data are made available to the scientific community and the explanations that are proposed for unexpected results. It is therefore, very important that the vast quantities of data received from the satellite should be processed speedily into an acceptable machine compatible form for each of the Space Research Groups who carry the ultimate responsibility for the final processing and the early publication of the results. The areas of activity involved in handling the telemetry data are outlined in Fig. 5.

The analogue tapes from the telemetry stations are first processed by the Radio and Space Research Station which possesses a specially designed 'digitizer' for handling p.f.m./p.m. telemetry data.[18] This machine was provided for the *Ariel II* project and has been modified to accept the *Ariel III* data format.

In January 1966 the S.R.C. arranged with A.W.R.E. Aldermaston[26] that they should undertake a major part of the data processing task for the project as they had had previous experience with data from *Ariel II*. The work involved the following stages of activity:

(i) To define the requirement by liaison with the experimenters and the S.R.C.

(ii) To recommend an operating system acceptable to S.R.C.

(iii) To prepare the different programs for use at A.W.R.E. and the Chilton *Atlas*.

In general, the experimenters require their own data to be separated from those of the other experiments and desire additional data to be incorporated such as orbital position. This latter information is obtained by R.A.E. from the tracking data provided by the STADAN stations.

The system outlined in Fig. 5 has provided the experimenters with good 'quick-look' data for preliminary work and a flow of their low-speed machine data within two months of the launch and their high-speed machine data within 4 months of the launch. This time-scale compares very favourably with that achieved on other similar projects.[19]

Regular post-launch meetings are held by the S.R.M.U. to formulate the relative priorities in the data processing activities and to consider all aspects of the final stages of the project.

11. Conclusions

The first British scientific satellite has been outstandingly successful in the quality and quantity of the scientific data obtained and so has satisfactorily achieved the main objective of the project.

As a by-product, the Royal Aircraft Establishment and parts of British Industry now have considerable practical knowledge and ability in the field of satellite technology and have acquired the special facilities for the manufacturing and testing of spacecraft.

The generous attitude of NASA in this Anglo-American co-operative project has enabled the U.K. engineers and scientists concerned to benefit greatly from a free exchange of information and experience with their American colleagues.

The project has clearly demonstrated that staff from Industry, the Universities and Government departments can successfully work together on a major technological task with a basic scientific objective.

12. Acknowledgments

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The authors jointly acknowledge the permission of the Science Research Council and the Ministry of Technology to publish this paper. They also take this opportunity to thank their many colleagues in the U.K. and the U.S.A., and in particular, in the National Aeronautics and Space Administration, for their willing help and advice in the course of the *Ariel III* project.

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20. J. F. Smith, 'Engineering aspects of satellite experiments'.

21. F. C. Treble, R. C. Cook and P. G. Garratt, 'The *Ariel III* power system', *The Radio and Electronic Engineer*, **35**. To be published.

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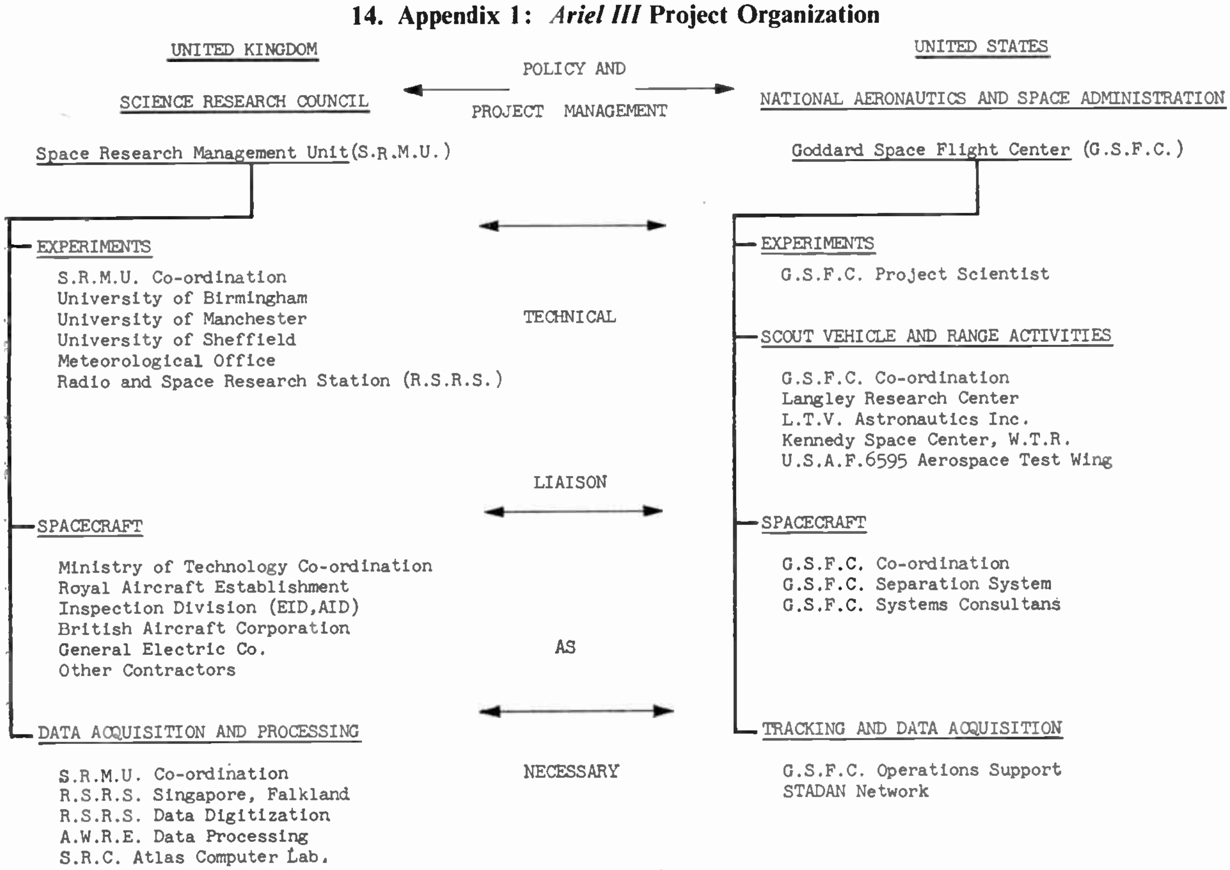
14. Appendix 1: *Ariel III* Project Organization



15. Appendix 2: *Ariel III* Qualification Tests

	Design qualification		Flight acceptance	
	Unit	Spacecraft	Unit	Spacecraft
Performance	×	×	×	×
Leak (pressurized items)	×	×	×	×
Balance		×		×
Weigh	×	×	×	×
C. of G. and M. of I.		×		×
High and low temperature storage	×	×		
High and low temperature operation	×	×		
Humidity	×			
Spin		×		
Boom deployment and separation		×		
Linear acceleration	×	×		
Vibration	×	×	×	×
Thermal vacuum	×	×	×	×
Solar simulation		×		•
Magnetic moment		×		×
Aerial directivity pattern		×		
Solar spin		×		
Scout compatibility		×		

16. Appendix 3: Launch Data

16.1. *Scout* vehicle stages

Stage	Total impulse (lb s vacuum)	Average thrust (lb vacuum)	Control
1st: *Algol 2B*	5 472 350	100 944	Jet vane and fin tip
2nd: *Castor 2*	2 317 000	60 764	Peroxide reaction jets
3rd: *Antares X259-A3*	719 540	20 942	Peroxide reaction jets
4th: *Altair X258-E6*	140 300	6 481	Spin stabilized at 160 rev/min

16.2. *Ariel III* launch vehicle sequence of events

Event	Nominal timing (seconds)
1st stage ignition (lift-off)	0
1st stage burn-out	78·2
2nd stage ignition and 1st stage separation	81·08
2nd stage burn-out	120·07
Heat-shield separation	136·97
2nd stage separation	138·67
3rd stage burn-out	173·57
Spin motor ignition	543·24
3rd stage separation	544·74
4th stage ignition	549·24
4th stage burn-out	572·44
De-spin yo-yo release	634·74
Boom deployment starts	664·74
Spacecraft separation	874·74

16.3. *Ariel III* countdown summary (spacecraft only)

Task	Starting time (P.D.T.)	Item	Contents
	0300	Communication check	Test intercommunication between all parties.
A	0305	Pre-sequence	External and internal power supply checks.
B	0330	Pre-erection tests	Command spacecraft into all modes and monitor telemetry r.f. output. Check all systems.
	0655	Communications check	
C	0700	Post-erection tests	Check internal power supplies. Command into all modes and monitor telemetry r.f. outputs. Check all systems.
	0825	Communications check	
D	0830	Terminal countdown	Ground equipment checks. Switch to internal power supply. Maintain continuous monitor of telemetry r.f. output.
	0900	Ignition	
E	0900	Post launch	Monitor spacecraft signals to extinction.

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A Wideband Array of Non-uniformly Spaced Directional Elements

By

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B.E.(Hons.)†

Summary: This paper discusses the design of an economical wideband array suitable for low-frequency radio astronomy applications. The array consists of 32 non-uniformly spaced, uniformly excited, log periodic antennae designed to operate over a 2 : 1 frequency band. At the highest operating frequency, the array has a beam-width of approximately 1° and side-lobes at least 16·5 dB below the main beam level. The theoretical limit to which the side-lobes of an idealized array, having the same gain and length, can be suppressed is 17 dB.

1. Introduction

Until recent years, antenna arrays have invariably been designed with uniform element spacings. The patterns of such arrays can be controlled by appropriate adjustment of the excitation to each element.

Though effective, pattern control using weighted excitation is basically inefficient from the point of view of antenna utility. Also, due to the periodicity in the pattern of such arrays, secondary major lobes will appear in the 'visible' space if the inter-element spacing is equal to or greater than one wavelength. However, these limitations were then of little practical significance because arrays were used mainly for the purpose of communications where few elements were generally involved.

Today, with the advancement of radio astronomy, long arrays are often required. These arrays have to be designed not only to meet the pattern specifications but also to reduce cost. An array which shows a great potential for bridging the gap between performance and economy is the array with non-uniform element spacings. Here, uniform excitation can be used to give maximum feed efficiency and spacings larger than one wavelength are permitted so that less elements will in general be needed for a given performance specification.

The full exploitation of the potentials of non-uniformly spaced arrays is at present, still limited by design difficulties. The basic design problem is to specify a set of element positions which will optimize the pattern function. The difficulties arise from the fact that the position variables, which are to be optimized, lie in the arguments of the cosine terms in the pattern expression. Consequently, the problem becomes highly non-linear. Approximate solutions have been proposed in recent years by various investigators. Most of the works published have been directed towards the synthesis of arrays with isotropic elements.

The purpose of this paper is to show that a very economical array can be designed using non-uniformly spaced directional elements. The economy results from the use of average inter-element spacing considerably larger than one wavelength. Good side-lobe suppression can be achieved by taking the directivity of each element into account in the array synthesis. The array can be made broadband with little increase in cost.

The synthesis of a 32-element symmetrical array of non-uniformly spaced log periodic antennae is discussed in this paper. The array is designed to operate over a 2 : 1 frequency band.

The aim of the synthesis process is to improve progressively the pattern of a starting array by repeated application of computed perturbations to the positions of the elements. Since the pattern of the array under consideration has many more side-lobes than there are antenna positions to juxtapose, it is theoretically not possible to design such an array to have equal ripple response in the side lobe region. However, using the synthesis technique as discussed in this paper, the peak side-lobe level of the synthesized array is only about 10% higher than the theoretical minimum, estimated from the side-lobe level of an idealized pattern.

2. Array Theory

The voltage response pattern for a symmetrical array of $2N$ directional elements is, in the most general form,

$$F(\theta) = F_0(\theta) . \sum_{n=1}^{N} I_n \cos(2\pi X_n . \sin\theta + \phi_n) \quad \ldots(1)$$

where $F_0(\theta)$ = normalized voltage response pattern of each element,

I_n = normalized amplitude of excitation to the nth element,

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ϕ_n = phase of excitation to the nth element,

X_n = distance, in terms of wavelengths, of the nth element to the array centre,

θ = angle an incident ray makes with the normal to the line of the array (Fig. 1).

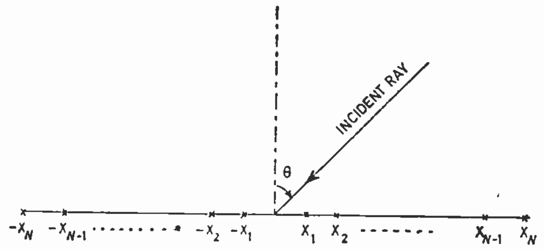

Fig. 1. Symmetrical array of $2N$ elements.

From eqn. (1), there are three parameters with which a designer can control the array pattern. These are: (i) I_n, (ii) ϕ_n, and (iii) X_n.

2.1 *Uniformly Spaced Array*

The classical approach assumes uniform spacings between elements and zero or progressive phase shifts: i.e. $X_n = nx$, where x is the constant spacing between adjacent elements; and $\phi_n = -2\pi nx \sin\theta_0$, where θ_0 is the angle to which the main beam is steered.

The advantage of this method is that, provided the inter-element spacing is small, the side-lobes can be suppressed to any desired level by appropriately adjusting excitation to each element. Array patterns can be expressed in polynomial forms. Known properties of certain polynomials like the Chebyschev polynomial,[5] can be used to synthesize array patterns with optimal relationships between beam-width and side-lobe levels. The design of long arrays with large numbers of elements presents few analytic difficulties because the pattern is approximately that of an array with a continuous aperture distribution.[6] For example, in the celebrated Mills Cross[7] in Sydney, excitation approximating to a truncated Gaussian distribution is used to achieve very low side-lobe level as required in cross-type radio telescopes.

Often, good side-lobe suppression can be achieved only by mismatching the far out elements. Thus side-lobe suppression is obtained at the expense of broadening the main beam.

Since the array pattern is the Fourier transform[8] of the current distribution, the periodicity in the spacings will result in a periodic space pattern. In order that no grating lobe appear in the 'visible' space, inter-element spacing must be less than one wavelength. From considerations of mutual coupling between elements, spacings should be greater than $\lambda/2$. It can be shown[9] that a uniformly spaced array with good electrical steerability is operative over a very narrow frequency band.

2.2 *Non-uniform Progressive Phase-shift (n.u.p.p.s.) Array*

When amplitude of excitation and inter-element spacings are held constant but the phase constraint is relaxed, the array can be called a non-uniform progressive phase shift array. Such an array was shown by Ma[10] to be capable of providing higher directive gain and better side-lobe suppression than a current tapered array. The periodicity in its space pattern renders it unsuitable for the application discussed in this paper.

2.3 *Non-uniformly Spaced (n.u.s.) Array*

An array with uniformly excited but non-uniformly spaced elements can, in general, be designed using fewer elements, to give the same performance as a current tapered array. Inter-element spacings larger than one wavelength are permitted. The space pattern is non-periodic and the array is operative over a wide frequency band. With uniform excitation, side-lobes can be suppressed without increasing the width of the main beam. Progressive phase shift can be used for the purpose of steering the main beam.

Assuming that each element can be tilted about its mount to align its direction of maximum radiation with the direction of the main beam of the array, it is then sufficient, in the array design, to consider only the case when there is zero progressive phase shift.

The normalized response pattern for a 32-element array becomes

$$F(\theta) = \tfrac{1}{16} F_0(\theta) \, . \sum_{n=1}^{16} \cos(2\pi X_n \sin\theta) \quad \ldots\ldots(2)$$

Design of this array involves the determination of a set of 16 positions, X_n, such that the space pattern $F(\theta)$ is satisfactory. Because the spacing parameters appear inside the argument of the cosine terms, no simple analytic solution exists.

Unz[11] was one of the first to investigate synthesis of n.u.s. arrays. Later, King *et al.*[12] studied computed patterns of arrays in which the spacings were derived from various arbitrary functions. Sandler[13] expanded each cosine term in the series to find some equivalence between the n.u.s. array and the current tapered array. Andreason[9] and Skolnik[14] examined the use of computer techniques to synthesize n.u.s. arrays. Approximation to the Fourier integral of a continuous distribution was developed by Maffett[15] using a staircase function and by Lo,[16] using a

Gaussian quadrature technique. A perturbation method was proposed by Harrington[17] to suppress lobes near to the main beam. The possibility of synthesizing a Chebyschev-type pattern using non-uniform element spacings was investigated by Baklanov[18] using a matrix technique. Ishimaru,[19] Chen[20] and Chow[21] studied the pattern function as an infinite series expansion using Poisson's summation theorem. A method to design large n.u.s. arrays using a random theory approach was proposed by Lo.[22]

Most of the above techniques were developed for synthesis of arrays of isotropic elements. An array 'optimized' for isotropic elements is clearly not 'optimum' when directional elements are used. The array design discussed in this paper takes into account the directivity of the elements.

3. Array Design

Since the desired array must be operative over a 2 : 1 frequency band, it is necessary to design the spacings at the highest operating frequency. At this frequency, the minimum spacing should not be less than λ. The average spacing is arbitrarily set at 2λ.

3.1 *Element Pattern*

To simplify computation, it is desirable to define a simple function which is a good approximation to the directivity pattern of a log periodic antenna. An acceptable approximation is

$$F_0(\theta) = \frac{0{\cdot}2+\cos^2\theta}{1{\cdot}2} \qquad \ldots\ldots(3)$$

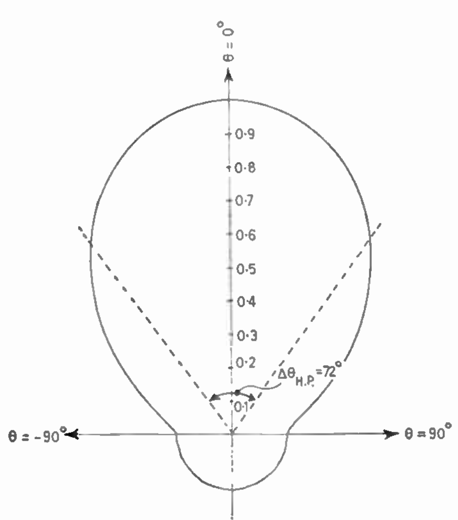

Fig. 2. The idealized element pattern.

The constants 0·2 and 1·2 in the expression for $F_0(\theta)$ are arbitrarily assigned in order to provide a more realistic approximation for θ approaching 90°. Such a pattern is shown in Fig. 2.

Assuming axial symmetry, the directivity of the adopted pattern is given by[4]

$$D = \frac{2}{\int_0^{\pi} F_0(\theta)^2 \sin\theta \, d\theta} \qquad \ldots\ldots(4)$$

The computed directive gain of the element is 8·4 dB above isotropic. This gain is easily obtained with a log periodic antenna.

3.2 *Synthesis Technique*

The array pattern can be simplified by expressing eqn. (2) in u-space, where $u = \sin\theta$. Thus

$$F(u) = \frac{1{\cdot}2-u^2}{19{\cdot}2}\cdot\sum_{n=1}^{16}\cos(2\pi X_n u) \qquad \ldots\ldots(5)$$

Consider the effect of small perturbations in u, X_n and I_n on the pattern $F(u)$ at a region $u = u_i$,

$$dF(u_i) = \left.\frac{\partial F}{\partial u}\right|_{u=u_i} du_i + \sum_{n=1}^{16}\left.\frac{\partial F}{\partial I_n}\right|_{u=u_i} dI_n + \sum_{n=1}^{16}\left.\frac{\partial F}{\partial X_n}\right|_{u=u_i} dX_n \qquad \ldots(6)$$

If u_i corresponds to the point at which a secondary maximum occurs, $\partial F/\partial u_i = 0$. Also $dI_n = 0$ for all values of n, follows from the restriction of constant excitation.

Equation (6) reduces to

$$dF(u_i) = \sum_{n=1}^{16}\frac{\partial F(u_i)}{\partial X_n} dX_n \qquad \ldots\ldots(7)$$

If 16 values of u_i, corresponding to 16 secondary lobe positions are available, eqn. (7) becomes a set of 16 simultaneous equations. These can best be expressed in a matrix form.

$$\begin{bmatrix} dF(u_1) \\ \vdots \\ dF(u_{16}) \end{bmatrix} = \begin{bmatrix} \frac{\partial F(u_1)}{\partial X_1} & \cdots & \frac{\partial F(u_1)}{\partial X_{16}} \\ \vdots & & \vdots \\ \frac{\partial F(u_{16})}{\partial X_1} & & \frac{\partial F(u_{16})}{\partial X_{16}} \end{bmatrix} \cdot \begin{bmatrix} dX_1 \\ \vdots \\ dX_{16} \end{bmatrix} \qquad (8)$$

The solution of eqn. (8) gives the amount each element has to be shifted in order to improve the level of the 16 arbitrarily selected side-lobes.

This technique was first used by Baklanov *et al.*[18] to synthesize n.u.s. arrays with equal ripple response in the side-lobe region. Due to the fact that a solution is only possible when there are as many equations as there are antenna positions, Baklanov's arrays invariably contain small spacings between elements; some falling below $\lambda/2$.

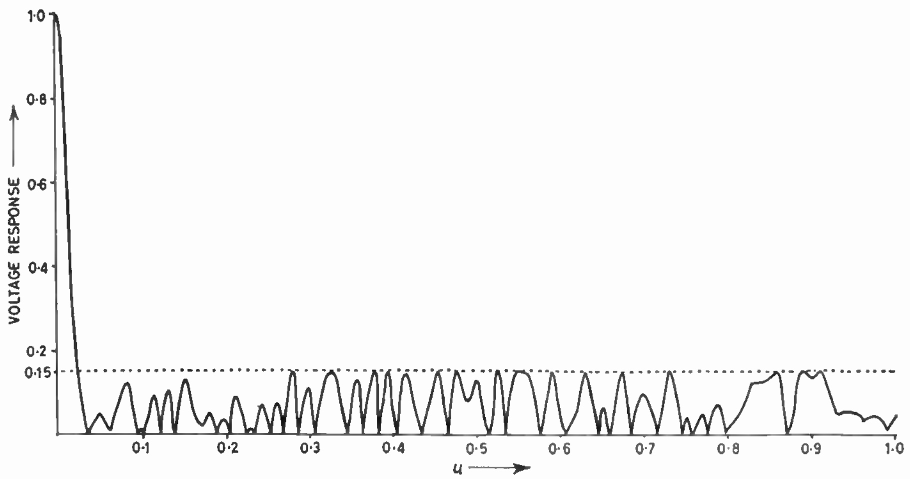

Fig. 3. Array pattern at frequency $2 \times f_{min}$. (f_{min} is the frequency at which the minimum inter-element spacing of the array is $\lambda/2$.)

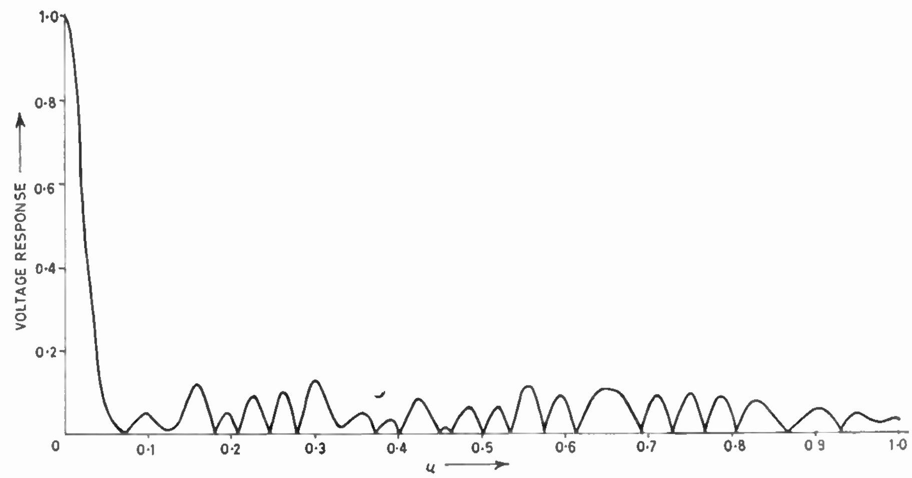

Fig. 4. Array pattern at frequency f_{min}.

However, in the array under consideration, there are about 40 side-lobes and only 16 antenna positions to juxtapose. To overcome the analytic difficulty, a computer sub-program has been developed to scan through all the secondary maxima in $F(u)$ for any given set of element positions. The 16 highest side-lobes are selected and their levels determined. The values of u_i at which these maxima occur are also computed for use in the main program.

3.3 *Computation*

Computation was carried out on the IBM 1130 digital computer at the University of Auckland. To start computation, an initial array that would give a reasonable pattern at an average inter-element spacing of 2λ is postulated (Section 3.4). The peak determination sub-program is used to determine the positions u_i at which the 16 highest peaks occur. By comparing the levels of these peaks with a prescribed reference level, the constant vector $[dF(u_i)]$ can be computed. Knowing u_i, the elements of the 16×16 matrix can also be computed. Using standard matrix inversion program, eqn. (8) can be solved for 16 values of dx_n. It is then necessary to multiply the column vector $[dx_n]$ by a scaling factor if the values of dx_n are not small.

Now the perturbations dx_n are added to the corresponding element positions X_n to give a new set of element positions which should have an improved space pattern.

The process is repeated until all the 16 highest lobes are reduced to the prescribed level. This prescribed level can then be decreased and the entire process repeated.

There is, of course, a limit to which the side-lobes can be reduced. This would seem to occur whenever there are more than 16 secondary lobes of level greater than the prescribed level. Should this occur, convergence is slow. Eventually, either the iteration becomes divergent or the array length gradually shortens so that further side-lobe reduction is achieved at the expense of widening the width of the main beam. The minimum level to which the 16 maximum peaks can be reduced, whilst still maintaining an average spacing of 2λ between elements is 0·15. The total computing time was about 5 hours. The computed element spacings are shown in Table 1.

Table 1

The positions of the elements from the array centre

X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
1·013	2·104	3·137	4·301	5·345	6·625	7·684	8·759
X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
10·072	11·341	13·437	15·448	17·116	20·093	22·805	30·668

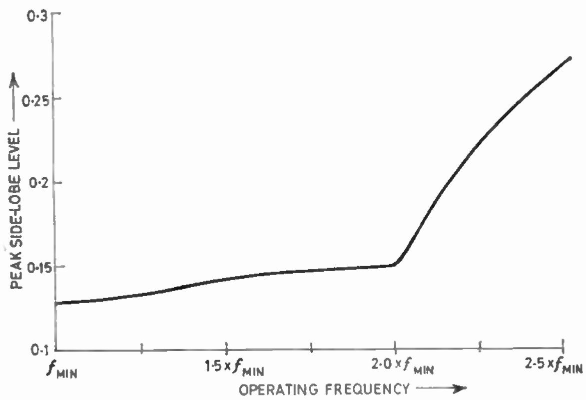

Fig. 5. Peak side-lobe level as a function of operating frequency.

From the computed pattern (Fig. 3) it can be seen that the 16 highest peaks are exactly at a level 0·15 of the main beam level. This corresponds to a power response of about 45 times below the main beam power. A few more peaks are only slightly below 0·15. Any further attempt to reduce the peak side-lobe levels will result in the computation going divergent. The theoretical limit to which all side-lobes can be suppressed for the particular array is 0·14 (Section 3.5). Thus the results obtained are near optimal. The array is still operative at half the design frequency. Below this, the minimum spacing is less than $\lambda/2$ and the effectiveness of the array is limited by mutual coupling between elements. The array pattern at the minimum operating frequency is shown in Fig. 4. A continuous plot of maximum side-lobe level against operating frequency up to $2{\cdot}5 f_{\min}$ is shown in Fig. 5. It will be apparent that the side-lobe level remains fairly constant until the operating frequency exceeds twice the minimum operating frequency, beyond which the side-lobe level increases rapidly.

3.4 *Initial Array*

A convenient initial array can be obtained by using the theories developed for an array with isotropic elements. Ideally, the pattern for such an array should have small side-lobes close to the main beam and gradually increasing at increasing angles. The methods of Harrington[17] or Maffett[15] can be used. The initial array used by the author to give the results published in this paper is Maffett's 'quadratically non-uniform array'[15] in which the spacings are

$$X_n = 7{\cdot}5 X_{\text{av}}\left(1 - \sqrt{1 - \frac{n}{16}}\right) \qquad \ldots\ldots(9)$$

where $X_{\text{av}} = 2$, the average spacing in terms of λ.

Taking into account the assumed element pattern, the computed peak side-lobe level for this array is 0·246, reducing to 0·15 in the final form.

3.5 *The 'Optimal' Pattern*

In order to test the effectiveness of the side-lobe suppression, an estimate is made of the theoretical minimum to which the side-lobe level can be suppressed. The 'optimal' pattern assumed is one in which the side-lobes are all at the same level and the pattern oscillates rapidly in the side-lobe region. Assuming such a pattern, Andreason[9] has shown that the theoretical minimum side-lobe suppression E is, in dB,

$$E = -10\log\left(\frac{G}{2}\right) + 10\log\left(1 - \frac{G\lambda}{2L}\right) \ldots\ldots(10)$$

where G is the maximum power gain of the array, whose pattern normal to the line of the array is assumed isotropic. Each element must therefore be assumed to have a doughnut-type pattern[4] in this computation.

The computed theoretical minimum side-lobe level is 17 dB. This corresponds to a voltage response 0·14 of the main beam level. The peak side-lobe level in the synthesized array is 0·15, less than 10% above 0·14.

4. Conclusion

This paper has presented the design of an economical 32-element array suitable for applications in low frequency radio astronomy. Cost reduction and increased performance are achieved through the use of non-uniformly spaced directional elements. The maximum voltage side-lobe level achieved by the synthesis technique is less than 10% above the theoretical minimum. The array is operative over a 2 : 1 frequency band.

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7. Appendix 1: Note on the University of Auckland's Radio Astronomy Programme

In February 1965, a research programme in radio astronomy was started by the Electrical Engineering Department of the University of Auckland. One of the purposes of this programme was to provide topics and a central theme for post-graduate research in the department.

With limited funds, the initial programme was necessarily unambitious. It was thought that efforts could best be directed under such circumstances towards two lines of research: (i) the absolute flux measurement of strong radio sources at frequencies below 50 MHz using a phase-switched interferometer of very simple antennae,[1,2] (ii) the relative flux measurement on as many sources as possible using two collinear arrays of antennae as an interferometer, the purpose being to study the low-frequency spectra of these sources.

The choice of an interferometer rather than a large cross for the purpose of discrete source study was again a matter of cost. Extremely low-level side-lobes are required of the arrays forming a cross whereas in an interferometer, the requirement is not as stringent.

The array specification was dominated by two factors: (i) simplicity and economy of supporting structures, and (ii) electrical efficiency.

It was immediately apparent that the use of directional elements would tend to decrease the number of antennae needed and so decrease the number of structural supports required. Unlike the dipole array, no associated ground planes would be necessary in most directional antennae so that each antenna could be fully steerable and can be simply mounted on a single pole.

The electrical requirements of the array system were:

(i) to provide adequate collecting area in the direction of the main beam so that noise signals from the radio sources could be detected above the background noise of the system,

(ii) to provide adequate resolving power so that radio sources could be 'observed' without confusion.

8. Appendix 2: Basis of Design of Directional Arrays

The detection power of a system is determined by its maximum detectable flux density ΔS_{min}:[3]

$$\Delta S_{min} = \frac{2k(NT_0 + T_A)}{A_e\sqrt{\Delta f . \tau}} \qquad \text{......(11)}$$

where k = Boltzmann's constant,

N = receiver noise figure,

T_0 = ambient temperature (°K),

T_A = antenna temperature (°K),

A_e = effective collecting area in the direction of the main beam (m^2),

Δf = noise bandwidth of the receiver (s^{-1}),

τ = post-detector integration time-constant (s).

An empirical estimate of the number of sources resolvable by an antenna system is, by Ko's criteria,[3]

$$N_r = \frac{4\pi\gamma}{\Omega} \qquad \text{......(12)}$$

where N_r = maximum number of sources resolvable,

γ = fraction of the sky 'visible',

Ω = beam solid-angle.

The assumption made in eqn. (12) is, of course, that the response of the array outside the main beam is well suppressed, the degree of suppression required being dependent on the ratio of the flux densities of sources against which the system is expected to discriminate.

It can be shown[3] that a filled array is highly resolution limited at frequencies below 100 MHz. In other words, an interferometer at these frequencies will always be confusion limited. To improve this basic limitation, an attempt is made in the array design to secure as small a beam solid-angle as possible for a given collecting area while still maintaining an acceptably low side-lobe level.

Assuming each element to have an axially symmetric pattern of half-power beam-width ϕ, the gain of each element is given by[4]

$$G \simeq \frac{4\pi}{\phi^2} \qquad \text{......(13)}$$

The maximum effective collecting area is

$$A = \eta M G A_0 \qquad \text{......(14)}$$

where η = array efficiency,

M = number of elements used,

A_0 = $\lambda^2/4\pi$, the average collecting area of an antenna.

The half-power beam-width of an array with uniform excitation is approximately λ/L, where L is the total length of the array.

The beam solid-angle

$$\Omega \simeq \frac{\lambda}{L}\phi \qquad \text{......(15)}$$

Substituting eqn. (13) in eqn. (15),

$$\Omega \simeq \frac{2\lambda}{L}\sqrt{\frac{\pi}{G}} \qquad \text{......(16)}$$

From eqn. (16) it can be seen that the beam solid-angle can be reduced by increasing L and G. Since the collecting area of the array is usually more than adequate at these frequencies, the result of using high-gain elements and increased feed efficiency is that the number of antennae needed can be reduced significantly, as shown by eqn. (14).

The above analysis would indicate that an array of widely spaced directional elements would be ideally suited for the purpose. In order that inter-element spacings larger than one wavelength are permitted without incurring large grating lobes in the pattern, non-uniform spacing technique is used in the array design. The side-lobe level of the array can be suppressed to an acceptably low level by careful design of the antenna spacings.

A further advantage of using the non-uniform spacing technique is that the array is basically suited to wideband operation. This feature is advantageous in the study of the spectra of solar and other radio sources.

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(Paper No. 1163/Com.1.)

Atomic Second Adopted as International Unit of Time

A new definition of the international unit of time, the *second*, was adopted on 13th October, 1967 in Paris by the 13th General Conference on Weights and Measures. The second has now been defined in terms of a characteristic rate of electromagnetic oscillation of the caesium 133 atom. The Conference also made terminological decisions in regard to the 'micron,' the 'degree Kelvin,' and the candela; and it added several to its list of derived units in the International System.

The General Conference on Weights and Measures, convened every few years, is a meeting of delegates from the countries (now numbering 40) adhering to the Treaty of the Metre. It is the principal body concerned with working out international agreements on physical standards and measurements.

The Conference agreed overwhelmingly that the existing definition of the second, based on the Earth's orbital motion around the sun, should be replaced by the following 'atomic definition':

> 'The unit of time of the International System of Units is the second, defined in the following terms: "The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the fundamental state of the atom of caesium 133." '

The frequency (9 192 631 770 Hz) which the definition assigns to the caesium radiation was carefully chosen to make it impossible, by any existing experimental evidence, to distinguish the new second from the 'ephemeris second' based on the Earth's motion. Therefore no changes need to be made in data stated in terms of the old standard in order to convert them to the new one.

On the other hand, the atomic definition has two important advantages over the preceding definition: (1) it can be realized (i.e. generated by a suitable clock) with sufficient precision, ± 1 part in 10^{11} or better, to meet the most exacting demands of current metrology; and (2) it is available to anyone who has access to or who can build an atomic clock controlled by the specified caesium radiation, and one can compare other high-precision clocks directly with such a standard in a relatively short time—an hour or so as against years with the astronomical standard.

The development in the last few decades of atomic clocks, without which the new definition could not have been considered seriously, has laid the preliminary groundwork for an eventual experimental assault on a fundamental question: Are the time scales based respectively on gravitational, electrical, and nuclear forces compatible and consonant with each other? And if (as some think might be the case) they are not, then why not?

The Conference also made the several other decisions summarized below:

Length. The name 'micron' for a unit of length equal to 10^{-6} metre, and the symbol 'μ' which has been used for it, are dropped. The symbol 'μ' is to be used solely as an abbreviation for the prefix 'micro-', standing for multiplication by 10^{-6}. Thus the length previously designated as 1 micron, should be designated 1 μm.

Temperature. The Conference asked the International Committee on Weights and Measures to consider the steps necessary to put a new International Practical Scale of Temperature into effect as soon as possible.

It is proposed that the name of the unit of thermodynamic temperature should be changed from *degree Kelvin* (symbol: °K) to *kelvin* (symbol: K). The definition of the unit of thermodynamic temperature thus would read:

> The kelvin, the unit of thermodynamic temperature, is the fraction 1/273·16 of the thermodynamic temperature of the triple point of water.

It was also proposed that the same name (kelvin) and symbol (K) be used for expressing temperature intervals, dropping the former convention which expressed a temperature interval in degrees Kelvin or, abbreviated, degK.

Photometry. Recognizing that photometry must take into account the principles and techniques of colorimetry and radiometry, the Conference approved plans drawn up by the International Committee on Weights and Measures to expand the scope of its activities to include the fundamental metrological aspects of colorimetry and radiometry. The definition of the unit of luminous intensity, the *candela*, was rephrased.

Derived units. To the derived units and associated symbols that the 11th General Conference (1960) had included in its Resolution 12, which introduced the International System of Units (official abbreviation: SI, from the French designation, Système International d'Unités), the 13th General Conference added the following:

Wave number	1 per metre	m^{-1}
Entropy	joule per kelvin	J/K
Specific heat	joule per kilogramme kelvin	J/kg K
Thermal conductivity	watt per metre kelvin	W/m K
Radiant intensity	watt per steradian	W/sr
Activity (of a radioactive source)	1 per second	s^{-1}

(*Editorial note:* These recommendations will naturally have to meet with the agreement of the International Organization for Standardization (I.S.O.) with which engineers are linked through their national standards organizations, e.g. the British Standards Institution.

Certain of these latest decisions may ultimately affect the practice of the Institution in its publications. Broadly speaking current practice is as set out in the article 'The Use of SI Units' which was published in *The Radio and Electronic Engineer* in July 1966: an announcement will shortly be made setting out the requirements for units in papers pending the full adoption of SI units throughout.)

This report of the 13th General Conference is based on a note received from the National Bureau of Standards, Washington, D.C.

U.D.C.629.19

Thermal Design and Thermal Testing of the *UK-3* Spacecraft

By

E. C. SEMPLE†

Presented at a Symposium on 'The Ariel III Satellite', held in London on 13th October 1967.

Summary: The factors affecting the thermal design of a spacecraft are first discussed in general terms. Attention is then given to the thermal design problems on *UK-3*, and in particular to the difficulties associated with the gold plate and white paint which had to be used as the main thermal control surfaces. The distribution of the thermal control surfaces finally chosen is given together with the predicted temperatures for the more critical items of equipment.

The form of the simulation of space heating conditions provided by the R.A.E. 2½ metre Space Test Chamber is discussed together with the details of the trials performed on the *UK-3* to ensure the accuracy of its thermal design.

Finally, a comparison is made between the temperatures predicted and the temperatures measured in orbit: an overall correspondence to better than 5 deg C was obtained.

1. Introduction

At the beginning of the *UK-3* programme, no experience existed in Britain in the techniques of spacecraft thermal control and thermal testing. This paper outlines the work which was done in developing the required expertise, and shows that a close correspondence was obtained between (*a*) the predicted temperatures, (*b*) the temperatures measured during solar simulation tests in the R.A.E. Space Test Chamber, and (*c*) the temperatures telemetered from the spacecraft in orbit.

2. Thermal Design

2.1. *General Principles*

On the Earth the temperature of an object is very largely determined by the temperature of the air which surrounds it. In space no convective effects exist, and the temperature of a spacecraft is determined by the balance between the heat the spacecraft absorbs (largely from the Sun), and the heat it radiates to space. This situation, in its simplest terms, is shown in Fig. 1 for the case of an isothermal sphere. In steady state the heat balance of the sphere is given by the equation

$$aA_pS = eArT^4 \qquad \ldots\ldots(1)$$

where the symbols have the following meaning:

- a absorptance of the sphere to solar radiation,
- A_p projected area,
- S mean intensity of the heat from the Sun in the vicinity of the Earth (the solar constant),
- e infra-red emittance,
- A total surface area,
- r Stefan-Boltzmann radiation constant
- and T absolute temperature of the sphere.

Space has an apparent temperature of near 0°K so this temperature does not appear in the equation.

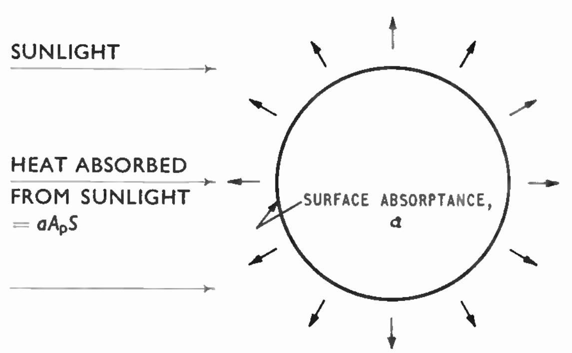


Fig. 1. Heat balance of a sphere in space. Heat transmitted to space in infra-red = $AerT^4$.

Re-writing eqn. (1) gives

$$T = \sqrt[4]{\frac{A_pS}{Ar}\,\frac{a}{e}} \qquad \ldots\ldots(2)$$

In eqn. (2) the first group of terms is constant, and the temperature of the sphere can be controlled by choosing the ratio a/e. The values attributable to a and e depend on the surface coating of the sphere, and may vary widely. Table 1 shows typical values of a and e for metallic surfaces and for painted surfaces,

† Ministry of Technology, Royal Aircraft Establishment, Farnborough, Hampshire.

and also shows the operating temperature for the sphere which would be obtained by substitution in eqn. (2). To attain a temperature around room temperature, a mean value for a/e of about 1·1 or 1·2 is required, and this can be achieved by combining areas of these surfaces in suitable proportions.

Table 1

Typical values for a and e for different surfaces

Surface finish	a	e	T derived by using eqn. (2)
Polished metal	0·25	0·05	418°K (+145°C)
Black paint	0·95	0·90	284°K (+11°C)
White paint	0·20	0·90	192°K (−81°C)

The situation on a real spacecraft is, however, considerably more complex. Additional heat inputs come from the Earth due to reflected sunlight, and direct infra-red radiation; the heat input varies substantially as the spacecraft passes in and out of the Earth's shadow; and the spacecraft may be far from isothermal so it is important to take thermal gradients into account. To solve this detailed problem, the technique employed is to divide the spacecraft into a large number of nominally isothermal nodes (usually about 50) and calculate the external and internal heat exchange of these various parts of the spacecraft.† A series of simultaneous differential equations, one for each node, is constructed and these can be solved digitally using a step-by-step integration process: the form of these equations is given in Appendix 1. Using a digital computer, calculations are performed for cases covering the full range of possible attitudes of the spacecraft relative to the Sun, and for the upper and lower extremes of heat input—for *UK-3* these correspond respectively to cases where the spacecraft is in sunlight for 100% and 63% of its orbit.

2.2. *Limiting Factors on UK-3 Thermal Design*

Temperature limitations will be discussed first. Two items presented the main limitations. These were: the nickel-cadmium battery, which was limited to the range −10°C to +40°C, and the tape recorder which was limited to −5°C to +60°C. Virtually all items of equipment were, however, temperature sensitive to some extent, and few would operate satisfactorily outside the range −15°C to +60°C.

Severe limitations were imposed on the thermal control surfaces which could be used on the outer surface of the spacecraft. A substantial part of the solar cell array was attached to the side of the spacecraft on trays supported away from the doors, and there was little scope for varying the thermal characteristics of these surfaces. Also the Birmingham University experiment required that the spacecraft should have an electrically conducting surface which presented a projected area of at least 400 sq. in. in any attitude. Because of its oxide layer, the aluminium used in the structure was not a suitable surface for this purpose, and a noble metal had to be plated on top. Gold was chosen for this purpose since, of the noble metals, it was the one for which most plating experience existed; it was also the surface used on *UK-1* which had a similar requirement.

It is worth noting that without these restrictions, particularly the latter, the approach to the thermal design would have been substantially different, and it is likely that most of the surface of the spacecraft would have been covered with black paint.

2.3. *Thermal Design Approach*

Accepting the above limitations, work on the thermal design of the spacecraft divided itself into two parts:

1. Developing the gold surface to go on the aluminium structure, and developing black and white paints which could be applied to this surface to modify its thermal characteristics as required.

2. Constructing a detailed mathematical model of the spacecraft's heat balance, using equations as outlined in Appendix 1, and using this model to find a combination of thermal control surfaces on the various exposed areas of the spacecraft which would keep the spacecraft temperatures within their required limits.

Development of the thermal control surfaces was not easy, and got off to a bad start. A very high quality gold finish was required on the spacecraft and had to be produced directly from the plating process without burnishing. The restrictions on burnishing, and the comparatively large size of pieces to be plated, produced considerable difficulties. An electroless process was first used to apply the gold, but troubles were encountered due to difficulties in obtaining uniform optical characteristics over the whole surface of the items, and due also to poor adhesion between the gold and the substrate. Gold was applied to the model D2 in this manner but was abandoned on subsequent models. An electroplating method was finally used which produced a very high quality surface on the flight spacecraft.

Likewise initial work with paints was disappointing. Paints for use as thermal control surfaces, especially white paints, are difficult to develop since they must be able to withstand the extreme temperature cycling experienced by the skin of the spacecraft as it goes in

† E. C. Semple, 'Principles and Techniques in the Passive Thermal Control of Spacecraft', R.A.E. Tech. Report No. 67100.

and out of the Earth's shadow, and must also be able to withstand the degrading effect of ultra-violet radiation which is liable to cause the paint to darken in colour (thus altering its absorptance to solar radiation). Tests on early American silicone paints recommended for this purpose proved unsatisfactory on both accounts, and work was started in this country to develop paints for *UK-3*. A black acrylic paint, and a white acrylic paint overcoated with white silicate paint were successfully developed and were used on the spacecraft.†

A mathematical model of the spacecraft's thermal characteristics was made by the British Aircraft Corporation and was used to deduce a satisfactory distribution of the thermal control surfaces. Because of the large gold area required, it was inevitable that most of the painted surfaces had to be white: this produced the greatest reduction in (a/e) for the least quantity of paint. However, a number of detailed factors had to be taken into account in deciding the optimum design, the main ones being as follows:

(*a*) The battery and tape recorder were the most temperature-sensitive items on board and were both towards the base of the spacecraft. The thermal design therefore had to be arranged so that the temperature variations caused by changes in solar aspect were minimized in this region. This meant that items towards the top of the spacecraft, notably the Meteorological Office experiment, would go through a much wider temperature range with variations in attitude. This was considered acceptable since the temperature of this experiment could be made satisfactory for the first few months after launch, and would only reach its minimum or maximum when precession of the spin axis had brought the Sun round from the side of the spacecraft to one or other of the ends. The expected life of the experiment was only a few weeks.

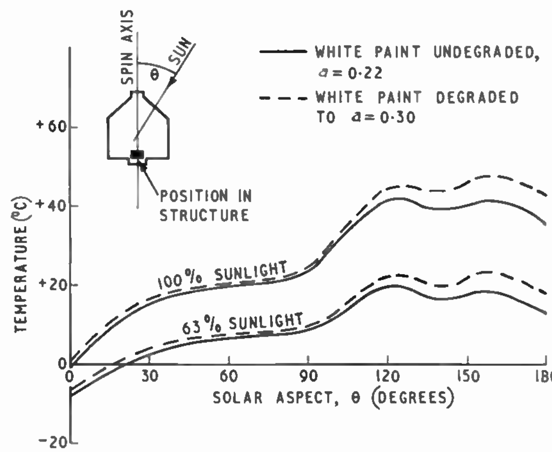
(*b*) Allowance had to be made for possible degradation of the white paint and the gold. How much to allow for this was difficult to assess since none of the surfaces developed had previously been used on spacecraft.

The initially proposed thermal control surface pattern was

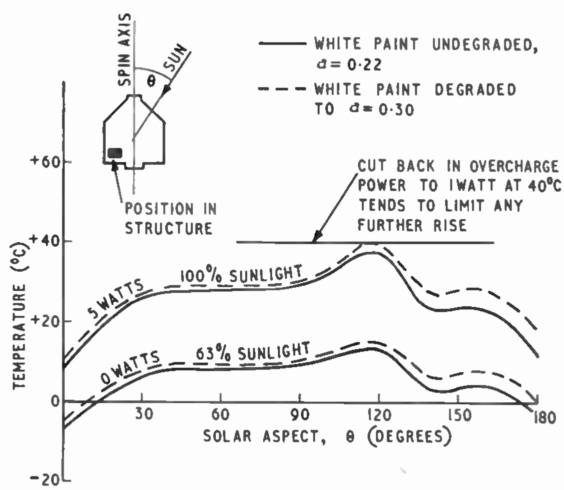
	Gold	Black paint	White paint
Cone	65%	25%	10%
Base	70%	0%	30%

—the gap emittance between the solar cell trays and the doors being about 0·1. With this pattern, however, control surface degradation was liable to cause over-

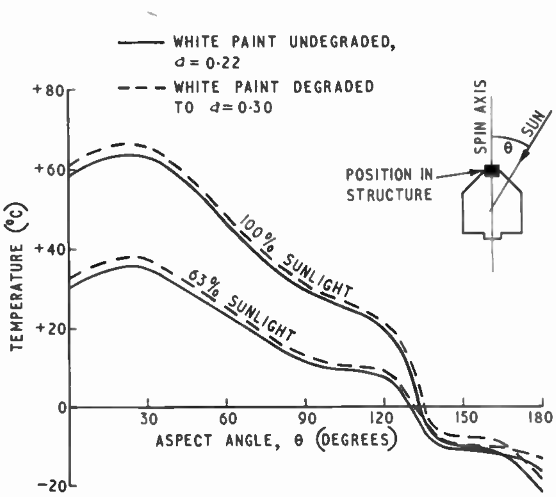
† J. J. K. Rhodes, 'Stable White Paint System for the *UK-3* Spacecraft', D. C. I. Report No. 146.



(a) Predicted tape recorder temperature.



(b) Predicted battery temperature.



(c) Predicted Meteorological Office experiment temperature.

Fig. 2. Predicted temperatures of units in *UK*-3 showing effect of white paint degradation if it occurred. (Based on B.A.C. calculations.)

heating in the battery, and through a number of intermediate steps the pattern was finally changed to

	Gold	Black paint	White paint
Cone	65%	10%	25%
Base	55%	0%	45%

The paint pattern on the base was disposed asymmetrically so that there was 60% white paint in the vicinity of the battery. The door/tray gap emittance was also increased to 0·7.

This final paint pattern was such that even with a degradation of the white paint from an absorptance of 0·2 to 0·4 no limits would be exceeded and it was unlikely that any serious damage would be done unless the absorptance reached 0·6 . This was done at the risk of possibly overcooling the tape recorder in the top-to-Sun attitude if no degradation of the white paint in fact took place. Again, since this attitude was remote from the side-to attitude into which the spacecraft would be launched, the risk was considered acceptable.

Figures 2 (a), (b) and (c) show the final predicted tape recorder, battery and Meteorological Office experiment temperatures in all attitudes relative to the Sun, and for the maximum and minimum heating cases; the consequences of white paint degradation are also shown. All the other units in the spacecraft had a temperature range within that given for these three items.

3. Thermal Testing

3.1. *Space Test Chamber*

In parallel with the work already described, work was also proceeding on the installation and commissioning of a Space Test Chamber at R.A.E. in which solar simulation tests on the spacecraft could be carried out to check the overall thermal design.

The chamber, illustrated in Fig. 3, is about 11 ft in diameter and is designed to simulate the main features of the thermal environment in space. The two 36 inch diffusion pumps can sustain a vacuum in the chamber of 10^{-6} torr against the outgassing load from the spacecraft. A battery of six carbon arc lamps simulate the Sun and can illuminate a 2·5 m diameter circle at the working section, each lamp providing a nominal intensity of about $\frac{1}{4}$ of the solar constant at this distance. Liquid nitrogen in the black painted shrouds lining the chamber cools them to about 100°K or less and this produces a radiative heat sink similar to that of space.

The cylindrical support, or sting, which is attached to the base of the spacecraft can rotate to simulate the spin of the spacecraft in orbit. In this chamber it does not rotate continuously, but makes three revolutions one way then three revolutions back. It is thus possible to avoid the use of slip rings to transmit data by line from the spacecraft by using a mechanism like a clockspring which winds out and in as the outer part of the sting rotates to and fro. There are about 400 such connections through the sting to monitor the working of the spacecraft and to transmit temperature information. A relay box is fitted to the top of the sting near the spacecraft to disconnect selected groups of these monitoring leads if their capacitance is upsetting the operation of the spacecraft.

The attitude of the spacecraft relative to the heat flux from the lamps can be altered by turning the quadrant arm which supports the sting. The rotation mechanisms are hydraulically operated.

While all this produces conditions similar to those in orbit, it will be realized that the conditions are not identical.

One discrepancy is the use of liquid nitrogen to cool the shroud. 100°K may appear to be a poor approximation to the absolute zero temperature of space, but examination of eqn. (1) shows that if space were at a temperature of 100°K the equation would have been written as:

$$aA_pS = eAr(T^4 - 100^4) \qquad \text{......(3)}$$

Typically T = 300°K for a spacecraft and the difference which the extra term makes in the total heat-flow is little over 1%. In the analysis of chamber results this can be taken into account, but it clearly is not a very significant term.

The heating effects from the Earth are not simulated, but other similar effects do unavoidably occur in the chamber. These can be observed in Fig. 4 which shows the D2 model of *UK-3* without paddles under test in the chamber.

The first of these additional heat sources is light reflected off the back shroud. As will be seen, a sizable area is illuminated by the beam, but the reflectance of the surface is no more than about 3% and only a small amount of the light reflected again impinges on the spacecraft. The contribution this makes to the total heat input to the spacecraft is about 2 or 3%.

The other secondary heat inputs are from the sting, and are partly conductive and partly radiative. Conduction from the spacecraft to the sting could be quite significant and, since it would be difficult to estimate the quantity of heat involved, it could seriously affect the usefulness of the test. To avoid this problem, a heater is fitted to the top flange of the sting and this is controlled to minimize the temperature difference between the spacecraft separation ring and the flange: in practice the temperature drop across the junction is limited to 2°C. This plus an insulating ring effectively stops all conductive transfer.

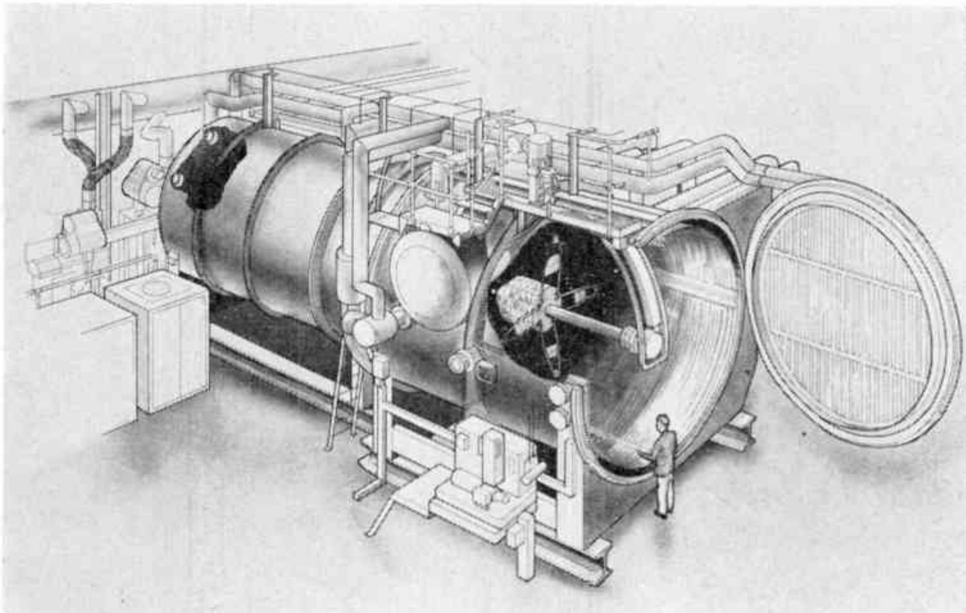


Fig. 3. 2·5 m space test chamber at R.A.E., Farnborough.

Radiative heat transfer between the two parts is significant since the outer surface of the sting is not cooled with liquid nitrogen, but the effects of this can be calculated.

The main problem arises from the beam of the carbon arc lamps. In the first place this differs from the characteristics of the Sun in that there is considerable divergence, and the flux comes from a number of separate and discrete points. Also, and what is more difficult to keep track of, the intensity falls off with time, and the rate at which this degradation occurs varies considerably across the beam. To overcome these problems a comprehensive digital computer program was written to take account of the divergence and multiplicity of the beams when calculating the heat flux on a particular part of a spacecraft in the chamber. The degradation of the lamps is monitored during a run by recording the temperature of black disks suspended in the chamber in the most critical areas. Figure 4 shows three such disks suspended in the chamber; in later tests more disks were used. This, combined with extensive intensity measurements before and after each run, allowed a fairly accurate estimate of heat flux to be obtained during tests.

3.2. *UK-3 Tests*

In the solar simulation tests on *UK-3*, the aim was to check that the spacecraft had thermal characteristics which corresponded closely with those of the mathematical model which had been used at B.A.C. to predict in-orbit temperatures. This involved a series of tests with the spacecraft in different attitudes relative to the beam from the lamps. Because of the differences between the conditions in the chamber and in orbit, the exact conditions of a specific orbital case could not be reproduced; the aim of the tests was simply to create a series of known thermal situations which would exercise the main thermal characteristics of the spacecraft. By applying the chamber heat

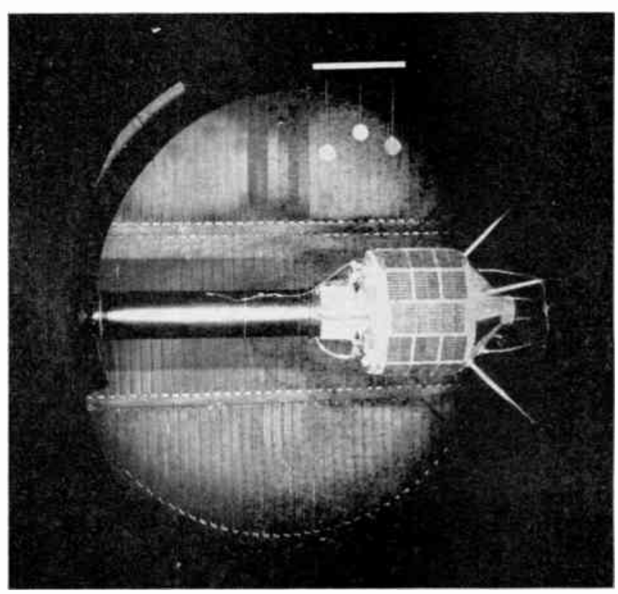
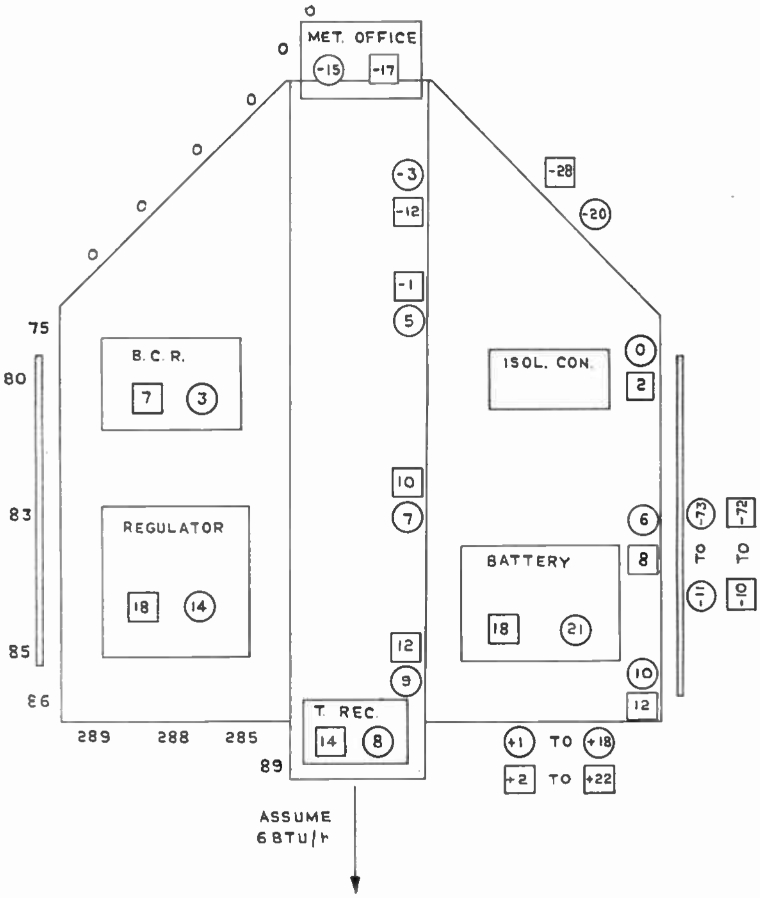


Fig. 4. D2 model of *UK-3* during solar simulation tests.



□ = predicted temperature °C ○ = measured temperature °C

Plain numbers = estimated local intensity Btu ft^{-2} h (1 Btu ft^{-2} = 98 Jm^{-2} h)

Fig. 5. Typical comparison between measured and predicted temperatures obtained during solar simulation tests (base and side are illuminated).

inputs to the mathematical model, a comparison between theory and practice could be obtained.

Two main series of solar simulation tests were carried out on *UK-3*, the first being on the D2 (electrical compatibility) model, and the second on the prototype. The initial series of tests was aimed largely at establishing test procedures and sorting out interface problems between the spacecraft and the chamber. It was feared that the in-chamber temperatures would not correspond well with theory because the thermal control surfaces were below standard on this early model, and because there was some doubt about the method being used for intensity measurement. In the event the results obtained corresponded well with theory.

The prototype tests were, however, regarded as the main tests to verify the thermal performance of the spacecraft. Again the difference between calculated and measured temperatures was low—typically about 5 degC; an apparent error of 15 degC or so in one attitude was found to be due to difficulties in intensity measurement. It was considered that general accuracy better than 5 degC could not be expected from the experiments, and such possible errors could easily be accommodated by the spacecraft when in orbit.

In each series of tests, four cases were studied. These were:

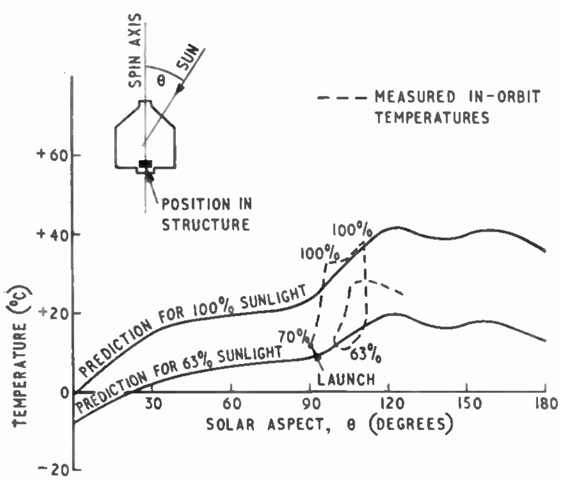
(*a*) Top to lamps, with spacecraft power on.

(*b*) Side to lamps (Fig. 4), with spacecraft power on.

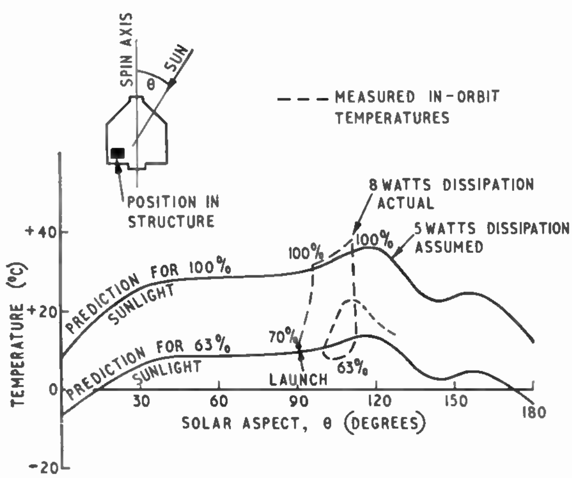
(*c*) Side to lamps, with spacecraft power off.

(*d*) Partially base to lamps, with spacecraft power on.

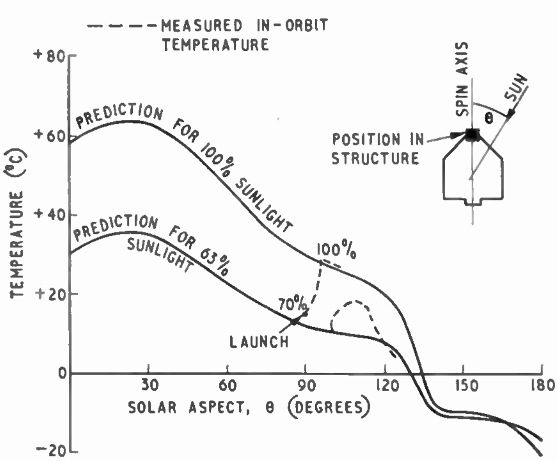
The latter case was chosen because a complete base-to-lamps test could not be performed without excessive shadowing by the quadrant arm. During these tests the paddles were not fitted, but were tested



(a) Tape recorder temperatures.



(b) Battery temperatures.



(c) Meteorological Office experiment temperatures.

Fig. 6. Comparison of predicted and measured mean in-orbit temperatures for the units in *UK*-3.

separately after the D2 tests. Supplementary tests on P1 body in two attitudes were carried out later to check minor design changes.

To allow temperatures to settle, the tests in each attitude lasted typically about 16 hours, and variations in temperature as the spacecraft passes in and out of the Earth's shadow were simulated by switching the lamps off for the last ½ hour of each nominal 2 hour simulated orbit. During the off-time, maintenance of the lamps could be carried out. Only 5 of the 6 lamps were used at one time, the other one being kept in reserve in case of a failure.

Throughout the tests 40 temperatures from thermocouples on the spacecraft and sting were recorded every 10 minutes. These were presented on-line in approximate form, and were also punched on paper tape for subsequent processing on a computer. Figure 5 shows a typical comparison between measured and calculated temperatures.

The satisfactory results from these tests added confidence to the results obtained from theoretical work on the spacecraft's heat balance in orbit, and provided useful information in areas which were difficult to analyse. The tests also exposed the spacecraft in general to an environment typical of that which it would experience in space. More extended thermal soak tests in the same chamber did, however, test the spacecraft more thoroughly in this latter respect. In these tests the spacecraft temperature was controlled with radiant heaters.

4. In-orbit Temperatures

Comparison between the predicted temperatures and the measured temperatures in orbit is given in Figs. 6 (a), (b) and (c). The spacecraft was launched in a side-to-the-Sun attitude and has more or less maintained this attitude since launch, so the thermal design has not yet been tested in all aspects. The temperatures so far measured are, however, very satisfactory and show that the predictions were correct to within a few degrees.

Even such differences as there are can be largely explained. When the spacecraft was in full sunlight, the overcharge power dissipation in the battery was higher than expected—8 watts instead of 5 watts; this accounts for the higher than predicted temperatures in this condition. Also by the time the spacecraft was in maximum shadow (63% sunlight), the intensity of the radiation from the Sun was at its annual minimum; the operating temperature could therefore be expected to be 2 to 3 degC lower than the predicted temperatures which were calculated using the average intensity over the year. The asymmetry of paint pattern on the base was not taken into account accurately, and this could also contribute to the lower than predicted temperatures in the power quadrant at minimum sunlight. Despite the concern before launch, there is no evidence that the properties of the thermal control surfaces are significantly different from those predicted from laboratory measurements. No degradation of any of the main thermal control surfaces has been detected.

5. Conclusions

The all-round correspondence between the predicted temperatures, the in-chamber temperatures, and the in-orbit temperatures for *UK-3* was in general about 5 degC, and this compares very well with the best achieved in America. Of the various factors contributing to this, the main were:

(*a*) The high accuracy computing techniques used to predict the spacecraft's temperatures which were basically those developed by NASA at Goddard Space Flight Center.

(*b*) The high quality of the 'gold plate', 'white paint' and 'black paint' thermal control surfaces specially developed for the project, all of which have retained their nominal thermal properties without detectable change since launch.

(*c*) The care taken in measuring and computing the intensity of the beam from the carbon arc lamps during solar simulation tests.

The information now available on the performance of the *UK-3* thermal control surfaces in space will greatly simplify the thermal design of future British spacecraft. On *UK-3* a great deal of the design development was aimed at coping with possible extreme degradation of the surfaces (in particular the white paint) which, in the event, did not occur. That the surfaces have been so satisfactory reflects considerable credit on those concerned with their development, as the problem is generally accepted to be difficult, and experience on other spacecraft in America has shown that substantial in-orbit changes often occur.

6. Acknowledgments

The author wishes to acknowledge the work of the various organizations which contributed to the success of the thermal design of *UK*-3. These were the British Aircraft Corporation, Stevenage, the Directorate of Chemical Inspection, the Directorate of Materials, Precious Metal Depositors Ltd., and Space Department, R.A.E., Farnborough. Particular acknowledgment is made of the work of Mr. J. J. K. Rhodes of D.C.I., Woolwich, in developing the white paint system.

7. Appendix

The form of the equations used to describe the heat transfer between various parts of a spacecraft is given below for the *i*th node:

$$\underbrace{C_i\dot{T}_i}_{\text{Effective heating rate of node}} = \underbrace{Ha_in_iA_{pi}S}_{\text{Heating rate from sun}} + \underbrace{a_iA_iF_{ai}}_{\text{Heating rate from reflected sunlight}} + \underbrace{e_iA_iF_{ei}}_{\text{Heating rate from Earth-shine}} - \underbrace{\sum_j A_iG_{ij}e_{ij}r(T_i^4-T_j^4)}_{\text{Rate of heat loss by radiation to the rest of spacecraft}} - \underbrace{\sum_j K_{ij}(T_i-T_j)}_{\text{Rate of heat loss by conduction to the rest of spacecraft}} - \underbrace{A_is_ie_irT_i^4}_{\text{Rate of heat loss to space}} + \underbrace{I_i}_{\text{Internal heat dissipation rate}} \qquad \ldots\ldots(4)$$

The symbols have the following meaning:

a_i solar absorptance of the *i*th node,

A_{pi} projected area of the *i*th node in the direction of the Sun,

A_i surface area of the *i*th node,

C_i thermal capacity of the *i*th node,

e_i infra-red emittance of the *i*th node to space,

e_{ij} effective emittance between the *i*th and the *j*th node,

F_{ai} mean albedo flux from the Earth incident on unit area of node *i*,

F_{ei} mean Earth shine flux from the Earth incident on unit area of node *i*,

G_{ij} radiative shape factor of the *j*th node relative to the *i*th node,

H 1 or 0 depending on whether spacecraft is in sunlight or not,

I_i internal heat dissipation of the *i*th node,

K_{ij} conductive heat transfer between nodes *i* and *j* for a temperature difference of 1 deg,

n_i a fraction which can take account of shadowing due to paddles, etc., on the *i*th node,

r Stefan-Boltzmann constant,

s_i shape factor to space of the *i*th node,

S solar constant,

T_i absolute temperature of the *i*th node

$\dot{T}_i$ rate of change of temperature of the *i*th node.

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Conversion Between Binary Code and Some Binary-decimal Codes

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Summary: Recent papers have described controlled shift register systems with which conversion can be made between pure binary code and 8421 binary-decimal code. This paper shows how this technique may be extended to other weighted binary-decimal codes, and puts forward a wider theory of which 8421 b.c.d. is a special case.

1. Introduction

Conventional methods for decoding a number from pure binary code into decimal form, suitable for display or print-out, involve the conversion from pure binary code to a binary-decimal code from which the decimal display can easily be obtained, or printer solenoids can be driven. Their conversion has sometimes been carried out by using a diode or a similar matrix, but the matrix becomes very complex for even one or two decimal digits. An alternative method depends on setting the binary number into a counter which is counted down to zero by a gated train of pulses which also feeds a binary-decimal counter. The pulses cease when the gate is closed as the binary counter passes through zero. The required number is the count which is stored in the binary-decimal counter at the end of the pulse train. This method can be very slow since it depends on the process of counting rather than on logical decisions. Similar problems exist with decimal-binary encoders.

Couler[1] proposed that the conversion could be carried out by successive multiplication by two in a shift register and by using a test pulse to examine the condition of the register and if necessary to inhibit multiplication before further shifting. More recently it has been shown[2] that this process can be carried out by shifting, and at the same time adding binary 3 (011) under certain conditions. It has been further shown[3,4] that this is equivalent to division by 10 and recording the remainders.

2. Theory

Consider a number n to be divided by p such that

$$n = Qp+r$$

where r is the remainder. One shift along the register gives

$$2n = 2Qp+2r+s$$

where s is either 1 or 0 and is the next digit inserted into the register. The new remainder is thus $2r+s$ so long as $2r+s$ is less than p. In the case with which we are concerned, $p = 10$, so the remainder is $2r+s$ when this is less than 10. Then since s is less than 2, it is still true that $2r+s$ is the remainder so long as r is less than 5. When r is equal to or greater than 5 the remainder is $2r+s-10$. Now in binary code, subtraction of 10 can be carried out by complementing, that is by adding 6. Further, if this is done before shifting rather than after shifting, this is equivalent to adding binary 3.

Thus to divide a number by 10, it is passed through a 4-bit shift register and examined after each shift. When the number in the register is not less than 5, 3 is added when making the next shift. This is illustrated by an example in which the binary equivalent of 189 is passed through two 4-bit registers to convert it to 8421 b.c.d.

	L M N P	Q R S T		
			1 0 1 1 1 1 0 1	
		1	0 1 1 1 1 0 1	
		1 0	1 1 1 1 0 1	
		1 0 1	1 1 1 0 1	
	1	0 0 0 1	1 1 0 1	(3 added to units)
	1 0	0 0 1 1	1 0 1	
	1 0 0	0 1 1 1	0 1	
	1 0 0 1	0 1 0 0	1	(3 added to units)
1	1 0 0 0	1 0 0 1		(3 added to tens)
1	8	9		

This example shows that when the number has been shifted into the registers, the remainders are given in 8421 b.c.d. This is because the code follows the same pattern as pure binary code for the ten decimal digits. In a similar way it is possible to shift a number already in this binary-decimal code, in the opposite direction out of the controlled registers, subtracting 3 whenever the number in a 4-bit register is not less than 5.

3. Operation in Other Codes

If it is desired to express the number in other binary-decimal codes, it will still be necessary to divide the pure binary number successively by 10, but it will also be necessary to modify the combination which

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Table 1
Comparison of 8421 b.c.d. code with other binary-decimal codes.

States before shifting				States after shifting into code															
				8421 b.c.d.				2421 b.c.d.				4221 b.c.d.				6221 b.c.d.			
Q	R	S	T	P	Q	R	S	P	Q	R	S	P	Q	R	S	P	Q	R	S
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1	1
0	0	1	1	0	0	1	1	0	0	1	1	0	1	0	1	0	1	0	0
0	1	0	0	0	1	0	0	0	1	1	1		†				†		
0	1	0	1	1	0	0	0	1	0	0	0		†				†		
0	1	1	0	1	0	0	1	1	0	0	1		†			0	1	0	1
0	1	1	1	1	0	1	0	1	0	1	0		†			1	0	0	0
1	0	0	0	1	0	1	1		†			0	1	1	1	1	0	0	1
1	0	0	1	1	1	0	0		†			1	0	0	0	1	0	1	1
1	0	1	0		†				†			1	0	0	1	1	1	0	0
1	0	1	1		†				†			1	1	0	0	1	1	0	1
1	1	0	0		†				†				†				†		
1	1	0	1		†				†				†				†		
1	1	1	0		†			1	0	1	1	1	1	0	1		†		
1	1	1	1		†			1	1	1	1	1	1	1	1		†		

† These states cannot exist.

would otherwise result to obtain the desired coding. Thus, a set of rules must be drawn up for each code, which effectively divides by 10 and leaves the remainder in that code. Here this will be illustrated for 2421 b.c.d. However, Table 1 compares the process for 8421 b.c.d. and some other binary-decimal codes.

In Table 1 it is interesting to note that certain states can never occur, since those states which give rise to them would be modified at previous shifts before they could do so. In each case there are six of these states, since the sixteen binary states in each group are being reduced to ten, but due to the different coding, they occur in different parts of the sequence. The data in Table 1 can be deduced by considering the effect of a single shift on the number stored in the register. Thus 4 must be doubled to give 8, and 8 doubled to give 16.

4. Theory for Inflexible Codes

In the case of 2421 b.c.d. using the notation previously employed, the remainder after shifting must be $2r+s$ *in that code*, so long as $2r+s$ is less than 10. This code is an example of a class of codes, which will be called inflexible codes, in which the next digit, s, does not influence the coding of the other digits.

However, when $r = 4$ the coding of $2r$ then differs from that of 8421 b.c.d. In this case binary 6 must be added so that $2r$ is coded $111s$ rather than $100s$.

When $r = 5$, 6, or 7 the new remainder after shifting is $2r+s-10$ and the method is as before where 3 is added whilst the dividend, Q, (= 1) is propagated along the register.

When $r = 8$, $2r+s-10 = 6+s$, so that 1110 must become $1011s$. Similarly when $r = 9$, the remainder after shifting is $8+s$ so that 1111 becomes $1111s$.

This is a general treatment for all inflexible weighted codes. A theory for flexible weighted codes will be discussed later.

Again, decoding the binary equivalent of 189 can be used as an example of the method. The results, expressed in a number of codes, are obtained from Table 1.

(*a*) 2421 b.c.d.

				P	Q	R	S	T								
									1	0	1	1	1	1	0	1
								1	0	1	1	1	1	0	1	
							1	0	1	1	1	1	0	1		
						1	0	1	1	1	1	0	1			
				1	0	0	0	1	1	1	0	1				
			1	0	0	0	1	1	1	0	1					
		1	0	0	0	1	1	1	0	1						
	1	1	1	1	0	1	0	0	1							
1	1	1	1	0	1	1	1	1								
1		8				9										

(*b*) 4221 b.c.d.

				P	Q	R	S	T								
									1	0	1	1	1	1	0	1
								1	0	1	1	1	1	0	1	
							1	0	1	1	1	1	0	1		
					1	0	0	1	1	1	1	0	1			
				1	0	0	0	1	1	1	0	1				
			1	0	0	0	1	1	1	0	1					
	1	0	0	0	1	0	1	1	0	1						
	1	1	1	1	1	0	0	0	1							
1	1	1	1	0	1	1	1	1								
1		8				9										

(*c*) 6221 b.c.d.

				P	Q	R	S	T								
									1	0	1	1	1	1	0	1
								1	0	1	1	1	1	0	1	
							1	0	1	1	1	1	0	1		
						1	1	1	1	1	1	0	1			
				1	0	0	0	1	1	1	0	1				
			1	0	0	0	1	1	1	0	1					
		1	1	0	1	0	0	1	0	1						
	1	0	1	1	0	1	1	0	1							
1	1	0	1	0	1	0	1	1								
1		8				9										

5. Flexible Codes

These codes include, for example, 7421 b.c.d. and 5421 b.c.d. In order to deduce a method for successive division by 10, the incoming bit to the register must be examined so that the register can be controlled to give the correct coding after shifting.

This has two effects on the logic for controlling the register. Firstly, the new state of a decade must take into account the next less significant digit which is being inserted, and secondly, by taking this into account, the subsequent states of the next less significant decade may be affected also. The method for this class of code follows that of the example given here for 5421 b.c.d.

The example previously used for some inflexible codes can be used to show the decoding of a binary number into 5421 b.c.d.

				P	Q	R	S	T								
									1	0	1	1	1	1	0	1
								1	0	1	1	1	1	0	1	
							1	0	1	1	1	1	0	1		
					1	0	0	0	1	1	1	0	1			
				1	0	0	0	1	1	1	0	1				
			1	0	0	0	1	1	1	0	1					
		1	0	0	1	0	1	0	0	1						
	1	1	0	0	0	1	0	0	1							
1	1	0	1	1	1	1	0	0								
1		8				9										

Table 2

Code conversion into 5421 b.c.d.

States before shifting					States after shifting									
					when U = 0					when U = 1				
Q	R	S	T	U	P	Q	R	S	T	P	Q	R	S	T
0	0	0	0	0/1	0	0	0	0	0	0	0	0	0	1
0	0	0	1		0	0	0	1	0	0	0	0	1	1
0	0	1	0		0	0	1	0	0	0	1	0	0	0+
0	0	1	1		0	1	0	0	1	0	1	0	1	0+
0	1	0	0		0	1	0	1	1	0	1	1	0	0+
0	1	0	1				†					†		
0	1	1	0				†					†		
0	1	1	1				†					†		
1	0	0	0		(1)	0	0	0	0	(1)	0	0	0	1
1	0	0	1		(1)	0	0	1	0	(1)	0	0	1	1
1	0	1	0		(1)	0	1	0	0	(1)	1	0	0	0+
1	0	1	1		(1)	1	0	0	1	(1)	1	0	1	0+
1	1	0	0		(1)	1	0	1	1	(1)	1	1	0	0+
1	1	0	1				†					†		
1	1	1	0				†					†		
1	1	1	1				†					†		

† These states cannot occur.

The states shown in brackets will be 0 if the more significant decade had been those marked thus, + before shifting.

6. System Design

The practical implementation of these principles depends on the nature of the logical elements which are to be used. It will be assumed here that J-K flip-flops will be used. The Karnaugh[5] map method of minimization will be used in the way which has been described for the design of parallel counters.[6] The design of a converter operating in 2421 b.c.d. will now be explained to illustrate these techniques. A similar method could be used for any inflexible code, although a converter operating in a flexible code would be more complex than this.

The J-K flip-flop is a bistable element which is now commonly available on silicon chips and which may be defined by a truth table or by the steering conditions shown in Table 3.

Table 3

State transitions		Necessary and sufficient conditions	
First state	Second state	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0
†	0	0	1
†	1	1	0

X denotes an immaterial state.

† denotes a state the value of which is not known.

Table 4 shows the master Karnaugh map which defines the location of cells in 2421 b.c.d. It also gives certain states which, as shown in Table 1, do not occur, and so may be assigned any convenient value when minimizing the control logic.

Table 4

ST \ QR	00	01	11	10
00	0	4	X	X
01	1	5	X	X
11	3	7	9	X
10	2	6	8	X

It is now possible to deduce the logic for controlling a group of four bistable elements so that they will follow the transitions shown in Table 1 and illustrated in the example immediately after it. Logical inputs are fed serially to this group as shown in the example. The decode is complete when the number has been completely inserted into the register.

It may be of interest to note in this example, as in any of the decoders described here, that the states taken up after each shift pulse are as follows:

0, 1, 2, 5, 11, 23, 47, 94, 189.

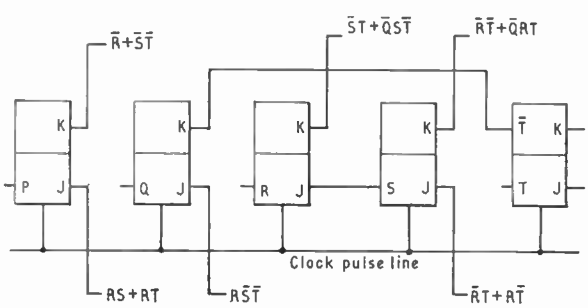
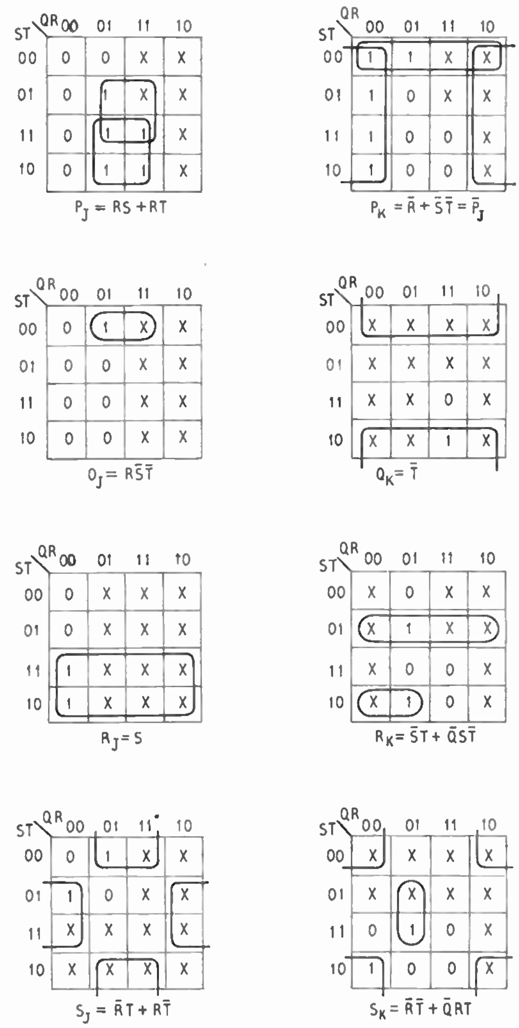


Fig. 1. Controlled shift register for one decade of a binary to 2421 b.c.d. converter.

The Karnaugh maps of Table 5 are based on the cell positions of Table 4 and the transitions of Table 1. The cells are assigned values using the conditions of Table 3.

Table 5



Minimization has been carried out in Table 5 by looping groups of cells. Logical elements can then be interconnected to implement these conditions. The outline of the controlled register is shown in Fig. 1.

7. Conclusion

By a similar process it is possible to deduce conditions for controlling registers, all of which effectively divide by 10, and so act as code converters, but in which the display is coded in different forms. Table 6 gives a summary of some of these results for some inflexible weighted codes.

Table 6

	8421 b.c.d.	2421 b.c.d.	4221 b.c.d.	6221 b.c.d.	6421 b.c.d.
P_J	$Q + RS + RT$	$RS + RT$	$QS + QT$	$Q + RT$	$Q + RT$
P_K	$\bar{Q}\bar{R} + \bar{Q}\bar{S}\bar{T}$	$\bar{R} + \bar{S}\bar{T}$	$\bar{Q} + \bar{S}\bar{T}$	$R\bar{T} + \bar{Q}\bar{R}$	$\bar{Q}\bar{R} + R\bar{T}$
Q_J	$R\bar{S}\bar{T}$	$R\bar{S}\bar{T}$	S	$R\bar{T} + \bar{R}ST$	ST
Q_K	$\bar{T}$	$\bar{T}$	$\bar{S}T + S\bar{T}$	$\bar{S}$	$Q\bar{S} + RT$
R_J	$S + Q\bar{T}$	S	$Q\bar{S}\bar{T}$	$\bar{Q}S\bar{T} + Q\bar{S}T$	$Q\bar{S}T + QS\bar{T}$
R_K	$\bar{S} + \bar{T}$	$\bar{S}T + \bar{Q}S\bar{T}$	$\bar{T}$	1	1
S_J	$Q\bar{R}T + Q\bar{T}$	$\bar{R}T + R\bar{T}$	$Q + T$	$Q + T$	$Q\bar{T} + R\bar{T} + \bar{Q}\bar{R}T$
S_K	$\bar{R}\bar{T} + RT$	$\bar{R}\bar{T} + \bar{Q}RT$	$\bar{Q}R\bar{T} + QST$	$\bar{Q}T + Q\bar{T}$	$\bar{Q} + \bar{T}$

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(Paper No. 1165/C101.)

Letters to the Editor

Superdirective Arrays

SIR,

Professor Tucker's paper (*The Radio and Electronic Engineer*, October 1967, p. 251) illustrates the importance of freeing ourselves from the limitations imposed by passive circuits. In an aerial array which consists entirely of interconnected passive elements which are fed from a single input port (pair of terminals), superdirectivity and supergain are synonymous and difficult to achieve. Gain is, of course, the ratio of the field intensity in the preferred direction to the intensity which would have been required with an omni-directional aerial in order to have the same power in the feeder: note that the direction of power flow is not stated, so that this definition applies equally to transmitting and receiving aerials.

In the buffer-amplifier technique the individual elements are fed with constant current and this implies a source of volt-ampere capability much greater than the power radiated from the aerial. The interesting question is whether an approximation to constant current of prescribed phase can be obtained from a purely reactive network, so that the increase in source volt-amperes need not represent a corresponding increase in power. In the receiving aerial the requirement is that negligible current should flow in the elements, and therefore negligible power will be supplied to the receiver, i.e. the receiving system *in toto* is voltage-operated and not power-operated. This indicates one of the limitations of the device, and incidentally shows that it will be difficult to define a noise figure since this is based on power ratios. The wording used by Schelkunoff and Friis, quoted by Professor Tucker, to the effect that a strong reactive field created by currents in the superdirective aerial changes the direction of power flow in neighbouring space, could be misleading. Since all electromagnetic phenomena in free space obey the principle of linear superposition, the re-radiated field from the antenna cannot alter the progress of the incident radiation; but by changing the relative phase between total magnetic field and total electric field it can change the power absorbed by the aerial as calculated, for example, by Poynting's theorem.

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7th November 1967.

(*continued on page 54*)

The Comparative Strengths of Polytetrafluoroethylene and Polychlorotrifluoroethylene under Nuclear Radiation

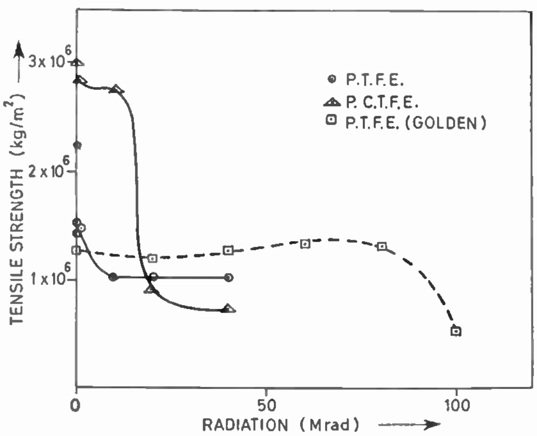
SIR,

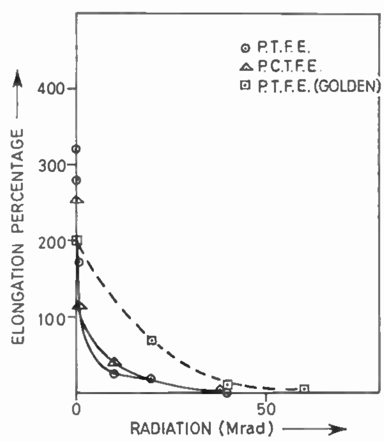
A low-loss insulating material was required for use in exposed positions on the surface of a spacecraft where, in orbit, it would be under mechanical stress and subject to high vacuum and nuclear radiation. Polytetrafluoroethylene (p.t.f.e.) and polychlorotrifluoroethylene (p.c.t.f.e.) appeared generally suitable† but their comparative strengths under the conditions of irradiation in high vacuum were not known, and have therefore been determined experimentally.

Small dumb-bell shaped samples of p.t.f.e. and p.c.t.f.e. suitable for tensometer tests were placed in separate thin-walled glass ampoules and held at a pressure of 1×10^{-5} torr and a temperature of $+100°C$ for 24 hours before being sealed. The outgassing process is important as p.t.f.e. degrades rapidly when irradiated in the presence of oxygen.

Pairs of samples were then irradiated using a 4 MeV electron beam accelerator with total dosages of from 1 to 40 Mrads. A further pair of samples was held unirradiated.

The samples were then stored at $+35°C$ for 24 hours to avoid effects due to the variations in the coefficient of expansion of p.t.f.e. which occur at room temperatures. Tensile strength and elongation determinations were then performed immediately at the same temperature, the elongation rate used being 1·25 cm/min. Results of the tests are shown in the accompanying diagrams and a series of measurements made by Golden‡ on p.t.f.e. alone is presented for comparison.





Figs. 1 and 2. Tensile strength and elongation measurements on irradiated p.t.f.e. and p.c.t.f.e.

The two series of measurements show that though p.c.t.f.e. has initially about twice the strength of p.t.f.e. it degrades rapidly with dosages in excess of about 10 Mrads and appears weaker than p.t.f.e. at higher radiation levels.

Elongation measurements are very similar for both materials and show that even small dosages produce substantial changes. Reasons for the higher elongation percentages obtained by Golden are not known but may be due to a difference in the cross-sectional area of the samples or to variations in the material.

I am indebted to the U.K.A.E.A., Wantage, Berkshire, and in particular to Dr. F. L. Dalton and Mr. J. D. McCann for the use of radiation facilities and for advice. The tensometer measurements were made by Mr. L. T. Harris of the Crane Packing Co., Slough. Discussions with Dr. J. H. Golden of the E.R.D.E., Waltham Abbey, are also gratefully acknowledged.

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20th October 1967.

† 'Fluoro-carbon plastics', *Materials in Design Engineering*, **93**, No. 215, 1964.

‡ J. H. Golden, 'The degradation of p.t.f.e. by ionising radiation', *J. Polymer Science*, **45**, p. 534, 1960, and private communication.

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The University of Birmingham Electron Density and Temperature Experiments on the *Ariel III* Satellite

By

J. H. WAGER†

Presented at a Symposium on 'The Ariel III Satellite' held in London on 13th October 1967.

Summary: An experiment to measure ionospheric electron densities based upon the detection of permittivity changes in a parallel plate capacitor is discussed briefly, together with a method of determining electron temperatures based on the comparison of differential currents to identical probes. The application of these techniques to the *Ariel III* satellite and some preliminary results are also described.

List of Symbols

- ε_0 permittivity of free space
- ε permittivity in the presence of free electrons
- N electron density number per cm^3
- e electron charge
- m electron mass
- C_0 capacitance between plates of probe in free space
- C capacitance between plates of probe in the presence of a plasma
- k Boltzmann's constant
- T electron temperature in degrees Kelvin
- ω angular frequency

1. Introduction

The measurement of the density and temperature of the electrons in the ionosphere from a satellite whose orbit is close to being circular and covering the polar region is useful in giving a world wide survey of the upper atmosphere and in studying the variation associated with changes in solar activity. The two instruments described produce data which are easily telemetered to earth and which need only a minimal amount of computation in order to yield electron number densities and temperature.

A description of the techniques used in the instruments developed to make these measurements is followed by details of the additions required to the basic designs in order to operate from the *Ariel III* satellite taking into account the limited power available on a space vehicle and the limitations imposed by the telemetry facilities available.

At this stage it is not possible to enter into detailed discussion of the results obtained as the enormous amount of data accumulated from a satellite borne experiment takes some considerable time to translate from raw telemetry tapes recorded at tracking stations situated throughout the world to finally computed data. However, some comment can be made on the general trends observed from the data which are at present available.

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2. The Electron Density Experiment

2.1. *Basic Theory*

A radio-frequency probe technique that has been employed over a number of years by the Electron Physics Department of Birmingham University is used. Its operation is based upon measurements of the permittivity of the medium in the presence of free electrons.

It can be shown[1] that the permittivity of a medium is a function of the free electron content and of the probing frequency which is used. At satellite altitudes certain simplifying assumptions may be made since the electron collision frequency is low and by a suitable choice of probing frequency the effects of electron gyro-frequency may be neglected. This gives rise to the following relation between permittivity, probing frequency and electron density number. Thus

$$\varepsilon = \varepsilon_0\left(1 - \frac{4\pi N e^2}{m\omega^2}\right) \qquad \ldots\ldots(1)$$

From this relationship it may be seen that if the probing frequency is known the changes in permittivity observed are directly proportional to the number of electrons present per cubic centimetre.

2.2. *The R.F. Probe—Principle of Operation*

The measurement of permittivity required from eqn. (1) may be made by observing the changes in capacitance of a parallel plate capacitor excited at a known fixed radio frequency. It is convenient to re-write eqn. (1) in the following form:

$$C = C_0\left(1 - \frac{8{\cdot}06\times10^7 N}{f^2}\right) \qquad \ldots\ldots(2)$$

where N is the electron number density per cm^3 and f is the probing frequency in hertz. The frequency of operation on the *Ariel III* satellite was fixed at 29·0 MHz in order to be compatible with the Radio and Space Research Station experiment. Since f is known eqn. (2) reduces to

$$1 - \frac{C}{C_0} = 9{\cdot}59 \times 10^{-8} N \qquad \ldots\ldots(3)$$

The capacitor probe takes the form of two grids each 7·6 cm (3·0 in) in diameter and spaced 5·7 cm (2·25 in) apart carried at the tip of one of the solar cell array paddles. If this structure is so biased that it is at space (or plasma) potential the volume between the grids will be filled with electrons at the ambient density. If the probe is held negative with respect to space electrons will be excluded from the volume between the grids giving a value of C_0 for the capacitance of the sensor. Thus a variation in the d.c. bias applied to the sensor structure will cause changes in the magnitude of the r.f. currents flowing between the grids.

Suppose that the potential of the sensor were varied by means of a square-wave switching between −6·0 V and space potential at a rate of a few kilohertz were to provide this bias voltage, it will be seen that amplitude modulation of the r.f. currents flowing between the sensor grids would result. However, since the exact value of space potential is dependent on a number of factors it is necessary to use a square-wave whose maximum positive amplitude gradually increases with time.

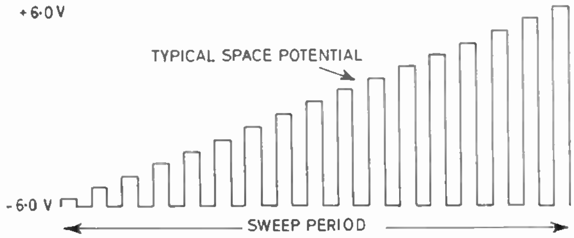

Fig. 1. Waveform applied to electron density sensor.

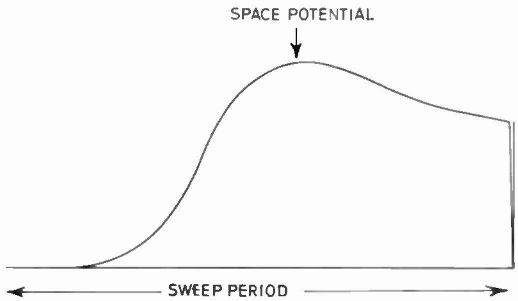

Fig. 2. Modulation envelope of 29 MHz r.f. signal.

The waveform applied to the sensor is shown in Fig. 1, a typical value for space potential being marked. Figure 2 shows typically how the magnitude of the modulation envelope would change with time. A fuller discussion of this technique will be found elsewhere.[2]

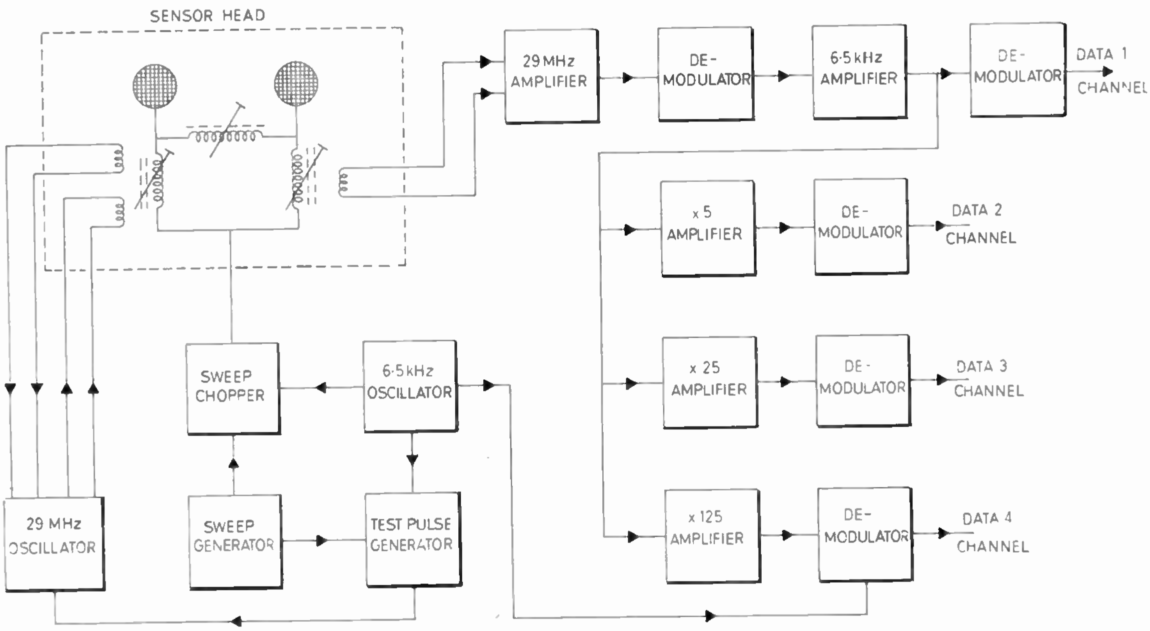

Fig. 3. Block diagram of the electron density experiment. Data 4 channel incorporates a synchronous demodulator.

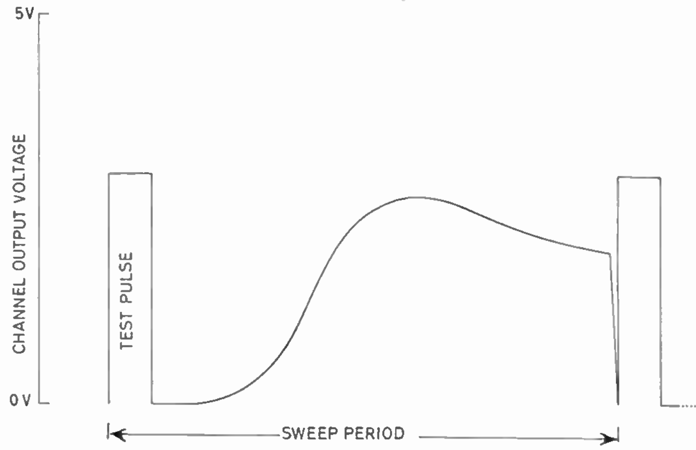

Fig. 4. Typical output of electron density experiment.

2.3. *Circuit Description*

Referring to Fig. 3, the circuitry shown within the dotted line is contained in a small box mounted directly below the grids forming the sensor head itself. Connections to the remainder of the circuitry contained within the satellite body are made by four coaxial cables.

The 29 MHz oscillator provides a signal of a constant amplitude and frequency which is applied to one of the grids. The signals flowing to the other grid via the parallel plate capacitor so formed are fed to the r.f. amplifier. The excitation voltage for the sensor is 3·0 V r.m.s. and the r.f. amplifier has a gain of approximately 100.

In the absence of electrons the capacitance between the grids is of the order of 0·9 picofarads and changes by approximately 10% for an electron density of $10^6/cm^3$. The inductor shown in parallel with this capacitor is tuned to resonate with it at 29 MHz in order to reduce the standing signal present on the pick-up grid and hence remove ambiguities which can arise due to spurious modulation of the r.f. oscillator. A fuller discussion of this phenomena is outside the present scope of this paper.

The sweep generator produces a linear saw-tooth varying between $-6{\cdot}0$ V and $+6{\cdot}0$ V with a period of 5·1 seconds. This together with the sweep chopper and 6·5 kHz oscillator generates the waveform shown in Fig. 1.

Since no modulation of the r.f. currents flowing between the grids of the sensor can occur in the absence of free electrons, it is useful to have a dummy signal in order to evaluate the operation of the equipment during pre-flight tests and to check on equipment performance when in orbit. By means of the test pulse generator a burst of modulation lasting 0·9 seconds is applied to the r.f. oscillator at the beginning of each sweep; this produces a pulse in the output data channels at a time in the sequence when no electron density data are being received.

The output of the r.f. amplifier consists of a 29 MHz signal amplitude-modulated by a square wave, the magnitude of this modulation being a measure of the electron density. The amplifier output is therefore demodulated using a conventional circuit, the 6·5 kHz signal output being further amplified by the 6·5 kHz amplifier which is tuned to improve the signal/noise ratio. The output of this amplifier is again demodulated to give a data channel output which has the form shown in Fig. 4.

Three more data channels will be seen, each one being five times more sensitive than the preceeding one. This choice of four channels allows coverage of a wide range of electron densities. In order to reduce system noise, data channel 4, the high sensitivity channel, has a synchronous demodulator on its amplifier output.

The sensitivity of the equipment on the *Ariel III* satellite is set so that a full-scale signal on data channel 1 corresponds to an electron density of about $2\times10^6/cm^3$. This value was chosen after consideration of the launch time with respect to the 11-year solar cycle.

3. The Electron Temperature Experiment

3.1. *Basic Theory*

The electron temperature measurement technique is essentially an extension of the Langmuir probe:[3,4] however, in this case use is made of two identical swept probes with a small potential difference ΔV between them. Added to the linear sweep voltage is a low-level sine-wave signal of 6·0 kHz which enables the differential current to each probe to be measured. These differential currents are compared and automatically kept in a fixed ratio by adjustment of the voltage ΔV. Under these conditions the electron

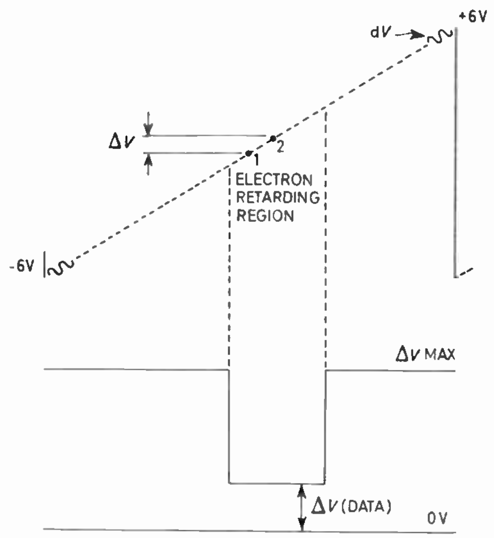

Fig. 5. Operating waveforms for the electron temperature experiment.

temperature is a function of this known ratio and the value of ΔV, as the probes are swept through the retarding region.

Figure 5 shows the sweep potential applied to the probes with respect to the spacecraft; the retarding region, i.e. just below space potential, is also indicated, together with the two electrodes ΔV apart on the sweep. The type of data signal obtained is also shown.

In practice a fixed ratio of 2 is chosen for the differential currents in which case the electron temperature may be determined from the equation.

$$T = \frac{e\Delta V}{k \ln 2} \qquad \ldots\ldots(4)$$

Examination of eqn. (4) shows that since e and k are known constants it is only necessary to telemeter the value of ΔV in order to calculate the electron temperature.

A full discussion of this technique is given elsewhere.[5]

3.2. *Circuit Description*

The block diagram of the temperature probe circuit is in Fig. 6. The sensor head shown contained within the dotted line is mounted at the tip of a solar cell array paddle diametrically opposite the one occupied by the electron density experiment. It consists of two rhodium-plated spheres 3·2 cm (1·25 in) in diameter with their centres 6·4 cm (2·5 in) apart. The surface of each sphere is chemically cleaned to ensure equal contact potentials between each sphere and the plasma.

Below the spheres a sensing transformer is contained in a small box. The windings in series with the lead to each sphere are in the ratio 2 : 1 and are used to sense the differential current to each sphere; these windings are in opposite senses so that when the currents to the separate spheres are in the ratio 2 : 1 no signal is obtained from the third winding. Connections between the sensor head and the amplifier and generator circuits are by coaxial cables.

The whole probe structure is swept in potential with respect to the spacecraft as described in Section 3.1.

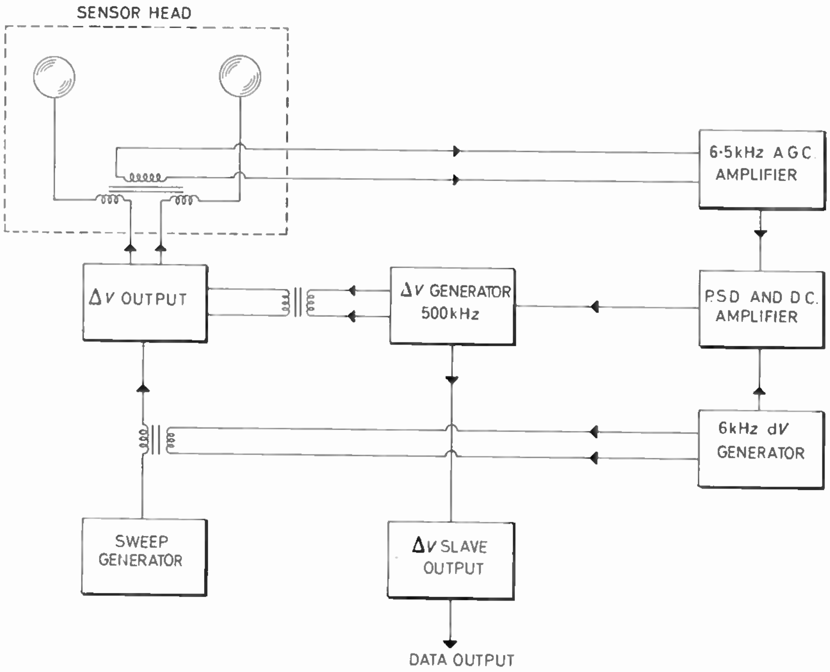

Fig. 6.
Block diagram of the electron temperature experiment.

The linear sweep generator has a period of 5·1 seconds and the addition of the low level 6 kHz signal is achieved by the transformer shown between the sweep generator and the ΔV output circuit. The magnitude of this 6 kHz signal, which is not critical, is 25–30 mV peak to peak.

The output of the sensing winding of the transformer is fed to a high gain tuned amplifier with an a.g.c. characteristic: this latter feature is required in order that the large unbalance signal which occurs when the probes are carried beyond the retarding region will not paralyse the amplifier.

The output of the a.g.c. amplifier is fed to a phase sensitive rectifier the output of which controls the amplitude of a 500 kHz oscillator. One output of this oscillator is fed, via a transformer, to the ΔV output circuit, here it is rectified to provide a 'floating' source for the ΔV potential difference between the two probes. The sense of the servo network so formed is such that ΔV is adjusted to maintain the differential current to the two spheres in the ratio 2 : 1 as determined by the sensing transformer ratio. Since the maximum value of ΔV that is required is only of the order of a few hundred millivolts a signal suitable for telemetering which is in the range 0–5 V is obtained from the 'slave output' circuit which consists of an identical circuit to the ΔV output but operating with respect to the signal common line of the telemetry system.

4. Realization of the Experiments in *Ariel III*

4.1. *Operational Requirements*

From the previous discussion of the two experiments the need to bring the sensors to space potential was indicated. This arises from the fact that when a spacecraft is immersed in an ionospheric plasma it generally takes up a potential somewhat negative to that of its surroundings and to overcome this a positive potential must be applied between the sensor and the spacecraft which forms a reference electrode. When the potential applied is positive with respect to the spacecraft an electron current is drawn to the sensor which must be equalled by a positive ion current drawn to the spacecraft hull.

As the spacecraft is used as a reference electrode its potential must not change when an ion current is drawn, implying that its conducting surface area must be large compared with that of the sensor, since this is determined by the relative ion and electron mobilities.

The conducting surface area of *Ariel III* which is available means that to meet the above requirements only one sensor may be swept in potential at a time whilst the other is held negative with respect to the satellite.

4.2. *Data Transmission*

The telemetry facilities on *Ariel III*, namely the high-speed encoder and the tape recorder require that the raw data from the experiments should be conditioned before they are suitable for transmission.

The data signal from the density experiment, whilst suitable for handling by the high-speed encoder (direct transmission), is too fast for the tape recorder data system. Since only the peak value of the signal is significant, this is held in a data store which is subsequently read out to the tape recorder.

In the case of the electron temperature experiment the signal which is in the form of a pulse lasting some 200 ms cannot be handled in this form even by the high-speed encoder. Data stores similar to those used for the density experiment are employed before the data are presented to either the high-speed or low-speed data systems.

4.3. *Circuit Description of the Satellite Equipment*

A block diagram of the satellite equipment is shown in Fig. 7 from which it will be clear that the overall complexity of the two experiments is greatly increased in order to be compatible with the satellite requirements. The discussion in Section 4.1 shows that it is only possible for one experiment to be operative at a time. This suggests that certain parts of the circuitry may usefully be common to both experiments and that a reduction in average power consumption can be achieved by switching off the experiment not in use.

Further, by synchronizing the saw-tooth sweep to the high-speed telemetry encoder, data reduction is simplified since the output waveform from the experiments is then fixed in time relative to the encoder format.

The block diagram readily divides into three sections for discussion purposes, the lower section which comprises the temperature experiment, the centre three blocks the circuitry common to both experiments, and the upper section which comprises the density experiment.

Pulses derived from the telemetry encoder at the start of each high-speed sequence are fed to the divide-by-three circuit, the output of which synchronizes the saw-tooth generator so that its period is equal to three high-speed encoder sequences or 5·1 seconds.

In the absence of synchronizing pulses the saw-tooth generator will run freely with a period of approximately 5·5 seconds and thus even with a partial circuit failure data would still be obtained. It is for this reason that the saw-tooth flyback is used to control further circuitry rather than the output of the divide-by-three circuit.

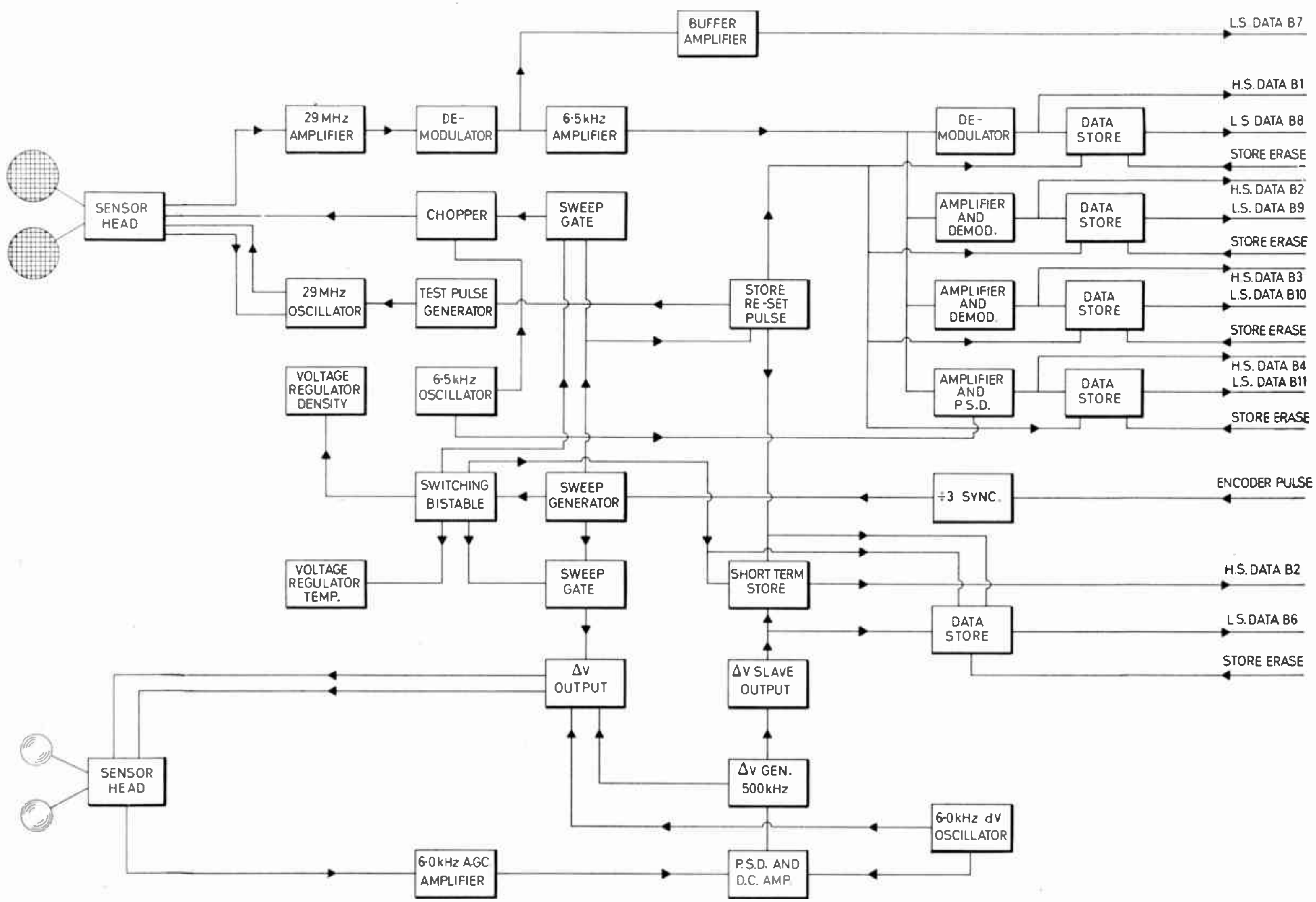

Fig. 7. Block diagram of the satellite equipment.

The switching bistable circuit driven by the saw-tooth generator is used to control the power switching circuits which operate the voltage regulators, and in this way each experiment functions alternately for a period of one saw-tooth sweep. Monitor signals are taken from the regulators to the telemetry system to provide 'house-keeping' data on the operation of the stabilizers.

The block diagram of the electron temperature experiment is the same as that discussed in Section 3.2 with the addition of two data stores, both of which are of the minimum reading type in order to store the value of ΔV obtained when the probes are in the electron retarding region (see Fig. 6).

The short-term store only has to hold the signal level until the end of a sweep period since its output is telemetered by the high-speed data system: at the beginning of the next temperature experiment operating sequence it is re-set by a pulse from the store re-set generator.

In the case of the data feeding the low-speed telemetry the store holds the lowest value of ΔV fed to it during a 27 seconds period (one low-speed encoder sequence). This store is then re-set by a pulse from the low-speed encoder immediately after the store has been sampled.

The upper part of the block diagram shows the density experiment in the form discussed earlier but with the addition of maximum reading data stores on each output which feeds the low-speed telemetry. In order that the test pulse which is generated should not be stored, since it might well exceed the data signal on a maximum reading store, an inhibit pulse coincident with the test pulse prevents data being read in at this time. The data stores used are based on a previous design which was used successfully on the *Ariel I* satellite.[6]

The saw-tooth gate circuit which is used on both the temperature and density experiments performs the function of holding the sensor of the unused experiment at a negative potential with respect to the satellite.

The remaining item of circuitry which differs from the block diagram of the basic electron density experiment is the monitoring via a buffer amplifier of the d.c. level on the output of the demodulator which follows the r.f. amplifier. This monitor, since it provides an indication of the r.f. level on the pick up grid of the sensor, is useful for indicating the stability of the null adjustment referred to in Section 2.3. Since the sensor is mounted at the tip of a solar paddle, thermal control of its surfaces is more difficult and any sign of overheating due to solar radiation would be given by this monitor. It is interesting to note that the monitor also provides a very low sensitivity channel, i.e. detects high electron densities, and has on occasions during the past months of operation been seen to record areas of abnormally high ionization.

4.4. *Details of Construction*

Figure 8 shows the complete equipment ready for installation in the spacecraft, the left-hand module containing the density experiment circuitry, the right-

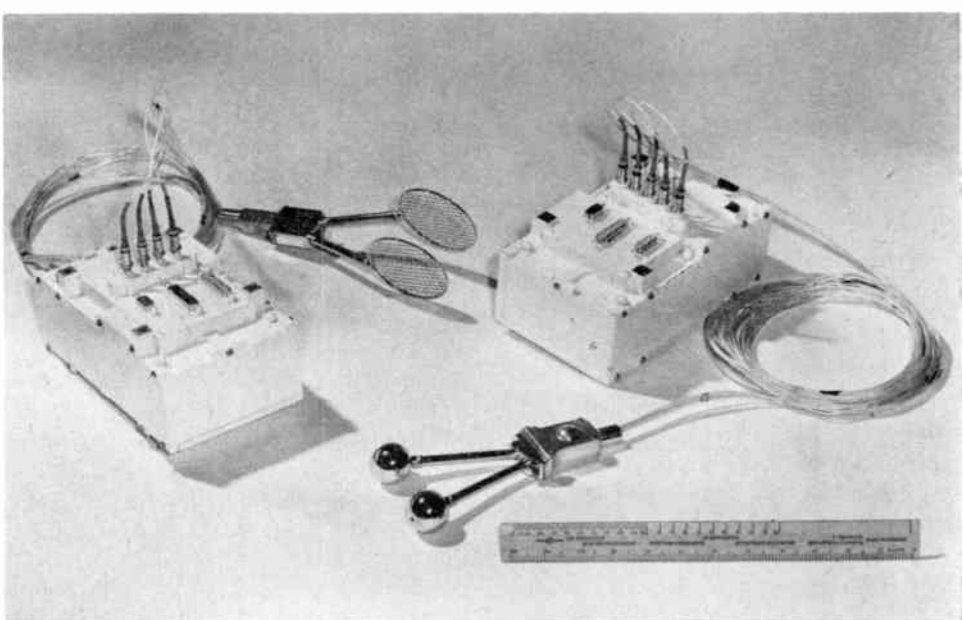

Fig. 8. The complete satellite equipment for the Birmingham University experiments.

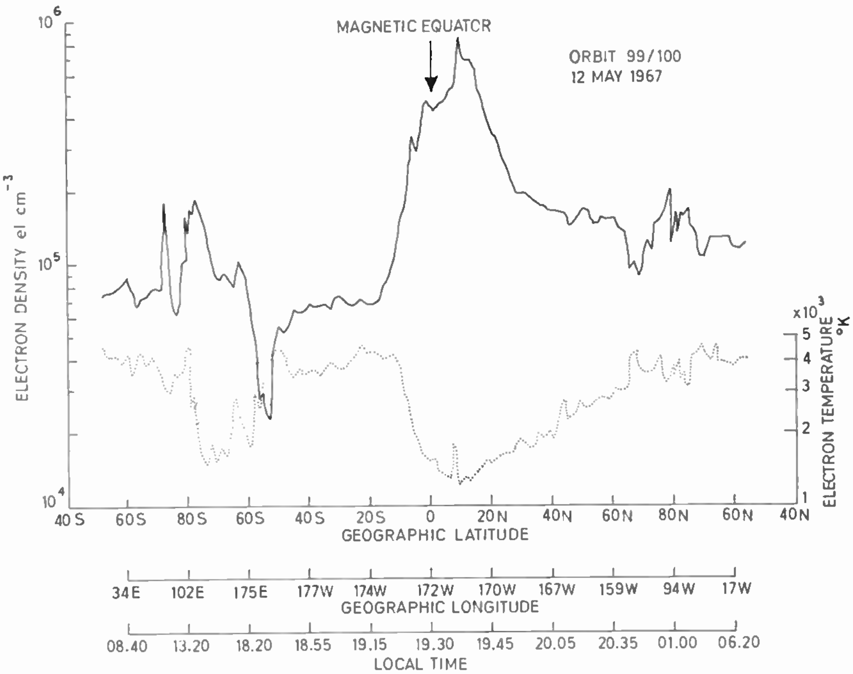

Fig. 9. A typical plot of electron density and temperature for one orbit.

hand module the temperature experiment plus the switching circuits which were common to both experiments. Each box, which is assembled from sections machined from duralumin, is divided into six screened compartments into each of which is fitted a circuit card encapsulated in polyurethane foam. With the exception of the printed circuit cards, which were assembled by a contractor, the entire equipment was designed, built and tested in the University of Birmingham.

5. Preliminary Scientific Results

The use of a satellite which remains in orbit for a considerable period of time enables the experimenter to observe the seasonal changes which occur in the ionosphere in addition to those changes which depend on geographic position. Diurnal variations also take place and these add to the complexity of the overall picture. In order to simplify this short discussion of preliminary results an orbit has been selected in which the satellite is in continuous sunlight.

Figure 9 shows a plot of electron density and temperature for one complete orbit and was compiled from data stored on the satellite tape recorder for orbits 99/100, this being on 12th May 1967.

From left to right across the figure, the satellite travels southwards to its southern apex of 80° S, then turning northwards it crosses the geographic equator at 172° W and, reaching its northern apex at 94° W again turns south, the recording ending over Winkfield when the tape recorder playback was commanded.

The peak density shown is $8{\cdot}6 \times 10^5$ electrons per cm^3 and occurs in the region of the geomagnetic equator with the densities in the mid-latitudes being fairly constant at a rather lower value of 7×10^4 in the southern hemisphere and $1{\cdot}5 \times 10^5$ in the northern hemisphere.

It will be seen that the mid-latitude values in the northern hemisphere are, on average, a factor of two larger than those in southern mid-latitude. This can be explained partly by a seasonal effect since it is early summer in the northern latitudes and winter with larger solar zenith angles and hence less ionizing ultra-violet radiation in the south. However, it is a well observed, and unexplained fact, that northern hemisphere ionization at mid-latitudes has a higher average value than southern mid-latitude ionization (for corresponding seasons).

The mid-latitude density distributions are terminated by well-defined troughs previously detected by Muldrew in 1965[7] at latitudes of 60° N and S respectively. These troughs also remain in the night-time ionosphere and appear to be affected by particle precipitation in that zone. Beyond this trough at higher latitudes the auroral zone is entered and electron densities are no longer dependent entirely on solar ultra-violet radiation, the spiky nature of the curve being attributed to incoming particle streams.

Examination of the curve of electron temperature along the satellite orbit shows that to a marked extent it is a mirror image of the electron density curve. This general anti-correlation is due to the fact that at the altitude to which these results relate electron cooling is mainly by coulomb force interaction between the electrons and the positive ions.[8, 9] The cooling rate of the electrons is thus proportional to the positive ion density, and the electron equilibrium temperature which is reached when the heat input balances the cooling rate is lower at the higher ionization densities.

In the auroral zones it will be seen that the effect discussed above is not so evident since the ionization present is not dependent solely on solar radiation. The incoming particle streams in these areas produce a generally increasing temperature as these zones are entered.

The large amounts of data which are now becoming available from the *Ariel III* satellite will enable further studies of the effects outlined above to be carried out.

6. Acknowledgments

The author wishes to acknowledge the help given by H. W. Bryan and G. Garside in the construction and testing of the circuitry described here and by M. J. Deeley and J. C. Ellams in the mechanical design and construction. Thanks are due to the project physicists, Miss B. Loftus and Dr. J. W. G. Wilson, for many helpful discussions.

He also wishes to thank Professor J. Sayers for the interest and support given throughout the project. The project was made possible by a grant from the Science Research Council.

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Forthcoming Conferences

International Broadcasting Convention 1968

The 1968 International Broadcasting Convention is to be held in London from 9th to 13th September, at the Grosvenor House Hotel, Park Lane, and will be sponsored jointly by the Electronic Engineering Association, the Institution of Electrical Engineers, the Institution of Electronic and Radio Engineers, the Institute of Electrical and Electronics Engineers (U.K. and Republic of Ireland Section), the Royal Television Society, and the Society of Motion Picture and Television Engineers.

The Television Conference to be organized in 1968 by the Institutions, which was announced in *The Radio and Electronic Engineer* of October 1967, is being incorporated within this Convention. A wide cross-section of the latest broadcasting equipment will be shown in the associated exhibition.

The Convention Secretariat address is to be: The International Broadcasting Convention, Savoy Place, Victoria Embankment, London, W.C.2. Prospective authors of papers are reminded that synopses of contributions should be submitted without delay.

Further information may be obtained from the I.E.R.E. or other sponsoring bodies.

Conference on Reliability of Service Equipment

A Conference on this subject, sponsored by the Ministry of Defence and the National Council for Quality and Reliability and organized by the Institution of Mechanical Engineers, will be held in London at the Institution of Electrical Engineers, Savoy Place, W.C.2, on 21st to 23rd February. The four main sessions will have the themes of:

The Services' Need for Reliability
The Achievement of Reliability
Partnership Between the Services and Industry
Contracting for Reliability.

Registration forms may be obtained from the Conference Department, Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1. (Telephone: 01-930 7476.)

Fourth I.F.A.C. Congress

The Fourth Congress of the International Federation of Automatic Control is to be held in Warsaw from 16th to 21st June 1969. The detailed arrangements are being made by the Naczelna Organizacja Techniczna W Polsce (N.O.T.), which represents Poland in the I.F.A.C.

The United Kingdom Automation Council, as the United Kingdom National Member Organization of I.F.A.C., is responsible for obtaining the British contribution to this Congress programme. The programme will comprise three main subject areas: theory, components and applications.

Offers of papers within the field of automatic control, and particularly papers on applications, are invited. Intending authors should submit a title with an abstract of approximately 250 words for consideration by the British Programme Committee. These should be sent without delay to: Honorary Secretary, U.K.A.C., c/o Institution of Electrical Engineers, Savoy Place, London, W.C.2.

Second Conference on Solid State Devices

The Institute of Physics and The Physical Society, in collaboration with The Institution of Electrical Engineers, The Institution of Electronic and Radio Engineers, The Institute of Electrical and Electronics Engineers (United Kingdom and Republic of Ireland Section) is arranging a second Conference on Solid State Devices from 3rd to 6th September, 1968, to be held at the University of Manchester Institute of Science and Technology.

The Conference will follow the same general pattern as the preceding one in 1967 and its object will again be to provide a forum for the presentation of applied research work in the physics and characterization of solid-state devices, together with associated technologies.

Leading workers are being invited to give survey and keynote papers and it is envisaged that subjects to be covered during the Conference will include:

> Silicon device design, integrated circuit technology, storage, display and imaging devices, detectors, thin films and m.o.s. devices, microwave devices, bulk effects, and the techniques for service diagnosis.

Contributions of about 15 minutes' presentation time are welcomed and should be sent to Dr. C. Hilsum, Royal Radar Establishment, St. Andrews Road, Malvern, Worcestershire.

The Proceedings of the Conference will not be published and speakers will be free to publish their papers in journals of their own choice.

Residential accommodation will be available in University Halls of Residence. Further details and application forms will be available from The Meetings Officer, The Institute of Physics and The Physical Society, 47 Belgrave Square, London, S.W.1, in April–May 1968.