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A Practical Engineer's Progress to the Presidency

The Presidential Address of

HARRY E. DREW

C.B., Hon. C.G.I.A., C.Eng., FIERE, FIProdE

Delivered after the Annual General Meeting of the Institution in London on 29th October 1981

It is indeed a privilege to be the 30th President of this great Institution and to follow in the footsteps of so many famous engineers. May I first thank you all most sincerely for electing me President and assure you that I will do my utmost to maintain the high tradition of the Institution. It is pleasing to me, too, to be the first career Civil Servant who has become President, also the first Royal Air Force apprentice to achieve that honour.

Re-reading past Presidential Addresses has left me with the conviction that anything I can contribute to the Presidency must be the product of my long and varied experience as a practical rather than a theoretical radio and electronic engineer. I have therefore decided to make this Address a survey of my rather unusual career, mentioning the various equipment projects with which I have been concerned and the way in which I was privileged to work from time to time with many of our Past Presidents; and to draw from all that some lessons which might be worthwhile noting for the future.

Early Days in Wireless

I joined the Institution in 1943 and have spent many years as Chairman of the Membership Committee and as a member of the Technical Committee and have served several terms as a member of Council. I had entered the Royal Air Force as an apprentice in 1924 and was sent for training to the Electrical and Wireless School, Flowerdown. Only 650 were trained there in seven years; over 400 eventually obtained commissions. One of the Institution's Fellows, Air Commodore W. C. Cooper, C.B.E., was the first Cadet, and another well-known personality was Sir Thomas Shirley, K.B.E. We were all recruited under the Trenchard scheme for building up the RAF as an independent force, and while the majority of apprentices went to Halton and Cranwell to be trained as Engine Fitters, Carpenters, Coppersmiths, etc., the top 50 or so of each entry were sent to Flowerdown for training as Wireless Operator Mechanics, Electricians, and Instrument Makers.

As far as Flowerdown is concerned let me quote from Sir Thomas Shirley: 'All those who were at Flowerdown as aircraft apprentices between 1922 and 1929 have common ground not only in their technical training, but also in that they received this training at a school which made its mark on us for the rest of our lives.'

In passing it might be interesting to know that the course was three years and our technical training started with a Sterling spark transmitter and finished with a superheterodyne receiver. By the time we finished our training most, if not all of us, could redraw from memory the detailed circuits of every receiver and transmitter in use in the Royal Air Force—all twelve of them.

The very foundation of the training was none other than that 'Bible' of Wireless Telegraphists called 'The Admiralty Handbook of Wireless Telegraphy' which was mostly written by one of our Past Presidents—Lord Louis Mountbatten. The educational content of the Flowerdown course was up to the then inter-BSc standard and we could all read and transmit morse at 25 words per minute at the end of our time there.

I am a product of that training, and it should not be surprising therefore that my subsequent professional history has been markedly diverse.

The Beginnings of Radar

Having served my time in the Royal Air Force my last unit was 601 (County of London) Auxiliary Squadron whose Honorary Air Commodore was Sir Phillip Sassoon, then Under Secretary of State for Air. He was instrumental in my transfer as a civilian to the Air Ministry Research Establishment at Bawdsey Manor

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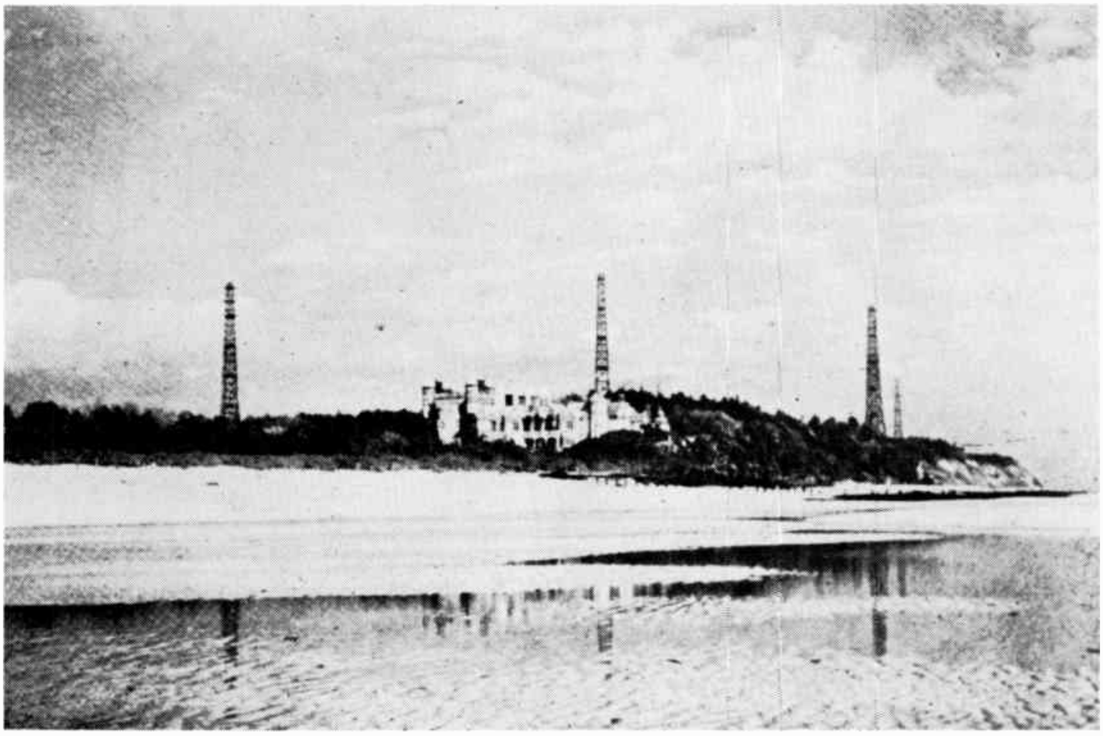

Bawdsey Research Station 1938 (From 'One Story of Radar' by A. P. Rowe).

and so I was fortunate in being one of the early arrivals at the home of Radar.

At this stage I must make it clear that I shall not in this paper attempt to trace the history of radar. Nevertheless I think it is appropriate to refresh our memories just how radar started.

In 1934 the Secretary of State for Air, Lord Swinton, set up a Committee for the Scientific Survey of Air Defence under the chairmanship of Mr Henry Tizard. One of its members asked Mr Robert Watson-Watt, the Superintendent of the National Physical Laboratory Radio Department, if it was possible to utilize some kind of damaging radiation as an aid in defence against air attack . . . a death ray. The latter, assisted by Mr A. F. Wilkins, proved numerically that radio destruction was impossible, but not radio detection. He wrote a memorandum to this effect which was presented to the Committee on 27th February 1935. This memorandum can be regarded as the birth certificate of radar in Britain. The term radar however, was not used until 1943. It was initially known as Radio Direction Finding (RDF) and sometimes referred to as Radio Location.

Bawdsey Manor was a fantastic 19th century manor house, part of an estate of 250 acres with enough space for laboratories, experimental work and for the construction of what eventually was to be the first of the chain of radar stations guarding our coasts. In passing it might amuse you to know that the motto engraved over the gateway of Bawdsey Manor translated into English was 'Rather die than change'.

I was attached to the scientists working on the first radar transmitter. This was for the Army and titled GL Mk1, GL standing for Gun Laying. The Research and Production contracts for GL were vested in A.C. Cossor (receivers) and Metropolitan-Vickers (transmitters). I arrived at the very late stage of development and it was decided that, because of my essentially practical Royal Air Force experience, I should concentrate on the lining up and testing of the equipment and I was eventually sent to Metro-Vick, Manchester, to approve first-off production and train the firm's testers. It was in this connection that I first met another of our Past Presidents, Leslie Bedford; the story of our association is dealt with in some detail in our Journal* which reports on the honour I had as a Past Master of the Worshipful

GL Mk. I trailer (Imperial War Museum photograph).

* 'Scientific Instrument Makers honour radar pioneer', *The Radio and Electronic Engineer*, **51**, no. 1, pp. 10–11, January 1981.

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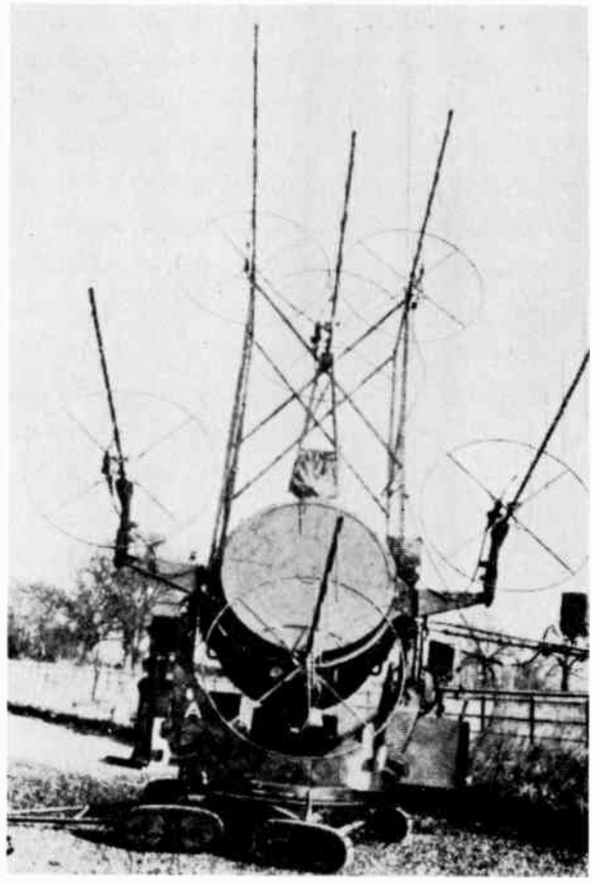
Company of Scientific Instrument Makers to present Leslie Bedford with our Achievement Award for 1980.

During my time at Manchester the Army side of Bawdsey had moved to Christchurch and was called the Air Defence Experimental Establishment (ADEE) where I joined the GL Mk2 design team. After Dunkirk I was called into the Superintendent's office (Dr. D. H. Black) to meet an irate Army Captain who had just come back from France and was thoroughly dissatisfied with the engineering design of Army radar. He was detailed to set up a section to look into the engineering design of equipments and build up a workshop suitable to make the first-off of most new equipments and to assist the other establishments engaged on radar. This Captain was none other than Col. G. W. Raby, C.B.E., yet another of our Presidents and I worked closely with him for six years. His responsibilities as head of Post Design Section embraced all workshop activities, all installation work and the introduction of radar equipment to its users.

Outstanding in the field of installation work was his super high-speed erection and commissioning of some 200 Coastal Chain and Naval Shore Stations. He also took over control of searchlight stations in the Ringwood area to allow the Three Musketeers' (D. R. Chick, Eric Eastwood and A. J. Oxford) to carry out their experiments on Searchlight Control Radar (ELSIE) and I was closely connected with this project. In June 1940 the initiative to apply radar to searchlight direction was started by Chick, Eastwood and Oxford who mounted a 200 MHz director based on standard but obsolescent ASV (Aircraft to Surface Vessel) equipment on a searchlight. The set had four Yagi receiving aerials which were switched by a commutator right and left, up and down, and signals compared. A single Yagi aerial served as transmitter and spot presentation was used in the receiver. The set was not in any sense designed but it worked after a fashion. We in the ADEE workshops were ordered to make the first 24 models and maintain them. The scientist 'nurses' accompanying the sets had the duty of instructing operators from the units and demonstrating the use of this novel equipment as well as keeping it in action and in working order—by no means an easy task.

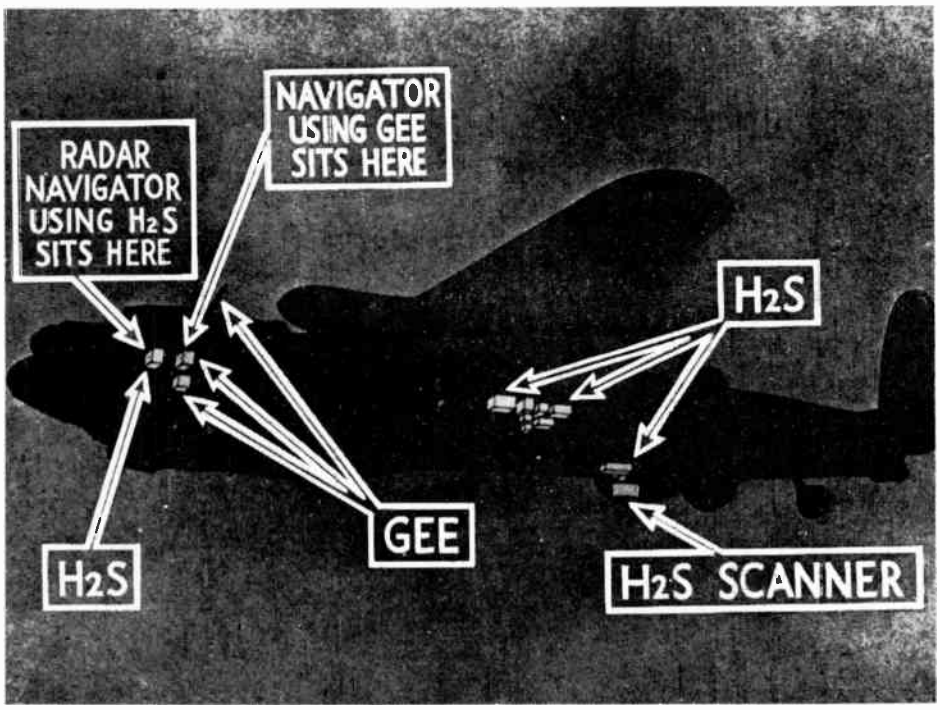
My next installation tasks were fitting and commissioning of the new GCI (Ground Control Interception) using PPI (Plan Position Indicators) for the first time at the Army Command Posts at Glasgow, Manchester and London. From those installations I recall the complaints of the Army 'top brass' that after looking at the PPI they took some time to read their maps again—couldn't something be done to change the colour of the tube?

The workshop at Christchurch was staffed by really first-class mechanics and was proving very popular and was used by Telecommunications Research Establishment (TRE) at Swanage to an increasing degree. One of our interesting prototypes was that of GEE. I had known that its inventor, R. J. Dippy, had proposed this scheme whilst we were at Bawdsey and was most interested to hear that it was now going to be used. The scheme aimed at laying down an invisible grid or network of position lines over Western Europe and providing every bomber aircraft with a special radio set enabling the aircraft's position on this grid to be determined. The radio grid was produced by transmitting accurately timed and synchronized radio pulses from three GEE stations near the East coast.



ELSIE—an early example of a searchlight directed by radar onto enemy bombers to reveal them to anti-aircraft gunners and interceptor aircraft (From 'Ack-Ack' by General Sir Frederick Pile).

The next equipment was rather a controversial one and named *Oboe*—this was one of the first equipments to be known only by code name. It had many modifications and was a trial to us all, causing much doubt as to its efficacy. The *Oboe* scheme involved two ground stations in England known as the 'cat' and the 'mouse': the 'cat' station enabled an aircraft carrying special equipment to fly with great accuracy over a target such as a large factory, while the 'mouse' station calculated the position at which a bomb should be released in order to hit the target. Because the station was able to observe with great accuracy the positions of the aircraft along its path over the target, it was able to send a signal from England telling the crew of the aircraft over Germany when to release the bomb. In order for all this to happen using the essentially short wave involved the aircraft had to fly at a great height for those days.



Aircraft installation of GEE and H2S.

Another equipment which we helped on the first prototype was what became the famous H2S series. This equipment was given special priority as it had the personal backing of the Prime Minister himself. Essentially it was a device producing a rotating centimetric beam which scanned the surrounding countryside producing a picture of towns and villages since better radar echoes were derived from the small walls and roofs of buildings than from the irregular surfaces offered by woods and fields. This equipment was probably the one piece of radar hardware around which it was possible to create the RAF Pathfinder force.

With the hotting-up of the submarine war we were also required to make urgent parts for ASV radar, the importance of which had been increased not only by the build-up of submarine warfare but also by its increased efficiency due to use of centimetre wavelengths. The essence of this equipment was the use of two lobes of radiation to the left and to the right of the direction of flight of an aircraft. By continuously and rapidly switching transmission from one aerial to the other indication was received as to whether a surface vessel was to left or right of the aircraft path and hence the aircraft could be homed to the ship or submarine on the surface.

'Rapid-Response' Production Tasks

At this stage (1943) I was given a break from R and D work and was sent from Christchurch to Woolwich to form a Radio Production Unit using the people who were not moving to Christchurch from SEE (Signals Experimental Establishment) to take the place of the ADEE staff who were moving to Malvern. The staff at Woolwich comprised a good standard workshop and drawing office team, a crystal research and design unit operated by the famous Miss Fletcher, and a Bomb Disposal Unit. The total staff was 350 and we were mainly used to manufacture quickly small quantities of the earliest pre-production models of new equipments and special requirements by the resistance units in Europe. Later a team of Canadians joined us and they designed, developed and produced a special Canadian Army radio equipment. Later a Norwegian captain was attached to make a pocket transceiver. I was appointed Works Manager with Colonel Raby as my non-resident superintendent.

One of our early commitments was involved in the production of *Window*. Many of you will remember *Window* and how effective operationally it became. *Window* was in fact packages of metallized paper strips cut to the lengths of half-wave dipoles for the particular wavelengths of the enemy radar equipment to be attacked by confusion of echoes. It was particularly useful in the softening-up period prior to the actual invasion of Europe and in the early stages of the invasion itself. I was later to again deal with the production of *Window* whilst in the Production Directorate.

The Radio Production Unit was used mainly by eminent scientists from Research Establishments serving all three Services to try out first experimental models of their devices particularly those requiring close tolerance of manufacture. The Bomb Disposal Unit was very active and used experimentally by all three Services.

With the ending of hostilities a study was made of the organization and functioning of the Royal Air Force Research Prototype Unit at West Howe, Bournemouth, and the Army Radio Production Unit at Woolwich. The net result of the study was that in 1946 it was decided that the establishments would continue but jointly under one man's control. So I spent half the week at West

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Howe and half at Woolwich. One of my early visitors at West Howe was John Langham Thompson, another Past President, and the General Secretary, Graham Clifford, who were paying an official Institution visit to inspect some of the new equipments and components we were manufacturing. I feel certain that this visit had some connection with my election to Council very shortly afterwards!

At West Howe I found they were working on the 'H' connection of both the H2S and GEE, which I had worked on previously. 'H' had been proposed simultaneously with GEE and was a system given a very high degree of accuracy for blind bombing by enabling a position to be determined in space from the measurements and ranges from two ground stations.

West Howe only lasted a few months and I presided over its funeral when the remains were handed over to Max Factor who still are in possession.

The Management of Larger Scale Production Work

Only a few months later the Radio Production Unit ceased to function at Woolwich and I was posted as a Principal Scientific Officer to the Directorate of Electronic Production at HQ (Castlewood House) and stayed in that branch until 1964, progressing to Assistant Director and ultimately Director.

As Assistant Director I was responsible for the production of most of the airborne equipment which I had worked on as prototypes when at Christchurch. One of the exceptions was the *Eureka/Rebecca* combination. *Eureka* was a radio beacon to be dropped in any particular target area. The beacon transmitted pulsed radio signals which were received by *Rebecca* carried in troop-carrying aircraft. Its application to operations like the invasion of Europe needs no detailing by me. Akin to the *Eureka/Rebecca* was the production of sonar equipment for the detection and location of submarines. This took up an appreciable part of our time and effort and I am sure it must still be doing so in the corridors of power today.

I paid my first visit to the USA as an Assistant Director in 1955, visiting Collins Radio at Cedar Rapids with representatives of the Plessey Company to inspect an equipment which was eventually to be used by the RAF for a long period of time. This was their first u.h.f. air-to-ground communication equipment, titled the AN/ARC52. It was the first real attempt to meet the ever-increasing demands for radically smaller, lighter, simpler and yet more easily maintained airborne communications equipment.

All the work which had steadily been progressing towards sub-miniature techniques with high component density had been directed in this new equipment towards the solution of the many problems confronting the designers. In particular, for the first time modular construction was effectively employed. Associated with the equipment itself there was of course the inevitable requirement for specially developed test equipment to meet the demand for simpler maintenance. All of this had been achieved by the Collins Company with no loss of communication efficiency and in fact an increase in that very high standard. I have no hesitation in claiming that here we had probably the most radical departure in my technical lifetime in the form and nature of all airborne communication equipment. My task was, in conjunction with the Plessey Company, to anglicize and arrange for the production of the AN/ARC52 in this country. This task proved to be onerous for all concerned as it was the first American equipment to be so anglicized and we learnt a lot about American methods and American 'waivers'.

A continuing commitment throughout the whole life of the Directorate of Electronic Production had of course been IFF, that is, the equipment designed to enable us to distinguish 'Friend from Foe'. This had of course been subject to many changes over the years but now we were faced with an ever-increasing linkage with its American counterpart and it fell to my lot to liaise in the matter with the Hazeltine Company of America.

Some Heavier Ground-based Equipment Interests

So far I have spoken only of airborne equipment production but as soon as I assumed the office of Director I automatically became responsible also for ground-based equipment which had probably followed a rather less stormy journey than airborne equipment but nevertheless had inevitably become much more diverse and certainly far more complex than had been the case in my days at Christchurch. The main ground radars I was concerned with were RAF Type 82 (*Orange Yeoman*) and Type 83 (*Yellow River*), and the Army *Green Archer* and *Blue Diamond*.

Orange Yeoman was the answer to a tentative requirement by the Army for a radically new approach to our defence, resulting in a proposal for area control of gun (and ultimately G.W. if it ever materialized) systems. Two prototypes were produced, the first near Chester covering the North West area (Liverpool, Birkenhead, Preston and Manchester) in 1953, and the second at North Coates in 1956. The radar was envisaged as giving three-dimensional data of sufficient accuracy on a large number of targets simultaneously to automatically position both the weapons and their associated lock-follow radars. Three production stations were built and commissioned in the early 1960's. The equipment was the earliest 3-D system using a stacked-beam technique for elevation measurement. It was the only system anywhere in which the transmitter, receiver, waveform generation, displays and data handling were completely integrated, in that each part was designed and matched to every other part, giving enormous flexibility and optimized performance.

Yellow River was designed as a lock-follow radar of high performance for illumination of targets to provide guidance for intercepting surface-to-air missiles, originally designed for the Army but later taken over by the RAF for SAM 1. It has two operating frequencies, using a single aerial, giving a 'wide' beam for target capture, and a 'narrow' beam to follow. In both modes, lock-follow facilities were provided independently in

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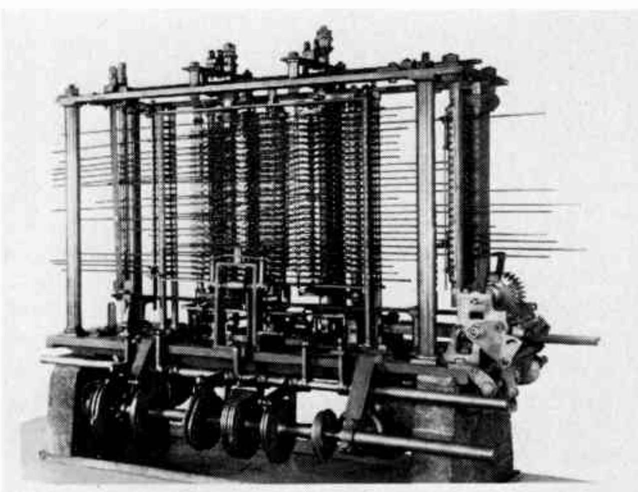
range, bearing and elevation. The 'wide' facility was adequate to accept putting-on data from the remote tactical control radar Type 82, although in general this data was normally adequate to put-on in the 'narrow' mode. Because of its high performance, this radar was used extensively as a radar theodolite, for which purpose it has only in recent years been superseded by more modern radars of large aperture.

Green Archer was the first UK radar to be designed specifically for rapid and accurate location of mortars. It operated on the principle of obtaining two points on the trajectory of the bomb in flight, and then computing the trajectory back to ground level. The heart of the design was a Foster scanner of novel design, which produced a linear, wide-sector azimuth scan by means of a simple rotary motion of one cone within another. The computer was an electro-mechanical analogue system. The $3\frac{1}{2}$ kVA generator required for *Green Archer* is of some interest. The military requirement insisted that 'the system should be inaudible at a distance of 50 yards on a still tropical night'. To achieve this stringent silencing level, the two-cylinder diesel alternator set was enclosed within a massive steel drum, fitted with an elaborate exhaust system. *Green Archer* went into UK service in 1959 and over 60 systems were exported.



Charles Babbage's Analytical Engine (Science Museum Photograph).

Blue Diamond was an Army field radar system contemporary with *Green Archer* and started life in a more basic form known as *Red Indian*. *Blue Diamond* was a target acquisition and fire control radar for the 40 mm Bofors anti-aircraft gun. The radar incorporated a Foster scanner similar to that used in *Green Archer* which scanned an arc of 40 degrees in azimuth twenty times a minute in the acquisition role. In the tracking role the X-band power was switched to a parabolic reflector, and an aided laying technique was used to provide the target positional data.

Specifications, Quality Standards and Costings

But that is enough about heavy ground equipment production matters as such. Let me turn now to some of the pervasive problems of the electronic production business—problems and solutions relevant to both military and civilian electronic production work.

In the mid-1950s almost every organization in the business was writing specifications for electronic components. The British Interscience Committee set up in the early 50s had floundered owing to Navy objection, so a new committee was set up under Rear Admiral G. F. Burghard with myself as deputy chairman. This committee's report was finally produced in 1965 and universally accepted as an international system with Europe as the first step. The specification structure evolved during the discussions in the Committee has remained in force with very few modifications in both the European CECC systems and the international IECQ systems. There are Basic specifications covering several families of components, Generic specifications for an individual family, Rules Documents (BS 9000 series) or Sectional specifications (CECC and IEC) appropriate to a sub-family, Blank Detail Specifications (CECC and IEC) and finally the Detail specifications themselves for an individual component or range of components.

We made many right decisions in the early days and the success of the BS 9000 scheme has been largely due to the enthusiasm and drive of the people concerned. I witnessed this at first hand as I was chairman of ECQAC (Electronic Component Quality Assurance Committee) for the first five years of its life. The Electrical Quality Assurance Directorate (EQD) has done and is doing, a tremendous job as supervising inspectorate. The new specification system was originally intended to deal with the large volume production of identical components in long runs but it has been extended by the adoption of BS 9000 of 'capability approval'.

The BS 9000 system has given us an excellent base, and will continue to do so for some years ahead. Its specification coverage is much more developed than those of CECC, but UK manufacturers have demonstrated their keenness to go European. The total of component approvals under the CECC system held by UK companies is well in excess of the number held by French, German or Italian firms. We must be prepared to build upon this base, and to gain every possible advantage from the CECC by the fullest UK participation.

The move into Europe is obviously a challenging one, but not as challenging as that of the ultimate move into the worldwide IECQ system, in which UK companies will be in direct competition with, for example, American and Japanese manufacturers. The basic question is: Can UK manufacturers gain sufficient experience and confidence within the BS 9000 and CECC systems to meet the inevitable challenge of IECQ? The answer has got to be 'Yes'.

In 1964 I was persuaded to look into another all-pervasive aspect of electronics production as Director of Technical Costs. This was a complete change of scene and created real problems because not only had the

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costing system of the Ministry to be sorted out but the morale of the staff had to be lifted dramatically. They were housed very badly both at headquarters and outstations and this I changed very quickly. I was allowed to recruit top staff from other departments and although progress seemed slow, improvement was certainly marked and the branch once again became alive: engineers and technicians quickly realized it was the right posting for career purpose. I discovered too, from looking at the records, that the Directorate's 50th anniversary was due so I arranged a top-level function and invited the then Minister, Roy Jenkins, and his wife as guests of honour. This did a lot to boost the morale both in HQ and outstations. I also paid visits to most contractors to learn the methods of costing but before I could really make a real impact I was promoted to other work. I am the first to admit that this appointment in the Directorate of Technical Costs was by no means the most successful of my career; with no thought of offering excuses I believe and suggest that the reason is not hard to find. The organization as such of the various departments concerned, and the specification and timing of the task, made the task itself almost impossible within the time limit set. My reign only lasted 18 months and merely resulted in sowing a seed. The plant is now a very healthy specimen and recognized as such.

Quality Assurance: a new approach

When I became Director General of Inspection in 1966 it soon became apparent that a wind of change was blowing. A growing lobby of progressive opinion from Industry, Government Departments and the Armed Forces began to draw attention to the high cost of inadequate quality, expressed both in terms of finance and the unreadiness of equipment.

Initially it was thought that these problems could be solved by introducing extensive techniques of reliability testing and by an even greater emphasis on statistical quality control. However, it quickly became apparent that while some features of this thinking were beneficial, the eventual solution lay with the adoption of achieving conformity with design. To bring about this change of emphasis AVP92 (a specification of Quality Management) was formulated by the then Ministry of Technology in 1968. At the same time in 1968 an independent Committee of Inquiry was set up with Colonel Raby—already mentioned as one of our Past Presidents—as chairman, and Dr Percy Allaway, another Past President, was a member of the Committee. The Committee's terms of reference were to examine the organization and methods of the equipment inspectorates of the Ministry of Defence and the then Ministry of Technology. Its report was accepted by the Government and the process of implementing its recommendations was begun in 1970.

The Committee considered that the fundamental problem was how to ensure the quality of a product. It defined a good quality product as one which meets the requirement of the Services adequately, is available at the right time, and will be economical and reliable through its whole life. Three basic recommendations were made:

(1) Overall responsibility for design development, production and quality assurance of an independent item of equipment should be brought together at the lowest effective managerial level, inspection being combined with the other activities of equipment procurement.

(2) The setting-up of a Defence Quality Assurance Board (DQAB)

(3) The Chief Executive of the DQAB should be assisted by an Industrial Advisory Committee.

The DQAB was set up in 1970 and I became the first Chief Executive, the title later being changed to Director General. Dr Allaway became the first chairman of the Industrial Advisory Committee, which was later called Defence Industries Quality Assurance Panel, with terms of reference:

(a) To encourage industries engaged in defence work to take over from Government a greater responsibility for ensuring quality and reliability in products supplied to the Services.

(b) To supply an industrial forum to assist the Defence Quality Assurance Board in the formation and implementation of realistic procedures and measures designed to improve the quality and reliability of defence equipment.

My task as Director General was to plan and compile a new set of Defence Standards based on up-to-date techniques using available knowledge in Japan, America and the already-established procedures of NATO. The individual papers were discussed at the main Quality Assurance Board which comprised Controllers of all activities. The new codes of Defence Quality Standards were finally approved and introduced in 1972/73 and are now of course well established in Industry.

During my term of office as Director General of Quality Assurance I spent a lot of time explaining our aims to Industry and also giving lectures in USA, Japan and Canada to inform them how we in Britain were tackling the problem of Quality Assurance. When I wrote and presented the George Bray Memorial Lecture for the Institution of Production Engineers in 1971 I outlined the history of Quality, and how we, the British, were dealing with Quality long before other nations, and it was we (the British) who educated the Americans, who eventually taught the Japanese. Though largely evolved within the last decade, Quality Assurance has its lineage in the excellence of workmanship and foresighted legislation of our early craftsman and administrators.

The Final Stage

Since my retirement from the Civil Service in 1972 I have been active as a consultant in the fields of engineering management and quality assurance. I have also been closely concerned with the management of innovation in disciplines ranging from electronics to packaging. In all

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this I have found myself calling to my aid lessons learnt throughout my earlier career. For example, I am now more than ever convinced that necessity really is the mother of invention and innovation: if we were all as hungry now as we were frightened in the late 'thirties and early 'forties we would soon become the quality workshop of the world again.

It is very disappointing that by joining the Common Market we haven't raised our standards to at least equal to those of the French and Germans. Nevertheless there are now signs that the present recession is teaching us to be more efficient and more quality conscious. The sheer competition has made us more concerned with accuracy and quality and we are beginning to take more interest in workers' participation exercises such as Quality Circles and not leaving the job to the other fellow. Historically this country has had its ups and downs but the ability has always been there to reach the top successfully and despite all the present doom forecast in the media I am still proud that I am British and can see us coming through successfully—particularly in the Scientific and Instrument fields.

Conclusion

As to the affairs of our Institution, I think that we are now set fair to move ahead once again with the primary role set out so succinctly in our Royal Charter, namely, to advance the art, science and practice of electronic and radio engineering and kindred subjects—in the public interest.

The announcement of the Government's answer to the Finniston Report in late July was welcome to the entire IERE Council, if only because it freed us from the deadweight of professional politics that has been our burden for so much of the past two years. The decisions on the education and training pattern for engineers of the future announced at the same time as the Royal Charter for the British Engineering Council were much to our liking, being very much in tune with the recommendations we had made in our original evidence to Finniston.

What we need now is a period of stability in all such matters during which we can widen our learned society interests to take in new 'system' aspects of our fast-developing discipline, giving to this world the same sort of flexible thinking and support as was displayed by our founding fathers when they set up our Institution in the face of those who said that there was no future in 'wireless'. In this it is to be hoped that we shall soon be released from the learned society limitations that stem from our membership of CEI—limitations inherent in any system that tries to standardize its approach to any activity as diverse as engineering, involving as it does disciplines ranging from the controlled force of the heavy mechanical to the abstract delicacy of micro-electronics.

How far we shall succeed in this new surge forward remains to be seen but I pledge my support to my Council colleagues and the entire membership in the year ahead, confident that some old dogs can not only be taught new tricks but can quite often offer some old ones of proven value in return.

Acknowledgments

I would like to thank: David Tomlin Esq., sometime of the Ground Radar Division, Royal Radar Establishment, Malvern: the Station Commander of No. 1 Radio School, RAF Locking, and his staff; and Professor J. R. James of the Royal Military College of Science, Shrivenham.

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The 56th Annual General Meeting of the IERE

Held at the London School of Hygiene and Tropical Medicine on Thursday, 29th October 1981

The meeting was opened at 6 p.m. by the Acting President, Professor William Gosling, when 51 members were present.

It was confirmed by the Secretary, Air Vice-Marshal S. M. Davidson, that due notice of the meeting, the twentieth since the Institution's incorporation by Royal Charter, had been sent to all corporate members in the July/August 1981 issue of *The Radio and Electronic Engineer* (Volume No. 51, No. 7/8).

The Secretary reported that the minutes of the 55th Annual General Meeting, held on 23rd October 1980, had been published in the January 1981 issue of *The Radio and Electronic Engineer* (Volume No. 51, No. 1, pp. 14–17). No comment having been received on these minutes, it was unanimously agreed that they be taken as read and the President thereupon signed them as a correct record.

The Honorary Treasurer, Mr S. R. Wilkins, pauses to emphasize a point in his presentation of the Institution's Accounts.

ANNUAL REPORT OF THE COUNCIL

The President then presented the 55th Annual Report of the Council for the year ended 31st March 1981 and said:

'Once again it falls to me to present the Annual Report of our Institution. As you all know, it was our hope that our good friend and highly respected colleague, Mr John Powell, would be undertaking this role as the retiring 29th President of the Institution. But this was not to be. His sudden and tragic death, which is formally recorded at the beginning of the Report, was a great shock to us all and has overshadowed much of our work this year. All his engagements and commitments were met, however, and it has been my privilege to hold his post as Acting President until this moment—the end of his full year of office.

'In view of all this I do not want to say more than a few words at this stage. The Council's report to you is, as always, comprehensive and full of detail for the record; but it is quite straightforward. Much of it, however, has already been overtaken by events. For example, there is the matter of the outcome of the Finniston Inquiry which occupied so much of our effort during the year under report but which has now been settled by the Secretary of State's announcement of the setting up of the Engineering Council. And then there is the important work that we did with our sister Institutions to make possible the award of designatory letters for our Associate Members, which I hope will be completed when you vote for the Resolutions this evening, which are put before you under later items of our agenda.

'On professional standards I do commend to your study the very useful report of our Education and Training Committee. As usual, that important Standing Committee of Council has had a very active year and I believe that its work has had a very considerable influence on the decisions that have now been made concerning the future standards of education for engineers in general and the best approach for the training of electronic and radio engineers in particular. As to the other plank of our professional standards work—the Membership Committee—all that I need do now is to refer you to Table 1 of the Report from which you can see that, despite all the pressures of the industrial recession and general inflation, we have managed once again to more than maintain the level of our overall membership whilst further strengthening the top tier of corporate members and of our highly valued Associate Member class.

'Which brings me to professional activities, where the picture was not so bright in the early part of the year under report. The conference side of our work was badly hit by the trade recession and we were not able to attract as many speakers as we would have liked for the full programme of colloquia we had planned. You will all appreciate the reasons for this: financial restrictions on the movement of qualified staff has limited the extra-mural activity of many of the best qualified engineers, and many employers have been more than ever reluctant to lose the services, even for a day or so, of those engineers who could have been expected to attend our up-dating conferences in normal circumstances. I would only add here that it is good to see from this year's conference programme that matters have not got any worse: on the contrary, interest in our last two major conferences has been very encouraging indeed.

'Next, turning to the work of the Papers Committee and our Publications Department, I need only say that there has been no further change of policy during the year under report and that, despite the drastic turn-down in classified advertising activity in all trade papers and professional journals, we have managed to maintain the publishing schedule of both *The Radio and Electronic Engineer* and *The Electronics Engineer*. We believe that the value of the communications service provided by our newspaper has now been established beyond doubt and it is the Council's intention to continue this service, albeit at no more than break-even level at present, in the hope that the current advertising famine will soon begin to ease as confidence returns to the wider electronic engineering section of the nation's economy. No doubt our Treasurer will have something further to say about our publishing activities when he deals with our Accounts, where Journal production and distribution costs are such a dominant factor.

'Finally, acknowledgments: although this courtesy is quite properly covered in each of our Annual Reports, I want this year to pay particular tribute to our Secretary and his staff, who have done so much to ease my burden whilst acting for Mr

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The three winners of the Lord Mountbatten Premium, Mr Robin Caine, Mr John O'Clarey and Mr Alan English, received their award from the President for their paper on a digital transmission system for sound programmes.

Powell. By taking on the additional role of Executive Vice-President, our Secretary was able to save me many visits to London for meetings concerned with the Finniston Report and other associated CEI matters—a role for which I am personally most grateful, and from which he is released by this Annual General Meeting.

'But before I move the adoption of the Report on our 55th year I would invite and welcome comments from the floor.'

No questions were asked and the President moved from the Chair that the Annual Report of the Institution for the year ended 31st March 1981 be adopted; this was approved unanimously.

AUDITORS' REPORT, ACCOUNTS AND BALANCE SHEET

The President called upon the Honorary Treasurer, Mr S. R. Wilkins, to propose the adoption of the Institution's Accounts for the year ended 31st March 1981, who said.

'The year to April 1981 shows a deficit of £20,546 compared with last year's surplus of £36,406. This result continues the pattern which has been prevalent during the past inflationary years whereby a year in which a subscription increase has been put into effect produced a good result, to be inevitably followed by a deficit on the second year of the subscription cycle when continuing inflation takes its toll. However, the net surplus of nearly £16,000 over the past two year period has had the desirable effect on the Adverse Balance which at March 1981 stood at £71,608.

Professor Vito Cappellini came from Florence to receive the Clerk Maxwell Premium on behalf of himself and his co-authors for their outstanding paper on data compression.

'This figure has shown a steady improvement over the past years and, with the anticipated results for 1982, should be still further reduced. I must, however, stress that the cumulative bank charges resulting from this deficit still militate heavily against the efforts of all concerned to keep the Institution's expenses to a minimum.

'With this in mind, Mr President, I am tempted to refer to the letter which the Secretary recently addressed to all Corporate and Associate Members of the Institution. I am pleased to inform you that his appeal has already evoked a generous contribution from some 35% of the members involved, and I would ask those of you who have not yet responded to give the matter your earnest consideration.

'Turning now to the accounts which you have before you, I am sure that their clear presentation of detail requires little comment from me. It is, however, worth mentioning that despite all the external problems, the sales income figure has been held to within 3% of last year's record figure. The inevitable costs associated with these sales—mainly printing and postage—have, however, increased by over 17% or some £21,000 for the year. At the same time it should be pointed out that these costs include a sum of £8, 000 to discharge the agreed loan towards the launching costs of *The Electronics Engineer*. This is a 'once for all' payment and will not arise in future years.

The President and Mr Stan Hill following presentation of the Lord Brabazon Premium for an outstanding paper on trans-horizon radio links over the North Sea.

'The Secretariat have done their usual excellent job in restricting the administrative expenses, despite numerous heavy increases in externally provided services which are entirely outside their control.

'Indications from the interim accounts for 1981/82, reflecting the benefit of the increased subscriptions effective from April 1981, are giving rise to optimism.

'Income from Conferences and Symposia is up on last year as are the receipts from the sale of publications.

'Despite the inevitable increase in costs of postage, printing and other services which are already in evidence, it is confidently expected that a substantial surplus for the year will result.

'This, Mr President, concludes my report for this year. With the help of our Auditors I will be pleased to answer any questions that you or members may care to ask, and then, if you will permit me, I would like on behalf of the Council to propose the adoption of the Accounts as published together with the Auditors' report.'

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Mr David Burt, recipient of the A. F. Bulgin Premium for an outstanding paper on c.c.d. sensors for television, with the President.

Professor Philip M'Pherson is congratulated by the President on the award of the J. Langham Thompson Premium for his paper on systems engineering.

There were no questions asked, and Mr P. M. Elliott (Member) seconded the Honorary Treasurer's proposal, which was carried unanimously.

ELECTION OF THE COUNCIL FOR 1981–82

Confirming that there had not been any opposing nominations to those made by Council and circulated to Corporate Members in a notice dated 5th June 1981 in the June 1981 issue of *The Radio and Electronic Engineer,* the Present said:

'We are therefore honoured that we shall have as our new President, Mr Harry Drew.

'Professor J. R. James and Dr P. K. Patwardhan are re-elected as Vice-Presidents, and Colonel W. Barker, Mr L. A. Bonvini, Major-General H. E. Roper, Mr D. L. A. Smith and Group Captain J. M. Walker are elected Vice-Presidents. Mr L. W. Barclay, Mr G. A. McKenzie, Mr V. Maller and Professor K. G. Nichols are elected as Fellows. Mr P. Atkinson is elected as a Member and Mr R. B. Michaelson as a Companion.

'Mr S. R. Wilkins is re-elected as Honorary Treasurer, and the remainder of Council will continue to serve in accordance with the period of office laid down in Bye-law 48.'

Professor Gosling presents Dr Michael Underhill with the P. Perring Thoms Premium for his paper on frequency synthesizers.

The Paul Adorian Premium for developments in broadcasting was presented by Professor Gosling to Mr Ray Hills and Mr Leslie Sherry for their paper on Teletext performance.

The recipient of the Leslie McMichael Premium, Mr Ron McLellan, contributed a paper on management in a competitive environment.

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The new President, Mr Harry Drew, wears the badge of office just presented to the Institution by Mr J. H. Crouch on behalf of Cable and Wireless.

PROPOSED AMENDMENTS TO THE ROYAL CHARTER AND BYE-LAWS

The President next referred to Resolutions seeking to amend the Institution's Royal Charter and Bye-laws, which had been approved in Council and circulated to Corporate Members in a Schedule annexed to the Agenda for the Annual General Meeting, and said:

'The Resolutions cover proposed amendments in two respects. First, to permit Associate Members of the Institution, i.e. Technician Engineers, to use appropriate letters after their names (AMIERE), a practice already approved for other Institutions having fully qualified Technician Engineers in membership.

'Second, it is proposed that a member whose subscription, due on 1st April, remains unpaid after 30th June should not receive any of the benefits of membership pending payment. At present, such a member retains these benefits until 30th September, i.e. six months in arrears, which your Council suggests is an inordinate length of time, especially in these days of financial stringency.

'Before seeking your approval for Resolutions Nos. 1 to 4 to be submitted for allowance by the Privy Council are there any comments?'

There were no questions asked and the President moved from the Chair that the Resolutions should be approved. This was carried unanimously.

APPOINTMENT OF AUDITORS AND SOLICITORS

Taking Items 6 and 7 of the agenda together, the President proposed that Gladstone, Jenkins and Company should be reappointed as the Institution's auditors, their remuneration to be at the discretion of Council, and that Bax, Gibb and Company (formerly practising under the style of Bax, Gibb and Gellatlys) be re-appointed as Solicitors to the Institution. This motion was carried unanimously.

PRESENTATION OF INSTITUTION PREMIUMS

Professor Gosling called upon Mr F. W. Sharp, Editor of the Institution's Journal, to describe the awards and introduce the recipients. Mr Sharp stated that full details of the twelve premiums of the available 20 awarded for 1980 had been announced in the July/August issue of the Journal and also as an Appendix to the Annual Report. He drew attention to the fact that of these twelve, five were to authors working in industry, four to authors on the staffs of universities or polytechnics and three to authors with public corporations. One or more of the recipients of eight of the premiums were present and these came forward to receive their chosen books or scientific instruments from the President.

A close-up view of the Presidential Badge. The Institution's Arms are in enamel with a gilt base and surround. On the reverse side is an inscription recording its presentation in memory of John Powell.

ANY OTHER BUSINESS

The President announced that notice of any other business had not been received. The Secretary confirmed this, but added that he understood that Mr J. H. Crouch of Cable and Wireless Limited wished to make an announcement to the assembled members.

Mr Crouch then came forward to pay tribute to the life and work of the late Mr John Powell (Engineer-in-Chief, Cable and Wireless) and to announce that in his memory his employers wished to present to the Institution a President's Badge, to be worn on appropriate occasions by the succeeding holders of that office. The badge was then presented to the newly elected President, Mr H. E. Drew.

Mr Drew acknowledged the generosity of the gesture, and said that he felt greatly honoured to be the first President to wear the insignia.

The newly elected President then expressed appreciation to Professor Gosling who had so willingly served as acting President for the remainder of Mr Powell's year of office. Professor Gosling made appropriate acknowledgement and then declared the meeting formally closed at 6.25 p.m.

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Membership Elections and Transfers

THE COUNCIL confirms the elections and transfers of the following members whose candidatures have been recommended by the Membership Committee and announced in Membership Approval Lists Nos. 281–288, published in issues of *The Electronics Engineer* dated 5th February, 5th March, 2nd April, 7th May, 30th July, 20th August, 3rd September, and 22nd October 1981.

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Transfer from Member to Fellow
HOLKER, Peter Mark. McVEIGH, Thomas Thompson. NORTHALL, Bertram Victor. OBERSBY, Derek.

WALKER, James Martin. WHITE, Robert George.

FRASER, Alexander Hugh Campbell. LOWE, Ronald. REAY, David. TRINOGGA, Lothar Alfred.

BIRKIN, Michael Sambrook. HODGSON, Peter Chester. LINTON, Roger Leslie. MAVOR, John.

DAVIES, John Jenkyn. DWIVEDI, Munesh Bal.

ROBERTS, Barry John.

ALLEN, Charles Edwin.

Direct election to Fellow
OWEN, Peter Lumsden Tudor.

BACKEN, David John.

SHEARMAN, Edwin Douglas Ramsay.

BURGESS, Boyd. DAVIS, Quintin Visser.

Transfer from Graduate to Member
ŠINCLAIR, Donald Alexander. THIEL, Geoffrey Lawrence.

CHOUDHURY, Mohammed Anwar. EKEKE, Chiso Inglis. JEYAVEERASINGHAM, Thilliar. WARREN, Simon John. WELLS, Andrew Hammond.

BUTLER, Gerard Hugh. CAHILL, Sidney Joseph. HIGGINS, Terence Michael. NEWCOMBE, Sean Benjamin. PEREGRINE, David. RUFF, Steven Charles.

BRUCE, John. EDGAR, Thomas Henry. FOX, Stephen John. THORN, Ian Phillip.

ALLIS, Richard William. BATES, Graham. BILLINGTON, Geoffrey Richard. HAWES, Anthony David McIntosh.

COLE, Christopher, James. EARNSHAW, Ian Stuart. PENDLEBURY, Barry Keith. WONG, Ming Kay.

ASH, Geoffrey William. WRIGLEY, Barry.

CLAY, Malcolm Nicholas. CROSBY, Paul Russell. HORNBY, Robert Maurice. LODGE, Dale William S.

Transfer from Student to Member
MIDGAL, Richard.

CLAYDON, Roger Paul.

RANCE, Grahame Edward. YAM, Kwing-Kwong.

Direct election to Member
CLARKE, Barry Lee. STANWAY John Desmond. SUTTON, Roy Joseph. WILMORE, Trevor.

BAINTON, Douglas Ogilvie. BATHO, Christopher John. BEESLEY, Graham Edgar. BRYANT, James Mitchell. DHOLOO, Jimmy. HOPKINS, Harman Henry. SLOGGETT, David Raymond. PATEL, Naushir Phirozsha.

BARTLETT, Michael. BUDD, Stephen Charles. CASE-UPTON, Peter. JACOBS, Raphael Simon. McCALDEN, Alexander John. PETROVIC, Vladimir. TINK, Kenneth Robert. TWEEDIE, Alistair Henry.

DEACON, Nigel Geoffrey. DEAKIN, Stewart. MURPHY, Shaun Patrick. NEVISON, John Graham. REBEIRO, Jackie Michael. SMOLEN, Andrew Peter.

CLARKE, Bryan. DIXON, Phillip William. KOUBA, Robert. McEWEN, John. RAJENDRAN, Kanagaratnam. STEPHENSON, Christopher. SUTTON, Malcolm Stuart. Walters, Robert.

HATTON, John Christopher. HUNT, Denis John. HUNTER, Timothy Robert. JOHNSON, Michael Charles. SLOANE, Iain Robert Fraser. WOOLRICH, Raymond Arthur.

COLLINS, Michael.

BRUNT, Steven Lewis. DOBLE, Richard Philip. GOPSILL, John Peter. PLUMB, David Michael. SHERRY, Leslie Arthur.

NON-CORPORATE MEMBERS

Transfer from Student to Graduate
BADCOCK, Alan Raydon Cooper. GAULT, Ian. POON, Hing Wai.

BLIZARD, Paul. FINDLAY, Andrew James.

WONG, Yew Thye.

O'KEEFE, Michael James. PROUD, Stephen John. WINSTANLEY, Graham.

TAI, Lee Lieh Robert.

ISHAQ, Syed Zahid. KENYON, Paul Douglas. ROWE, Timothy George. SITHIRAPATHY, Pasupathy. SMITH, Neil Grenville.

Transfer from Associate Member to Graduate
BGENTI, Patrick Sunday O.

GULLIFORD, Julian David.

Transfer from Associate to Graduate
YOUNG, Derek Ronald.

Direct election to Graduate
SHINMAR, Narinder Singh.

EZE, Geoffrey Eze. RAJASINGAM, Thuraiayau. SIVITER, Peter Julian. STEELE, Conrad Bancroft. THOMAS, Keith Owen.

BENBOW, Roy Douglas. HARRIS, James Charles Victor. HEARNE, Patrick. HEATH-CALDWELL, Jeremy James.

FILEMAN, Paul John. OPOKU-GYIMAH, Enoch. RAYNER, John William. SWINBANK, Peter Alan Jonathan.

COOPER, Stephen John. FITZPATRICK, Thomas. JACKSON, John Graham. LEITCH, Neil George Finlay. MORGAN, Christopher John. SAMDANI, Rafique. STEELE, Robert John.

DHUNA, Jagdish Rai.

FUNG, Chun Che. HUSSAIN, Amjad Mazhar.

BAMBRIDGE, Norman William. CIUPA, Martin. GALEA, Michael Andrew. GRAHAM, Christopher John. McARDLE, Brian Patrick. NEVILLE, Richard Stuart.

Transfer from Graduate to Associate Member
GRUSZKA, Stuart Henry.

CHAPMAN, Patrick Jeffrey.

Transfer from Student to Associate Member
YOUNG, Richard John.

HEWITT, David Paul.

JELF, Alan John.

CARR-CAMPBELL, Paul Martin St. John. JAMES, Stephen William.

Direct election to Associate Member
ANDREWS, John William. HEARNDEN, Graham, Brian. JENKINS, Peter Neil. OCRAN, Harry Thompson. PECKHAM, John Raymond. WILKINS, Dale. WILLIAMSON, James Henry.

CHAMP, Christopher James, GOSSET, Graham Alec. JAI, Davinder. LINDA, Martin John. O'SHEA, Patrick Joseph. OGUNSHAKIN, Solomon. PAIN, John. WILCOX, David Charles.

DIXON, Richard James.

COOPER, Paul. FONG, Shi Ghe George. HARLEY, Philip. RICHARDSON, Ian Farquharson. SAMPSON, Christopher David. SHARPLES, Stephen Joseph.

BURTON, Edward Ernest. JONES, George. K'YARWENDA, Gosbert P.T. PRYCE, Simon Gregory. SUMMERS, Brent.

ADAMS, Kenneth. CAMP, Alan John. DODDS, Henry. FOSKETT, Robert John. PIDDINGTON, Graham Stuart. ROBERTS, Clive, TONGE, Frank.

BATESON, John Lawrence. WALKER, Willima. WILLIAMS, Richard Thomas W. WILSON, Ian Maurice.

Direct election to Associate
BROTHERTON, William Dennis Wright.

LEGGETT, James William.

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member
LAM, Peter Ar-Fu. MBELU, Bennett Oduche. YAU, Pui Man.

LO, Yu-Chiu Peter. ODUTAYA, Samuel Adebola. OROGE, Clement Olusegan.

NG, Chiu Keung.

AKINHANMI, James Ayodeji. LAM, Lai Yin. SIU, Wan-Chi.

AKANNI, Adebisi Mosiudi.

Transfer from Member to Fellow
WONG, Joshua Sook-Leung.

FERGUSSON-NICOL, Alexander Emeric.

ULLAH, Irfan.

Transfer from Associate Member to Member
JONES, Eric George.

OGOLLA, John Joseph.

Direct election to Member
KINSMAN, Derek Wayne.

ABEYNAIKE, Christopher Ronald M. Cheung, Kai-Sum. CONIBEAR, Graham Richard. STITT, Raymond Victor. IOANNOU, Andreas. LO, Chung-Ming. SUBHANI, Ehsan-Ul-Haq.

EZEIBE, Michael Okoli.

ALWIS, Muthuwadige, L.C. OLANUBI, Richard Ola. PERERA, B.T.E.A. WONG, Wai Man.

CHAN, Yun Sum. KANE, James Ian. LIM, Koon Chow. MALIK, Nazir Ahmad. WIJAYAPALA, Vidarshana P. WONG, Ki-Sun Joseph. WONG, Wai-Yin Albert.

CHAN, Pak-Cheung. NG, Siu Keung. PERERA, Christodu Baduge R.

BAKRY, Saad Haj. BALASUBRAMANIAM, Kanashpari. TUCK, David Thomas.

ABAYASEKARA, Patricia Nirmalie E. ARACHCHIGE, Sarath Nandana. LEAPER, Mark William Eric. MOHAMMED, Sani. OYEDELE, Nathaniel Adelere.

NON-CORPORATE MEMBERS

Transfer from Associate Member to Graduate
CHEUNG, Yee. CHIU, Kai On. CHNG, Chee Heng. KWOK, Chi-Wah. WONG, Sik Hung.

Transfer from Student to Graduate
CHAN, Pak Ming Daniel. FUNG, Cheuk Ho. LIANG, Tin Sing. TSUN, Ka Yin. WONG, Kwong Hung.

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LEE, Chun Ho. LEUNG, Wing Chuen. LI, Hing Man. LUK, Koon Min. CHENG, Lam. LAU, Chak Fai. LAW, Chun Kwong. TO, Check Ming. TONG, Kok Ping.

CHEUNG, Ping-Chow. FUNG, Kwok Wing. KURUPPU, Premalal T. LOW, Wah Chai. NG, Kam Shing. WONG, Sek Kwong.

LAU, Chak Man. SIVAKUMARU, Thirunavukkarasu. TSUI, Chuen Cheong Adam.

ABDULLAH, Fouad Ahmed Sheikh. YAP, Chee Kian.

CHAN, Eddie Kam-Hon. CHEUNG, Pang-Hung. FUNG, Yeun Kwong Petrus. HO, Fuk-Hoi. NG, Kwing Leung.

Direct election to Graduate

KONG, Sik Ong.

AMMARI-AZAR, Esmail, A. LEE, Khek Hian. OYEBISI, Timothy Oyedepo. HO, Ka-Kui. HUNG, Hing Lun. NANAYAKKARA, N.P.L.

FRANK, Ajanaku Segun Peter.

KINNOO, Sarupanand. UDAWATTA, Kapila Bandupriya S.

ABEDIBU, Jibrin Segun. CHIU, Hong Lok. CHOI, Yiu Kuen. FYNTANIDES, Demetrios. TANG, Jeffrey Chi Kuen.

CHAN, Lo-Ching. GOULDING, John William. HO, Kwok On. TANG, Shek-Leung. TSE, Wai-Man Edward. YEUNG, Siu Hoi.

Transfer from Associate to Associate Member

ROBERTS, John Michael.

Transfer from Student to Associate Member

CHOE, Yaw Choon. SEOW, Hock Beng.

CHEUNG, Fu Wah.

SENEVIRATNE, Rohan Dushyand De Silva.

LEUNG, Sheung Ming. TAN, Kwang Chiang D. WONG, Ka Man.

Direct election to Associate Member

AU, Shiu Sun. CHAN, Chiu. ENO, Odiong Okon. LEE, Heng Onn. MILNE-DAY, John Miles. OBELE, Thompson A.B. PILLAI, P.T.

HASAN, Syed Abid. KHOSA, Balwant Singh.

WONG, Ming Choon.

CHAN, Wing Kai. SHANMUGATHASAN, Subramaniam. YUEN, Kai Kong.

CRILLY, William. HO, Sui Shing. LAI, Won Chew. OKUNDAE, Moradeyo A.A. Mushin. TAI, Shing Yuk Stephen. TAN, Thye Peng. UGWU, Oguijiofor Obadiah. WONG, Wing Wing.

LEE, Teck Voon.

ABAH, Sylvester C.O. DEWASURENDRA, Jayampathie. LAM, Wai Chi. EIGBULUESE, Matthias O. NGONEBU, Silas Ebo. PUN, Michael Vun Yung.

Direct election to Associate

OBARE, James Roberts O.

ADEGBEMIRO, Samule Ajayi. OLUKUNLE, David Tunji.

SINGH, Amar.

Obituary

The Institution has learned with regret of the deaths of the following members.

Albert Henry Appleyard (Member 1957, Graduate 1955) of Dover died on 2nd July 1981, aged 53. Following service in the Royal Navy from 1946 to 1948 as a Petty Officer, Bert Appleyard joined the Plessey Company as a Television Engineer. After obaining an HNC in Radio Engineering at Borough Polytechnic in 1951, he joined the English Electric Company where he worked as an Engineer on guided weapon circuitry. Two years later he went to A.C. Cossor to design television time-base circuits and components, and in 1956 he was appointed a senior engineer with Advance Components, responsible for the design of electronic instruments. From 1960 to 1970 he was with Avo as Senior Electronics Engineer and subsequently as Chief Engineer in charge of the development engineering department. Mr Appleyard represented the Institution for a number of years on BSI Technical Committee TLE/8 Instruments and Test Equipment for Telecommunications, and he was a member of the organizing committee for the conference on Digital Methods of Measurements in 1969.

Lieutenant Commander Kenneth Stanley Brown, RN (Rtd) (Member 1955, Associate 1954) of Cheltenham died on 19th July 1981 aged 66. Commander Brown was Manager of a Radio Service Department prior to the war when he joined the Royal Artillery as a Technical Instructor in fire control. He was commissioned in the Royal Electrical and Mechanical Engineers in 1943 and he remained with the Corps until 1949, latterly being officer-in-charge of anti-aircraft radar workshops. In 1950 he was commissioned in the Royal Navy and served as an air electrical officer to Fleet Air Arm Squadrons and with the Service Trials Unit. He also held staff appointments at the Ministry of Supply and at HMS *Ariel* prior to his retirement.

Arthur Sydney Dunstan (Member 1934) of Southfields died on 24th June 1981 while on holiday in Germany; he was 73 years of age. Sydney Dunstan worked in the radio industry in the Newcastle and London areas before the war in which he held a commission in the Royal Corps of Signals. He then joined Siemens Electric Lamps and Suppliers as a Technical Sales Representative based in Newcastle and in 1950 he moved to Rediffusion North East. In 1952 Mr Dunstan went out to take charge of the company's subsidiary, Rediffusion (Nigeria). In 1956 he returned to take up the appointment of Chief Engineer with London Rediffusion Service and remained with the company until his retirement. While in the North East Mr Dunstan was very active in the affairs of the North Eastern Section and he was Chairman from 1949 to 1952.

Ronald Buttrick Foster (Associate 1938, Student 1934) died on 4th August 1981, aged 69. Prior to the war Ronald Foster worked in the Harrogate area as a service engineer and in 1938 he was appointed Civilian Lecturer and Demonstrator in radio in the RAF Wireless School, Cranwell. He subsequently joined the British Broadcasting Corporation with whom he remained until his retirement in 1977.

John Goostray (Member 1973, Graduate 1969), of Leeds, died in July 1981, aged 54. After an engineering apprenticeship with David Brown Engineers, Mr Goostry served as Flight Engineer in the Royal Air Force and after demobilisation returned to the Company as an engineer fitter until 1949 when he joined the Post Office Telephones in Huddersfield as a Technician. He remained with the Post Office, working mainly on installation and subsequently the planning of systems. He was promoted to Executive Engineer following service in the Limited Competition in 1970 and he was appointed Head of the Works Division in the York Telephone area.

Lau Hin-Ho (Student 1980) of Kowloon City was drowned in October 1980, aged 20. He was a final-year student in the three-year full-time course for the Higher Diploma in Electrical Engineering at Hong Kong Polytechnic.

Duncan Glenallan MacKenzie (Associate 1928) of Lantzville, British Columbia, died early in 1981, aged 74. Mr MacKenzie was for many years with the Engineering Department of Air Canada in Montreal.

Captain Kenneth Arthur William Pilgrim, OBE, RN (Rtd.) (Fellow 1957, Member 1949, Associate 1946) of Wheathampstead, died suddenly at London Airport on 13th August 1981, aged 60. At the time of his death Captain Pilgrim was Executive Director, Sales, for the Hatfield Division of British Aerospace Dynamics Group, an appointment he received in 1980. Captain Pilgrim served in the Royal Navy from 1941 until 1973, his last appointment being on the staff of Flag Officer Sea Training as Chief Staff Officer (Technical) and Captain of the Portland Naval Base. He was appointed OBE in 1962. From 1973 to 1975 he was with Hawker Siddeley Dynamics, initially as Project Manager in the Underwater-to-Surface Guided Weapon Division, subsequently becoming Divisional Manager. He later held appointments as Divisional Manager of the Guided Weapon Support Division and of the Air Strike Weapons Division. Captain Pilgrim served on the Institution's Technical Committee from 1956 to 1965 and on the Membership Committee from 1965 to 1968.

Professor Krishnaji Balbheem Talwalkar (Member 1956) of Poona, died on 25th July 1981, aged 57. Professor Talwalkar studied electrical engineering and radio engineering at Sir Cusrow Wadia Institute of Electrical Technology, Poona, and stood 1st in the list of successful candidates for the Diploma in Electrical Technology of the State Board of Technical Examinations in 1942. He then joined the Radio Engineering Department of the Institute as a Demonstrator in 1944 and he rose to become Head of the Electronics Department in 1970.

One of his colleagues, Professor S. V. Kharkar (Member) writes, 'He combined in himself a scholar, a sportsman, an artist and a devoted teacher. To his credit is one of the best equipped and model Electronics Laboratories in the State.'

Geoffrey Palmer Woodbine (Member 1937, Associate 1935) died last summer aged 77.

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Members' Appointments

CORPORATE MEMBERS

Wg Cdr J. M. Brown, RAF (Fellow 1973, Member 1959) has been appointed to the post of ADET Eng 1 at the Ministry of Defence as a member of the Air Defence Environment Team (RAF). He was formerly Station Commander of Royal Air Force Staxton Wold, North Yorkshire.

J. R. Halsall, Dip. El (Fellow 1979, Member 1954, Graduate 1949) who has been with ICI for 30 years has retired from full time employment and is working as a part-time consultant. Mr Halsall was Group Manager (Cybernetics) at the ICI Corporate Laboratory and is an ICI Research Associate. He has served on the IERE Council, the Papers Committee and the Professional Activities Committee and on conference organizing committees.

Gp Capt. D. J. Breadner, B.Sc., RAF (Member 1968) is now a student at the Royal College of Defence Studies, London. Since 1979 he has been Staff Officer Engineering at the Headquarters of 11 Group, RAF Bentley Priory.

Major I. R. Lidstone, B.A., R Sigs (Member 1973, Graduate 1970) has taken up an appointment as Technical Officer Telecommunications, Data Communications, in the Communications Project Agency, School of Signals, Blandford Camp. His previous posting, as Captain, was to 8 Signal Regiment, Catterick Garrison.

Sqdn Ldr B. D. Longman, RAF (Member 1974) has been posted to the Canadian National Defence Headquarters at Ottawa for DEW duties. His previous appointment was Officer Commanding SADSU at RAF Scampton.

W. R. Lovett (Member 1973, Graduate 1969) is now Engineering Group Manager with Corning Medical & Scientific in Halstead, Essex.

I. D. Macey (Member 1977, Associate Member 1974) who was an Air Traffic Engineer I—Radar Data Processing and Display Systems Engineer at the London Air Traffic Control Centre, is now a Senior Air Traffic Engineer with the Civil Aviation Authority.

V. E. Nwebube (Member 1973, Graduate 1966) has been appointed Acting Chief Engineer in charge of studios at the Anambra Broadcasting Corporation in Enugu, Nigeria.

S. Ruff, B.Sc., Ph.D. (Member 1981, Graduate 1980) who was at The Queen's University of Belfast as an electronics engineer/computer programmer, has taken up an appointment as Electronics Engineer in the Resources Engineering Department of Gallaher Ltd in Belfast.

T. Scott (Member 1973, Graduate 1966) has taken up an appointment as Operations Manager with the Civil Aviation Authority in London. Mr Scott was previously based at Hurn Airport, Dorset and held the post of Senior Air Traffic Engineer.

Sqdn Ldr P. E. Sharp, RAF (Rtd) (Member 1973, Graduate 1969) has joined ENERTEC/Schlumberger as Programme Development Manager of the Mangetic Recording Division at Aldershot. Sqdn Ldr Sharp's last service appointment was Air Eng 12E at the Ministry of Defence.

Flt Lt D. R. Hignett, RAF (Graduate 1971) has been posted to HQ Strike Command, RAF High Wycombe, as Electrical Engineer Communications (NATO Liaison). He was previously Maintenance Officer at the NATO Joint Operations Centre at Maastricht in The Netherlands.

NON-CORPORATE MEMBERS

S. W. Holland, M.Sc. (Graduate 1980) has joined the South Shields Marine and Technical College as a Lecturer in the Department of Electrical Engineering and Radio. He was previously a Research Assistant at Newcastle Polytechnic.

G. T. Marechera, B.Sc (Graduate 1979) has taken up an appointment as Engineer, Switching Systems, with the Posts & Telecommunications Headquarters in Salisbury, Zimbabwe. Mr Marechera was previously an Assistant Engineer with the New Zealand Post Office in Christchurch.

Flt Lt K. A. Munson, B. Sc., RAF (Graduate 1976) is now Officer Commanding, Electrical Engineering Flight at RAF Benson. He was Officer Commanding Ground Electrical Training at No 4 School of Technical Training, RAF St Athan.

A. A. Zaidi, Ph.D., M.Sc. (Graduate 1971) is now working as a Lecturer in the Physics Department at the University of Kuwait. From 1975 to 1981 he was studying in the Department of Atomic Physics at the University of Stirling, where he gained his doctorate.

Contributors to this issue

Gareth Charles served an apprenticeship in electronic and electrical engineering with Partridge Wilson & Company of Leicester where he was subsequently employed as a Test Engineer. From 1972 to 1975 he was Electronics Technician for the School of Chemistry at Leicester Polytechnic where he was responsible for the design and construction of electronic equipment for the control and measurement of chemical processes. For the past 5½ years Mr Charles has been involved in the development of the digital facilities in the Department of Engineering Production at Loughborough University of Technology in the post of Experimental Officer.

Richard Weston worked for six years in the Scientific Civil Service as Assistant Experimental Officer mainly on design, development and testing of equipment for h.f., s.h.f. and v.h.f. In 1968 he became a Research Student at Southampton University working on computer modelling of the mammalian auditory system. After three years he was appointed as a Lecturer at Bournemouth College of Technology, during which period he was also involved in the work of the low-cost automation centre. Since 1973 Dr Weston has been a Lecturer in the Department of Engineering Production at the University of Technology Loughborough where he is responsible for development of the department's computing facility. He has been involved in the use of microprocessors for the past six years in many areas of manufacturing, including machine tool control, welding, materials handling, process control, distributed industrial control systems.

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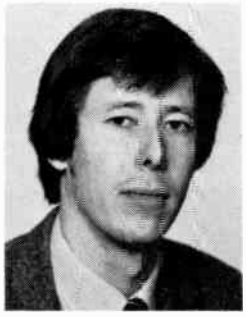
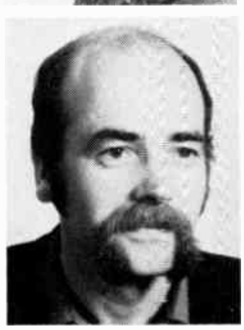


Anthony Lymer (Graduate 1977) obtained his degree in electrical and electronic engineering from the University of Wales (Bangor) in 1975 and joined the Marconi Research Laboratories, Great Baddow, working on the development of mobile radio data systems. In 1977 he moved to Bath University to study for a Ph.D. under a CASE scheme, co-funded by SRC and GEC-Marconi. He is currently employed as a Research Officer and is investigating the use of s.s.b. for mobile radio-telephones.

Professor William Gosling (Fellow 1968) has been Director of Technology of the Plessey Company for the past year. Prior to this he had occupied the chair of Electronic Engineering at the University of Bath since 1974, where he moved after spending some 16 years at the University College of Swansea—from 1966 to 1973 as Professor of Electrical Engineering and Head of the Department of Electronic and Electrical Engineering. He has contributed numerous papers to the Journal on a variety of subjects including instrumentation, semiconductor devices and circuits, and radio receiver techniques, being awarded the Clerk Maxwell Premium for 1976. Professor Gosling was President of the Institution in 1979–80 and Acting President for some nine months in 1981 following the death of Mr John Powell. He has served on standing and conference organizing committees and has represented the IERE on several outside bodies, notably on CEI and on EUREL of which he was President for 1978/79.

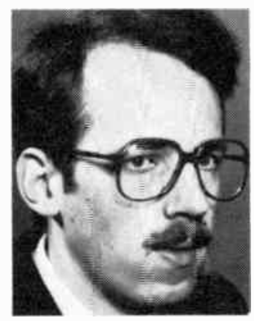
Bernd Adelseck received the Dipl.-Ing. degree in electrical engineering in 1976 from the Technische Hochschule, Aachen, of Germany. On graduating he joined AEG-Telefunken at Ulm where he is working on microwave and millimetre wave integrated circuits and components, especially in planar and quasi-planar waveguide structures.



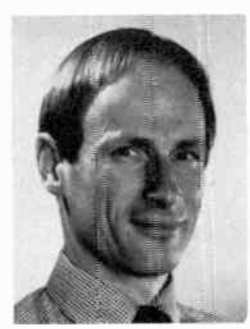
Heinrich Callsen began his professional education in a shipyard, serving his apprenticeship as an electrician. After a period as a sailor on a freighter he studied electrical engineering and in 1971 received the Ing.-Grad. degree from the Fachhochschule, Lubeck; three years ago he obtained the Dipl.-Ing. degree from the Technische Universitat, Berlin. In 1979 he joined AEG-Telefunken in Ulm where he is engaged in the development of integrated millimetre wave components and subsystems on the basis of planar and quasi-planar wave guide structures.

Holger Meinel received his Diploma Ingenieur's degree in 1973 from the Rheinsch-Westfälische Technische Hochschule of Aachen, Germany. Since then he has been with AEG-Telefunken, Ulm, involved with research and development in the mm-wave range. In 1977 he became laboratory leader and he is now working in the field of mm-wave integration and sub-assembly; his current work continues in this area with the development of experimental radar sensors and communication links for the mm-wave region.

Wolfgang Menzel received the Dip.-Ing. degree from the Technical University of Aachen, in 1974, and the Dr.-Ing. degree from the University of Duisburg in 1977. From 1974-1979, he worked on microstrip circuit problems at the University of Duisburg and in 1979, he joined AEG-Telefunken in Ulm, to work on integrated millimetre wave components and planar antennas.



Klaus Solbach received the Dipl.-Ing. degree from the Technical University of Aachen in 1974 and the Dr.-Ing. degree from the University of Duisburg, West Germany, in 1979. From 1975 to 1979 Dr Solbach was employed at the University of Duisburg as a research assistant carrying out investigations of the properties and circuit applications of dielectric image lines in the millimetre wave frequency range. In 1981 he joined AEG-Telefunken in Ulm where he is engaged in the development of integrated millimetre wave circuits.



Derek Webb graduated in physics from the City University in 1966. He worked as a Scientific Officer at the Government Communications Headquarters until 1968 when he joined Marconi Research Laboratories to work on optical communication techniques. In 1970 he transferred to Marconi Space and Defence Systems where he was responsible for two satellite instrumentation projects. Since joining the RSRE in 1973 he has been involved with the design and development of thermal imaging systems and he led the section responsible for thermal imager systems research. Mr Webb joined the scientific staff attached to the British Embassy in Washington in November 1981.

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Thermal imaging via cooled detectors

D. B. WEBB, B.Sc.

SUMMARY

The need to visualize thermal radiation is outlined. The characteristics of radiant energy and the transmission properties of the atmosphere are discussed to define the spectral range of interest. Practical methods of detecting thermal radiation are reviewed and the benefit of cooling the detector highlighted. Techniques whereby the detector can be made to interrogate the scene are described and contrasted. The manner by which the detected signal is processed is described with reference to several new electronic components. Finally some examples of present day systems are presented with examples of typical thermal imagery.

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1 Introduction

Thermal Imaging is that technique which converts the radiation pattern of a scene into a visible image. The term radiation refers to the continual emission of energy from the surface of objects with a temperature greater than absolute zero. For each object within the scene its radiated energy is the sum of the radiation transmitted and emitted by the body itself and the radiation reflected by the body from other objects. The radiation pattern within a scene is due to differences in self-emission from the surface of objects as a consequence of temperature differences, differences in energy emission efficiency i.e. emissivity and differences in surface reflectivity.

The principal reasons for wishing to be able to see this radiation are:

(1) The visualization of thermal radiation will allow the identification of objects within a scene at any time of the day or night. This follows since no source of illumination is needed.
(2) Covert sensing of our environment is thus possible via the formation of images upon receipt of object radiated energy. Contrast this situation with the human optical system or radar for which objects must be illuminated to be detected.
(3) Thermal radiation can be received from objects which lie beyond the limits of visual visibility when human vision is restricted by poor weather conditions or smoke.
(4) Any activity, animal or mechanical, can be readily detected since such activity becomes a dominant source of radiative energy within the scene. Thermal imagery therefore provides valuable intelligence by highlighting objects which are active.

Thus, the ability to perceive the thermal radiation pattern of a scene is highly desirable. To establish how it is best achieved the characteristics of thermal radiation and its transmission through an intervening atmosphere are reviewed. How the radiation reaching an observer can be detected is discussed and some of the techniques for scanning the scene outlined. Then the methods whereby the detected signal is processed to create useful

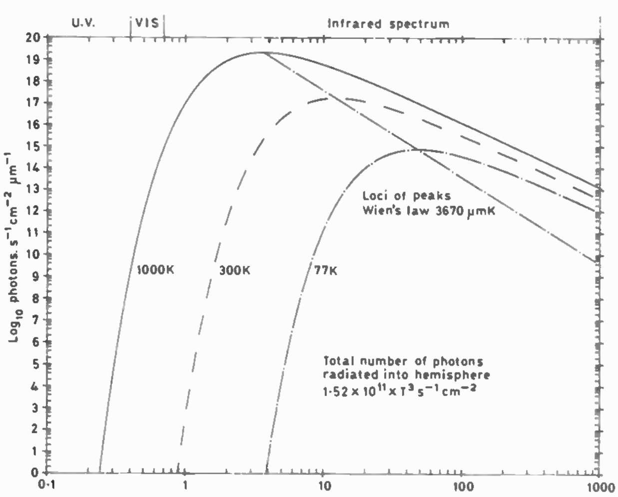

Fig. 1. Planck's law for spectral photon emittance.

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visible images of the thermal scene are described. Finally a few examples of the imagery typical of present day thermal imagers are presented.

2 Thermal Radiation[1-4]

The rate at which radiant energy is emitted by a surface depends upon the nature of the surface and its temperature. The Planck function defines the maximum number of photons radiated into a hemisphere per unit time from a unit area in a specified spectral interval that any body in thermodynamic equilibrium at the same temperature can radiate. This function is plotted in Fig. 1 as a function of wavelength for a variety of object temperatures. We note that energy is radiated as a continuous spectrum. At low temperatures the emission rate is small and the radiant energy spectrum is chiefly of relatively long wavelength. As the temperature is increased the rate of radiation increases very rapidly in proportion to the 4th power of the absolute temperature.

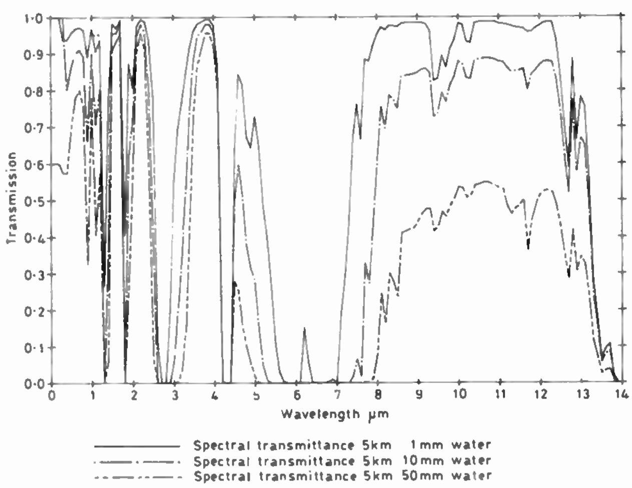

Fig. 2. Atmospheric transmission.

The energy radiated by an object has to pass through the atmosphere to the sensor which is to detect it. The radiated spectrum is modified by the absorption and scattering characteristics of the atmosphere. The choice of spectral interval for imaging is restricted to those wavelengths for which the atmosphere possesses good transmission. Figure 2 illustrates the transmission characteristics of the atmosphere[5] as a function of wavelength over a 5 km path for three different water vapour contents. Absorption by water in the 2·7 and 6·3 µm bands and the 2·7 and 15 µm carbon dioxide absorption bands restricts atmospheric transmission in the 2 to 20 µm thermal spectrum to two atmospheric windows. These are 3·5 to 5 µm and 8 to 14 µm. For a body at 300 K the proportion of photons radiated within the spectral interval 3·5 to 5 µm and 8 to 14 µm is 0·3% and 23·0% respectively.

As already mentioned, self-emitted radiation is a strong function of an object's temperature. It is useful to see how this radiation changes with differential changes in temperature. Figure 3 plots the thermal derivative of Planck's law for spectral-photon emittance.

As can be seen from Fig. 3, the thermal derivative of

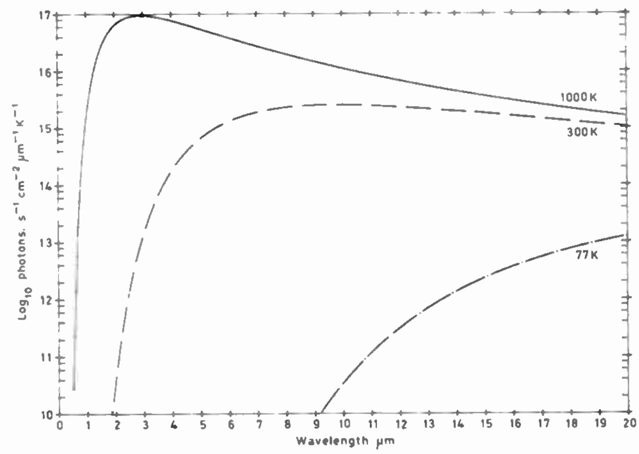

Fig. 3. Thermal derivative of Planck's law for spectral photon emittance.

Planck's radiation law is a maximum in the range 10 µm to 3 µm for objects in the temperature range 300 K to 1000 K.

It is informative to enquire what integrated photon flux difference exists between an object which is 1 K hotter than its background at 300 K within the 3·0 to 5 µm and 8 to 14 µm wavebands relative to the total flux emitted by the background over all wavelengths. This photon contrast is 8×10^{-5} and 1×10^{-3} respectively. Thus thermal imagery is concerned with sensing objects whose contrast relative to their background is very low. It is usual to a.c.-couple the thermal detectors to the processing circuits in order to reject the large static signal and amplify the small signal variations which correspond to the thermal contrast within the scene.

3 Detecting Thermal Radiation[1,4,6-10]

There are many phenomena which can be used to construct transducers to sense thermal radiation. Not all are practicable if we wish to construct an imager which provides real-time imagery at frame rates where luminance flicker is not apparent. The appropriate choice of detector is one which satisfies signal-to-noise requirements over the spectral range of interest, possesses adequate response speed and presents performance demands which are practicable in respect to the preamplifier used to amplify the detected signal.

Of the many different forms of detectors for sensing thermal radiation each can be classified into one of two categories, thermal or photon. Thermal detectors use materials which possess a characteristic which is temperature dependent. The absorption of incident radiation raises the temperature of the sensing material and so produces a change in the property being used to detect the radiation. The thermocouple, thermistor, pyro-electric detector and bolometer are examples of thermal detectors. The second category of detector employ photon-induced electronic transitions to modify the properties of the detector. The incident photons generally excite electrons from a captive to a mobile state, thus increasing conductivity as in a photoconductor or allow the electrons to drift from the captive site to modify an electric field as in the

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photovoltaic or photoelectromagnetic detectors.

The response time of the two types of detectors are quite different. As one would expect, the thermal inertia of the sensing element of thermal detectors generally renders them slow in comparison with photon detectors. A notable exception is the pyroelectric detector.[11] Thermal detectors typically possess response times of the order of 1 ms whilst the response time of photon detectors are usually less than 1 μs. It is this short response times that makes photon detectors the most appropriate choice for real-time thermal imaging systems.

With regard to spectral sensitivity, the two categories of detector possess different characteristics. The thermal detector will inherently be responsive to all radiation which is incident. The spectral response is dictated by the spectral transmission of the fore optics and/or the detector window encapsulation and the spectral absorption characteristic of the thermal element. In the case of the photon detector its response is defined by the energy required to induce the electronic transition.

The sensitivity of both categories of detectors is ultimately limited by the noise inherent in the random arrival of photons from the background radiation. When a detector attains this performance limit it is said to have achieved background limited infra-red performance (b.l.i.p.). The detectivity of a detector is defined as the reciprocal of the incident power in watts required to yield a signal-to-noise ratio of unity, i.e. the noise equivalent power (NEP). Specific detectivity (D^*), is the figure of merit used for comparing the performance of different detectors. It is the detectivity of a detector normalized to unit area when coupled to an amplifier of unit bandwidth. The expression for D^* is

$$D^* = \frac{(A\Delta f)^{\frac{1}{2}}}{\text{NEP}} \text{ cm Hz}^{\frac{1}{2}}\text{ W}^{-1} \; (\lambda, 1\text{ kHz}) \quad \text{or } (500\text{ K}, 1\text{ kHz})$$

where A is the detector area in square centimetres
f is the noise equivalent bandwidth.

When quoting D^* it is normal to specify the measurement condition by quoting either the wavelength of the monochromatic radiation or the source temperature of the black body radiation incident together with the electrical signal frequency. The measurement noise bandwidth need not be quoted since a 1 Hz measurement bandwidth is implicit in the definition of D^*.

Figure 4 illustrates the peak signal-to-noise ratio or detectivity attainable from ideal thermal and photoconductive detectors as a function of cut-off wavelength for a background temperature of 300 K and a field of view of 180 degrees. The X on the curves for photoconductive detectors indicates the signal-to-noise ratio that would be realized by a detector with a quantum efficiency which is unity up to its cut-off wavelength of 12·5 μm.

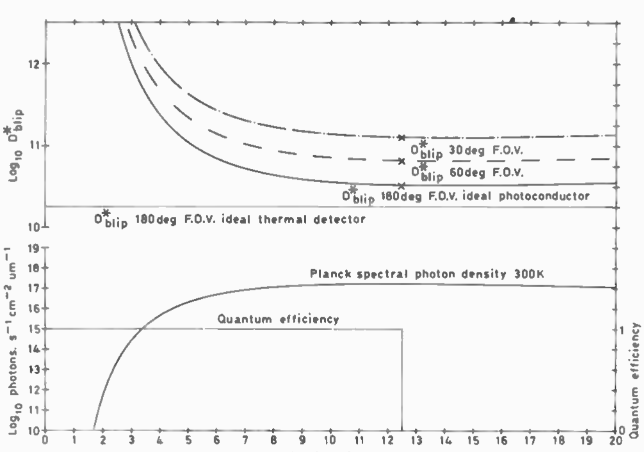

Fig. 4. D^* b.l.i.p.

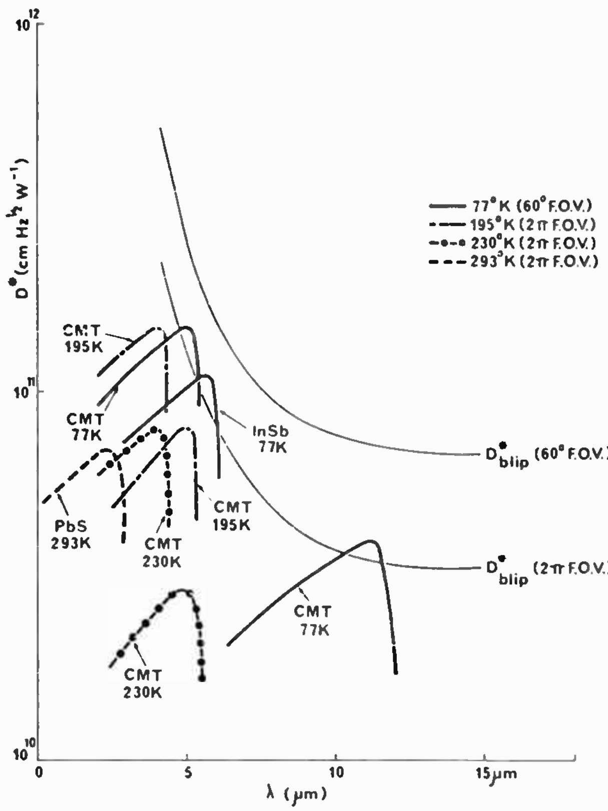

Fig. 5. Performance of present day photon detectors.

To attain high sensitivity in a photon detector at the wavelength corresponding to the atmospheric windows at 3–5 μm and 8–14 μm it is essential to minimize the number of carriers which are excited by the thermal energy of the detector itself. The number of thermally excited carriers can be reduced by cooling the detector. Should the detector not be cooled it is possible that all of the available charge carriers become thermally excited leaving none to be excited by incident photons and the detector therefore rendered ineffective. The benefit gained by cooling the detector to liquid nitrogen temperatures (77 K), in order to suppress self-emission can be seen in Fig. 1 where the spectral photon density of objects at 300 K and 77 K are presented. Figure 5 contrasts the D^* attained for a photoconductive cadmium mercury telluride detector at operational temperatures of 230 K, 195 K and 77 K.

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In order to further enhance the performance of a detector it is necessary to restrict the amount of unwanted radiation the detector receives. This is achieved by restricting the field of view of the sensitive element to match that of the optical system collecting the incident energy. The detector is mounted within a cooled enclosure having an aperture in it through which the detector can view the radiation from the objects of interest (Fig. 8 illustrates this). The relative improvement in signal to noise, i.e. D^* is inversely proportional to the sine of the half angle subtended by the hole in the cooled enclosure at the sensitive element. Figure 4 illustrates this dependence of photon noise limited detectivity upon the viewing angle.

The performance attained by a few present day detectors is summarized in Fig. 5. Detectors fabricated from an alloy of cadmium telluride and mercury telluride (CMT) are particularly useful.[9] The spectral response, dictated by the electronic transitional energy, of this detector material can be adjusted by varying the alloy recipe. Thus CMT is able to provide detectors for both the 3–5 μm and 8–14 μm wavebands. A similar adjustable energy gap is obtained by mixing lead telluride with tin telluride to form an alloy of lead tin telluride (LTT). However there are practical difficulties associated with producing low-power wideband preamplifiers for photovoltaic LTT. Thus for thermal imaging applications photoconductive CMT is preferred. This has resulted in the discontinuation of LTT detector manufacture by several companies.

The spectral response of the two other semiconductor detectors depicted in Fig. 5 are room temperature lead sulphide and indium antimonide at 80 K. These detectors find application for sensing radiation within the 2–2·7 μm and 3–5 μm atmospheric windows respectively. (For additional information with respect to detector characteristics the reader is referred to chapter 11 of Ref. 1.)

The choice of waveband for thermal imaging can only be made by consideration of all of the wavelength dependent parameters which influence the signal detected. Thus detector D^*, the spectral temperature differential radiance from the target of interest ($\partial W/\partial T$), the transmission of the intervening atmosphere and the collecting optics must all be considered. The figure of merit M^* is defined[10] as the integral with respect to wavelength which takes account of these factors.

$$M^* = \int_0^\infty \left(\frac{\partial W}{\partial T}\right) t_\lambda D^*_\lambda \, d\lambda$$

Figure 6 illustrates how M^* varies as a function of detector cut-off wavelength for the best and worst atmospheres (1 and 2) respectively depicted in Fig. 2. The values of M^* for an $f/3{\cdot}0$ detector viewing targets possessing surface temperatures of 300 K and 500 K through optics possessing unity transmission are presented. It is to be noted that the 3–5 μm window offers better performance than the 8–14 μm window when hot targets are to be viewed through a humid atmosphere.

To permit detectors to operate at 77 K a vacuum encapsulation is required. Present day CMT detectors adopt encapsulations such as that illustrated at the bottom right of Fig. 7. Shown also in this Figure are the various components required to cool the detector. Immediately to the left of the detector is a Joule–Thomson minicooler.[12] This is a miniature gas liquifier which utilizes the cooling of high-pressure gas on expansion in conjunction with a counterflow heat exchanger to pre-cool the gas supply. When fed with high-pressure, (2000 lb/in^2, 14 000 kN/m^2), air or nitrogen from a gas bottle such as that shown above the detector, the minicooler will produce a liquid pool at 80 K or 77 K respectively to cool the rear of the surface upon which the detector elements are mounted. The other components shown are a quick-release coupling/supply valve (top left) and a gas cleaner below.

Reference to how the sensitivity of the detector is improved by cooling and matching the field of view of the detector to that of the energy collecting optics has already been made. The temperature sensitivity of the overall system[13] can be enhanced by increasing the collecting aperture size and hence the energy grasp of the collecting optics. The sensitivity is proportional to the equivalent diameter, d, of the unrestricted collecting aperture. Sensitivity is also proportional to the square root of the solid angle subtended by the detector element when projected onto the scene of interest.

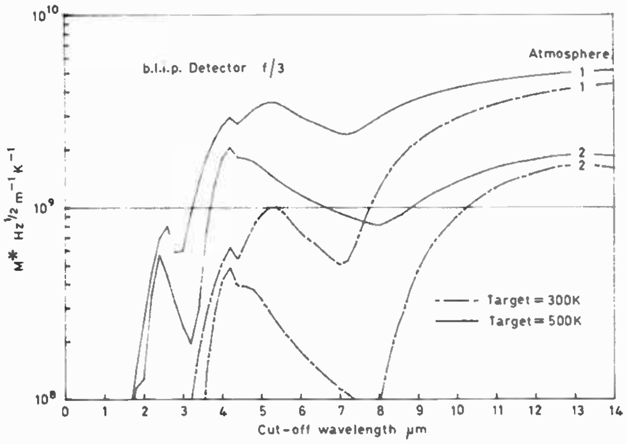

Fig. 6. M^* b.l.i.p. for 300 K and 500 K targets.

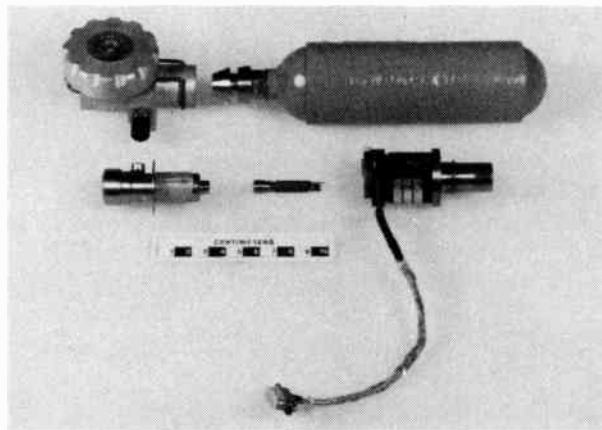

Fig. 7. Detector and cryogenic components for 77 K operation.

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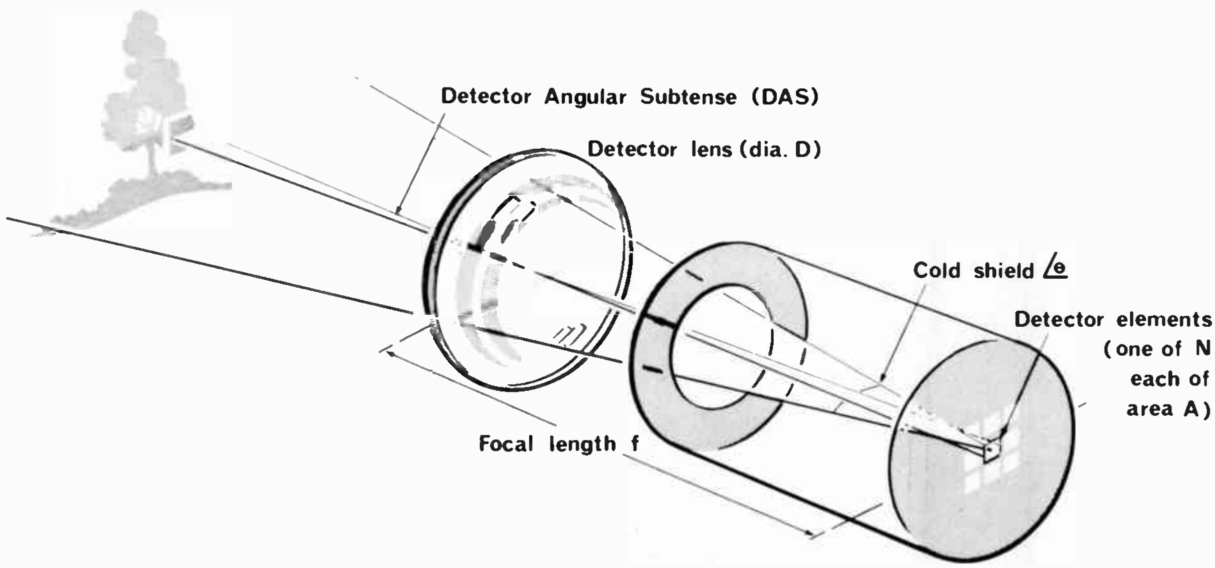

Cold Shield Efficiency $\eta = \frac{\text{ideal cold shield solid angle}}{\text{actual cold shield solid angle}}$

System $S:N \propto D\sqrt{\frac{A}{f}\,\eta_{cs}\,N}$

Fig. 8. Detector sensitivity relationships.

Furthermore, the use of a multiplicity of detectors will result in an improvement in the detected signal-to-noise ratio via a reduction in information bandwidth and/or the synchronous addition of the signals emanating from one point in the scene. The use of N detectors instead of just one will result in an improvement in signal-to-noise ratio of $\sqrt{N}$. Figure 8 summarizes these sensitivity relationships.

Most high-resolution thermal imagers employ several detector elements configured as a linear or matrix array. The array geometry selected is dictated by the manner in which the image of the scene is made to scan the stationary detector.

4 Scanning[14,15]

Armed with a method of detecting thermal radiation we must establish by what means the detector can be made to sample the radiation emanating from different parts of

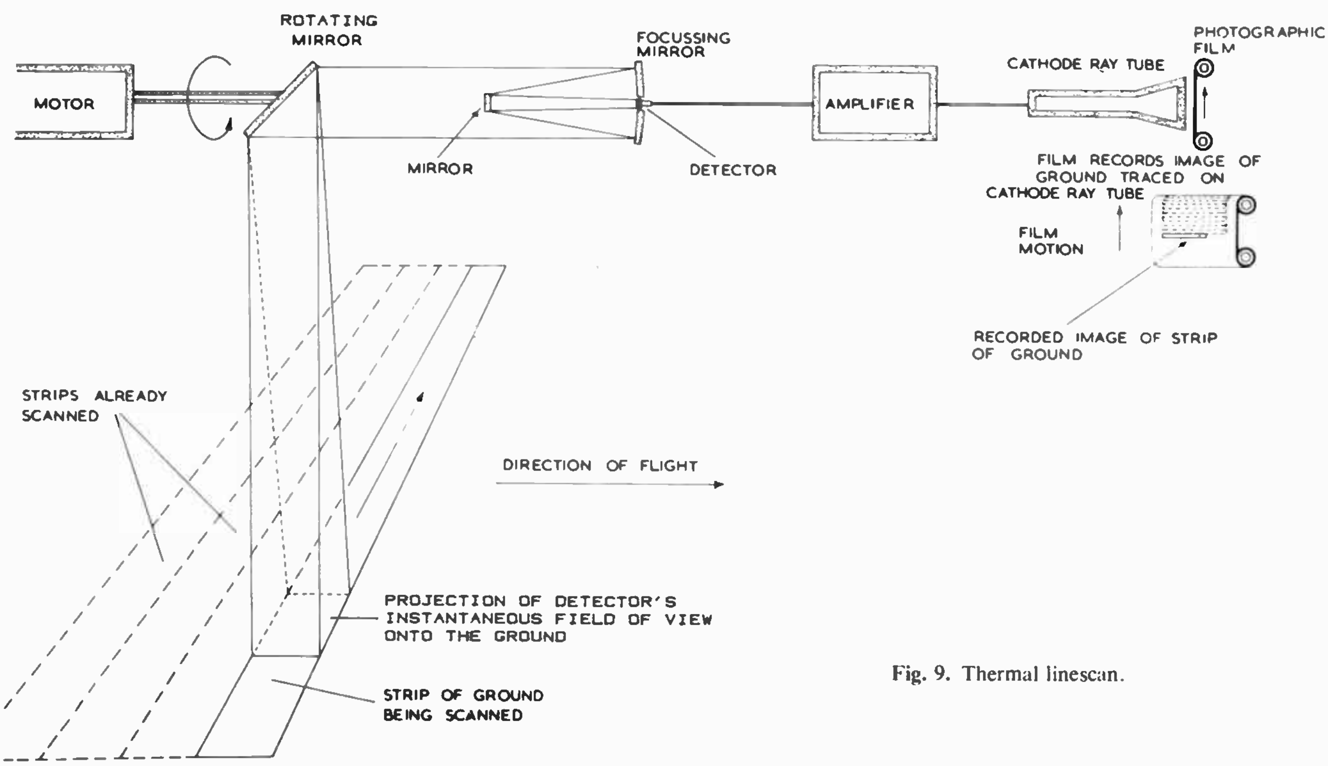

Fig. 9. Thermal linescan.

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the scene. At present there are severe practical problems which must be overcome before we are able to emulate the human eye by imaging the scene upon a large two-dimensional array of detectors. A 'starring array' of photon detectors is not a practical proposition yet. Instead we must provide a method of scanning an image of the scene across a modest number of detector elements.

One of the simplest scanning systems is that employed for aerial reconnaissance, the thermal line scan. This is illustrated in Fig. 9. The instantaneous field of view of the detector is made to traverse the terrain beneath the aircraft as a succession of narrow strips at right angles to the aircraft flight direction via reflection from the rotating mirror. The ability of such a system to resolve object detail is determined by the product of detector angular subtense and the range to the object. The detector angular subtense in radians is defined by the linear dimension of the detector element divided by the focal length of the collecting optics (Fig. 8 refers).

For a given aircraft ground speed and height the successive strips 'interrogated' by the detector can be made contiguous by adjusting the rotation rate of the mirror. The variations in thermal radiation sensed by the detector are translated into a fluctuating voltage which, after amplification, is used to modulate the beam current

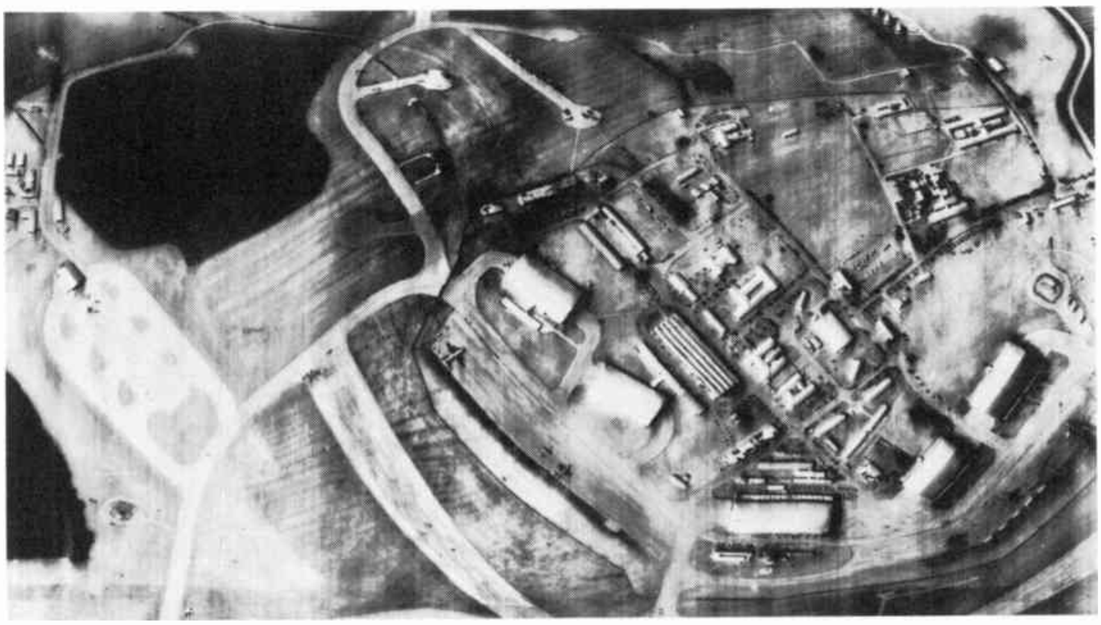

Fig. 10. Daytime imagery from thermal linescan.

Fig. 11. Night-time imagery from thermal linescan.

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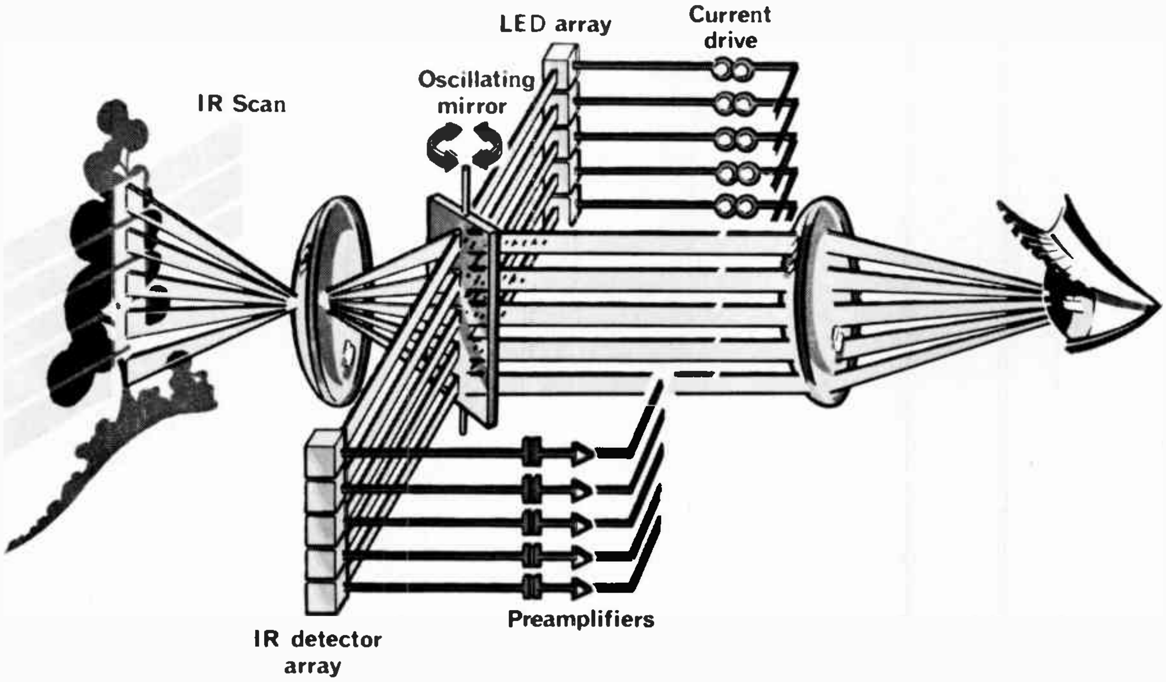

Fig. 12. A direct view thermal imager using parallel scanning.

of a cathode ray oscilloscope. The electron beam within the oscilloscope is deflected as a line image in synchronism with the scanning mirror. Photographic film is moved across the scanning line of the c.r.t. at a rate dependent upon the aircraft height and ground speed. In such a fashion a scale strip thermal map of the terrain overflown is produced. An example of a section of such a film record is shown in Figs. 10 and 11 where an airfield has been overflown at 11.15 and 23.59 hours respectively. A comparison of these two photographs illustrates how objects can leave thermal shadows. Movement of two of the three aircraft in the centre foreground is revealed by the persistence of the thermal shadows which remain in the night photograph.

For a ground-based equipment we cannot employ the motion of a host vehicle to assist us in scanning the scene of interest as is the case in airborne line scan. An alternative scanning arrangement has to be employed.

Two alternative scanning methods are illustrated in Figs. 12 and 14. In Fig. 12 a sufficient number of detector elements are employed to cover one dimension of the field of view. Typically between 60 and 400 detector elements are employed. With such a detector array the field of view can be scanned by a single scan mechanism such as the flapping mirror depicted. The detected signal from each detector element is amplified and used to modulate the current through one element of a light emitting diode array. The l.e.d. array is a scale replica of the thermal detector array. An observer viewing the l.e.d. array via the rear surface of the flapping mirror sees a visible analogue of the thermal radiation sensed by the detector.

The use of a large number of detector elements does mean that the information bandwidth of each channel is low since each detector has the complete frame time to access the information from only one scan line across the scene. However within the reduced video bandwidth, $1/f$ noise from the detector and preamplifier can be significant.

An example of the imagery produced by a scanner such as that depicted in Fig. 12 is illustrated in Fig. 13.

One of the consequences of scanning in this manner is that each detector element within the linear array scans a unique path across the scene. This introduces various sources of non-uniformity which together result in poor image quality for low contrast scenes.[16] The most significant sources of image degradation are:

(a) Detector non-uniformities, particularly spectral response variations within the array.
(b) Differences in channel gain due to tracking errors induced by temperature or supply voltage excursions.
(c) The necessary adoption of a.c. coupling to reject the large radiance pedestal equates the mean

Fig. 13. An example of the imagery using a parallel scanner.

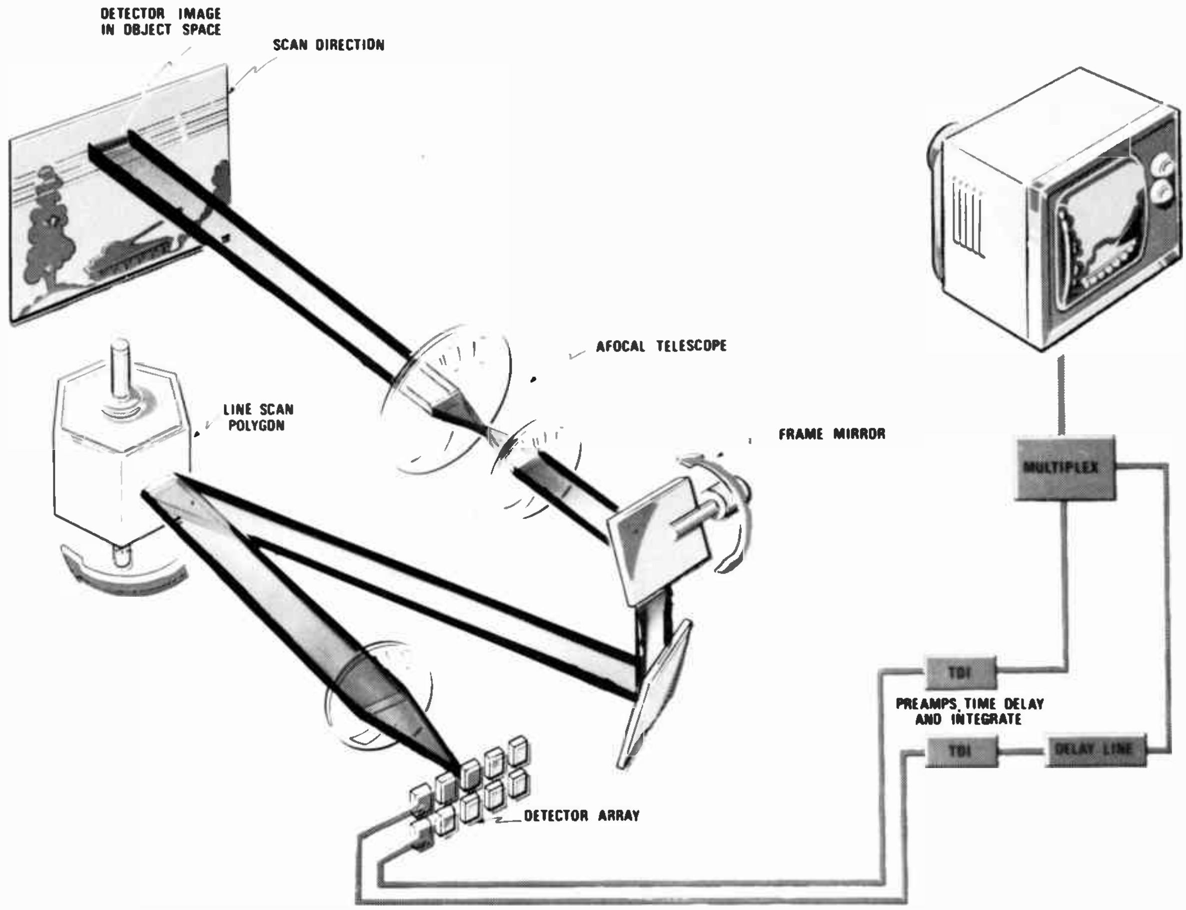

Fig. 14. A serial scan thermal imager with a remote display.

signal level, over a line repetition period, for all of the parallel channels. Accurate restoration of the radiance pedestal is very difficult and usually not attempted, with the result that the imagery can appear shaded.

To overcome the deficiencies associated with parallel scanning two independent scan mechanisms are employed so that several detectors sequentially scan a common path across the scene as Fig. 14 depicts. Such a scanning motion results in a set of video signals which are similar but staggered in time. Removing this time stagger enables signal contributions from the same point in the scene to be summed and secures a maximum improvement in the signal-to-noise ratio of N from an array of N detectors when compared to a single detector. It is this summation which integrates channel non-uniformities and removes the principal sources of display fixed pattern noise. An example of the imagery obtained via sequential scanning is presented in Fig. 15. The excellent image uniformity that signal integration yields is evident.

Sequential scanning, whilst it provides the desired improvement in image uniformity, imposes scan rates and information bandwidths which are high. If a single linear array of N detectors is employed the information bandwidth will be approximately N times that for the corresponding parallel scan approach. To reduce rotation rates within the scanner and to lower information bandwidths, more than one serial array of detectors is used. The detector array is now configured as a matrix. This compaction enables the detector array to be more efficiently cold shielded than is the case for a long linear array. Some slight compromise in display uniformity is accepted in this departure from pure serial scanning.

The need to reduce the unit cost of thermal imagers, whilst achieving high-quality displayed imagery, has monopolized thermal imager system design within the UK (and France) with matrix detector arrays. To satisfy

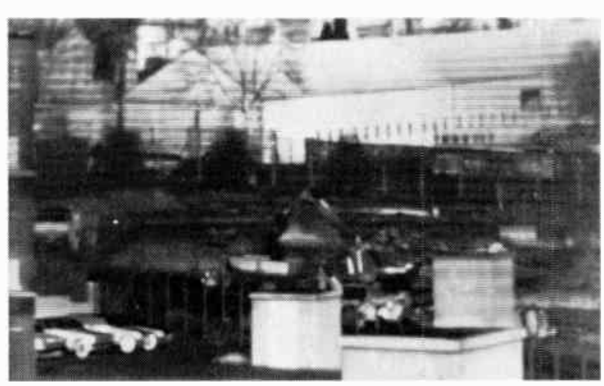

Fig. 15. An example of the imagery using a serial scanner.

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the signal processing demands imposed by the adoption of matrix arrays requires that we take full advantage of today's technology in electronic components.

5 Signal Processing[17]

The impetus for the development of thermal imaging systems has come mainly from defence funds. This funding covers all of the constituent parts of systems and includes novel signal processing components. Some of these will be described.

The signal to be processed for display originates at the detector. The most common detector employed in present-day, high-performance thermal imagers is photoconductive CMT. It is normal practice to bias the detector element with a constant current and sense the radiation-induced conductivity variations with a low noise voltage amplifier.[18] The voltage preamplifier is a.c.-coupled to the detector in order to ignore the large static radiance signal.

The input impedance of the preamplifier must be high ($> 1\ k\Omega$) relative to the detector impedance, typically $50\ \Omega$, to avoid attenuating the detected signal. Furthermore the input noise of the preamplifier must be lower ($\sim 1\ nV/\sqrt{Hz}$) compared to that of the detector ($5\ nV/\sqrt{Hz}$) if detectivity is not to be sacrificed. Very often thermal imaging systems employ 30 or more detectors to secure the desired thermal sensitivity. There is, therefore, a strong requirement for a small, low-power, preamplifier.

Two such preamplifiers have been developed specifically for multichannel photoconductive CMT detector arrays. Commercially these preamplifiers are known as Ferranti ZN460 and Plessey SL561. The small size of these wideband, 6 MHz, low noise, $1\ nV/\sqrt{Hz}$, preamplifiers is illustrated in Fig. 16 where 32 preamplifiers, each with their associated constant-current-bias diodes are disposed upon an annulus which plugs directly onto the detector encapsulation.

The preamplifiers are programmable with respect to gain and bandwidth. This permits detector element responsivity to be equalized and the wideband noise output to be reduced by restricting the noise bandwidth to match the information bandwidth. These

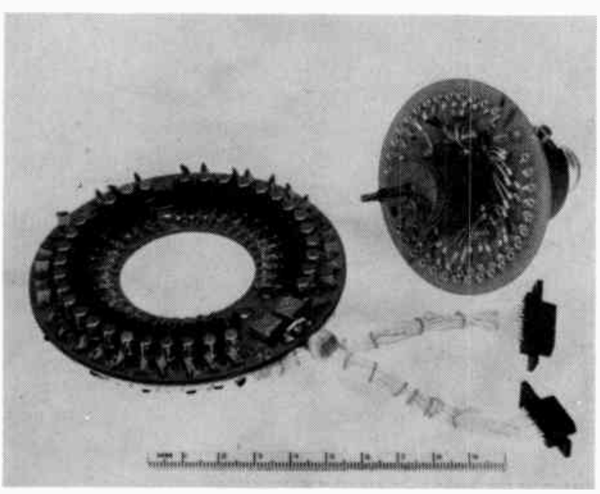

Fig. 16. 32-channel detector preamplifier assembly.

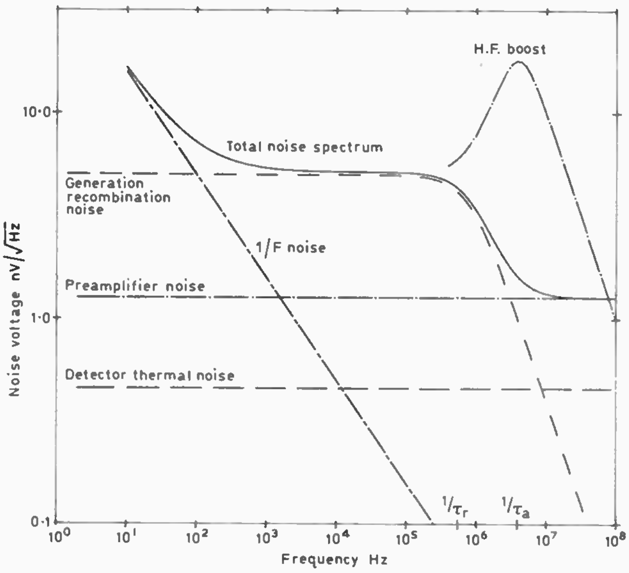

Fig. 17. Principal detector preamplifier noise spectra.

preamplifiers therefore are applicable to the whole spectrum of thermal imager system types from the wideband pure serial scanners to the low information rates characteristic of pure parallel scanners.

The noise spectrum of the detector preamplifier combination can be attributed to several mechanisms as illustrated in Fig. 17. Depicted are the $1/f$ noise region, generation recombination noise, and the thermal noise region. For a typical photo-conductive CMT detector at 77 K the $1/f$ noise corner would occur at 1 kHz, the g.r. noise level would be $6\ nV/\sqrt{Hz}$ and the thermal noise $0{\cdot}2\ nV/\sqrt{Hz}$. The preamplifier noise referred to its input is $1\ nV/\sqrt{Hz}$ and therefore becomes dominant at frequencies above the g.r. roll-off. Most detectors possess a roll-off of the frequency response of their signal which matches the 6 dB/octave roll-off of their g.r. noise. Thus the high-frequency response of a system can be improved by boosting the gain of the amplifier between the responsivity cut-off frequency and the frequency at which the g.r. noise is equal to the sum of the thermal noise and the shot noise of the detector bias current. This is shown in Fig. 17. The boost circuit should possess a +6 dB/octave slope from $1/\tau_r$ to $1/\tau_d$ and sharp cut-off slope (12 to 18 dB/octave) at $1/\tau_d$ in order to restrict the noise bandwidth.

The preference for matrix detector geometries does introduce the need for multiple time delay and integration (t.d.i.). When the matrix array scans the scene the detected video signals from the detector elements within a serial array are similar but are delayed with respect to each other. It is the function of the t.d.i. circuit to remove these time differences and to sum the signal contributions emanating from one point in the scene. Synchronous addition of the signals from N detectors will increase signal amplitude by N; however summation of the uncorrelated noise from each channel will increase the noise strength by $\sqrt{N}$, yielding an improvement in overall signal-to-noise of $\sqrt{N}$.

Two approaches have provided practical solutions to the t.d.i. requirement, i.e. lumped LC delay lines and

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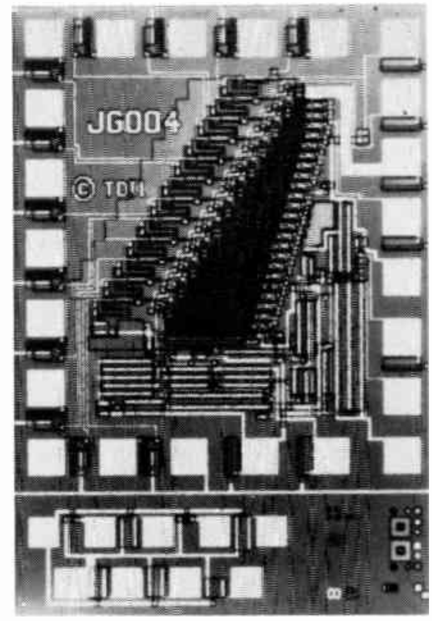
charge-coupled devices. Both techniques have their own advantages. The *LC* solution is passive and does not introduce temporal sampling with its unwanted modulation products. With the c.c.d. the disadvantage of temporal sampling is offset by small size and the ability to vary the delay period between signal summation to match scanner speed fluctuations. Figure 18 illustrates a t.d.i. c.c.d. that has been successfully developed by Plessey. As many as 12 linearly time staggered input signals can be summed. Synchronous summation is achieved by appropriate choice of the applied clock frequency *f*. The minimum time delay that can be accommodated is $2/f$ where f can be as high as 50 MHz. The device has been qualified over the full military temperature range with a guaranteed dynamic range of 60 dB.



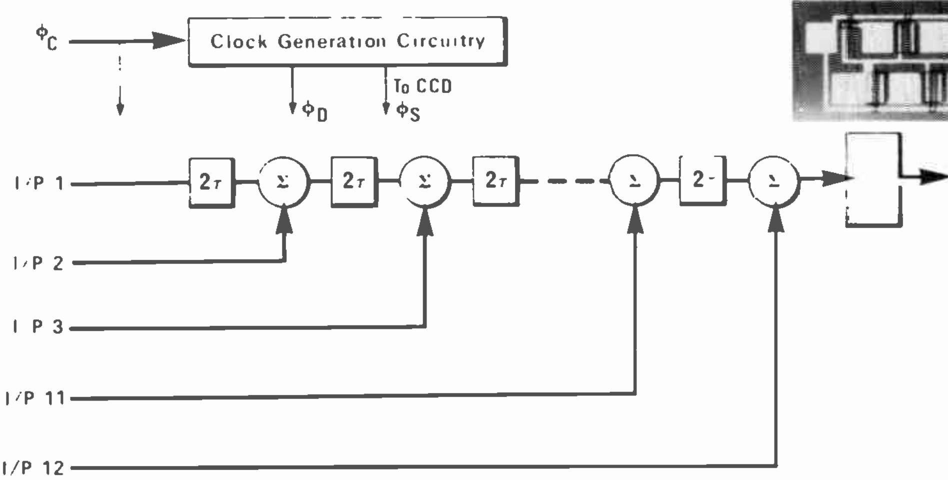


Fig. 18. Charge-coupled device for time delay and integration.

The recent development of TED detectors[19] has been of considerable benefit in reducing the electronic complexity of high performance thermal imaging systems. The TED is a device invented by Dr C. T. Elliott[20] at RSRE in which the time delay and integration required for sequential scanning takes place within a single CMT filament. The single filament is equivalent to a serial array of detectors together with their associated bias components, preamplifiers and integrating delay line.

When the scene is scanned simultaneously with several detectors in parallel a requirement is established for the temporary storage and time compression of the video signal in order to achieve compatibility with a conventional raster-scanned single beam c.r.t. The charge-coupled device possesses size, weight and power characteristics which are attractive when compared with the digital alternative. Representative of the state of the art today is the Plessey 850 sample analogue shift register depicted in Fig. 19. The device is notable for the very low level and uniformity of its spatial noise signature. To simplify the removal of the d.c. component introduced by temporal integration during the data storage period an input clamp is provided. The performance of this c.c.d. is such that the 40 dB dynamic range achieved for a 0·5 ms storage period at 70°C is superior to a 6-bit digital store.

Quite deliberately most thermal imaging systems do not have a d.c. response. Thus there is no pedestal corresponding to the d.c. scene radiance displayed unless some method is used to restore a d.c. level onto the a.c. signal. There are several methods of d.c. restoration, all of which are simpler to implement for systems with a low number of parallel video channels. In its most simple form an operator-adjustable d.c. level can be superimposed upon each of the parallel video channels once a.c. amplification is almost complete. This method is arbitrary in that there is no correspondence between the d.c. level introduced and the original radiometric pedestal.

Whilst such a technique is viable for thermal imagers which employ serial scanning it is not very satisfactory for imagery obtained via parallel scanning. To illustrate this point, reference is drawn to Figs. 13 and 20 where the respective Figures depict the same scene as imaged via a parallel scanner and via a serial scanner. The combination of a.c. coupling and parallel scanning introduces artifacts such as horizon suppression and the shading shown in the radome within Fig. 13. This shading arises since a.c. coupling within a parallel scanner ignores the line to line d.c. pedestal differences by setting the average signal level on every line to be equal to the operator adjustable d.c. level. Contrast this with the imagery depicted in Fig. 20 where every detector

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is permitted to see all of the scene information. The radome is imaged uniformly and the horizon is delineated.

A second d.c. restoration technique is to permit the detector to view the radiation from a surface at a controlled temperature. The signal detected at that time is then clamped to a d.c. voltage. The equivalent black body temperature which corresponds to the black level of the imagery can be chosen by adjusting the temperature of a reference surface.

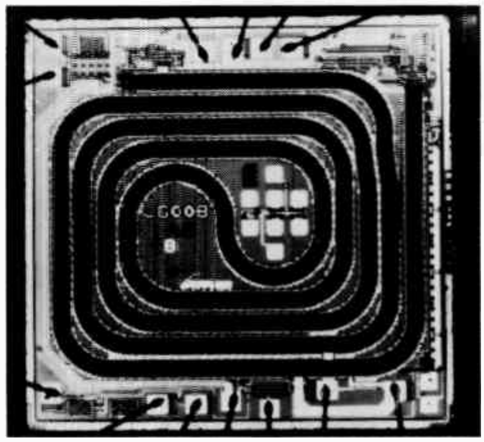
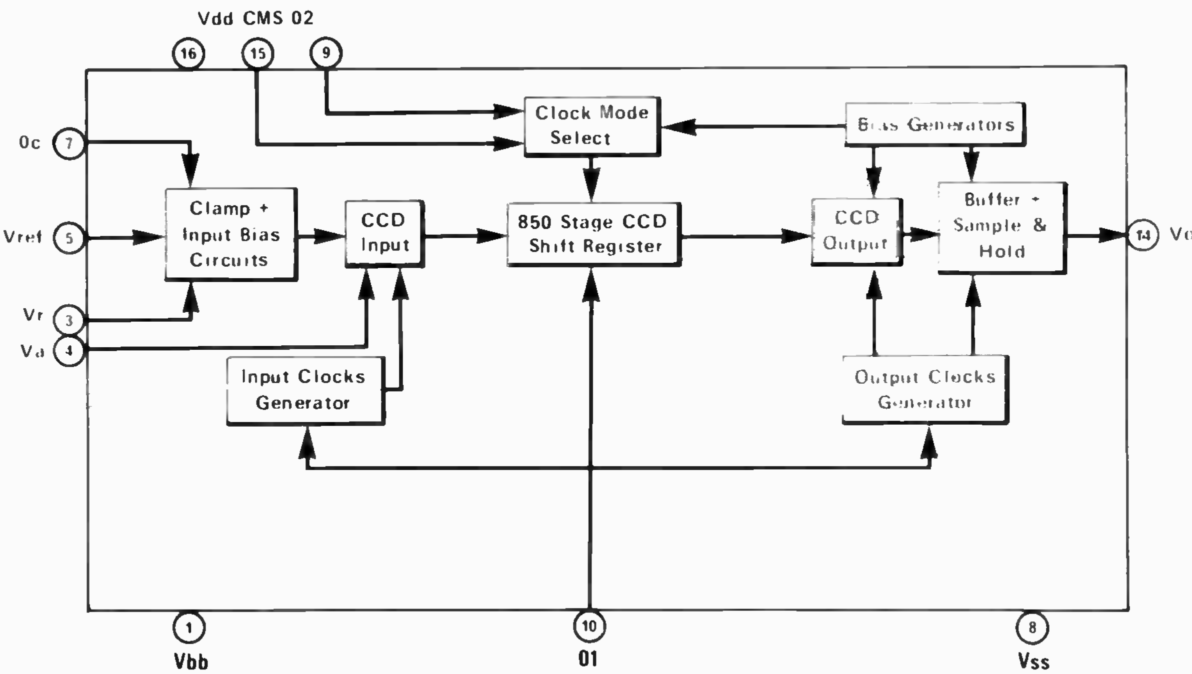


Fig. 19. Charge-coupled device for analogue video storage and time compression.



A third technique is to establish a reference level from the video signals obtained by scanning the scene and to equate this reference to a mid-grey luminance in the displayed imagery. Several options are possible depending upon how the average video level is derived. The average can be that of just a few scanned lines, or that of a whole frame. There are circumstances when it is desirable to be able to switch from one option to another. For example, under high contrast conditions a frame average mid-grey provides a bright foreground and dark sky detail. Within both these regions objects can be masked by saturation; however, the horizon is emphasized. Where suppression of the horizon does not matter, a better match of a scene, exhibiting a wide dynamic range, to the limited dynamic range of the display is achieved using a shorter averaging time.

6 Present Day Systems

To conclude, a few illustrations of present-day thermal imagers are presented together with an example of the imagery each provides.

Figure 21 depicts a lightweight direct-view thermal imager developed at RSRE. This imager employs a germanium refracting polygon in conjunction with a linear array of 32 detector elements to scan the scene.

Fig. 20. Thermal imagery acquired via serial scanning of the same scene depicted in Fig. 13.

Fig. 21. The RSRE hand held thermal imager (H.H.T.I.).

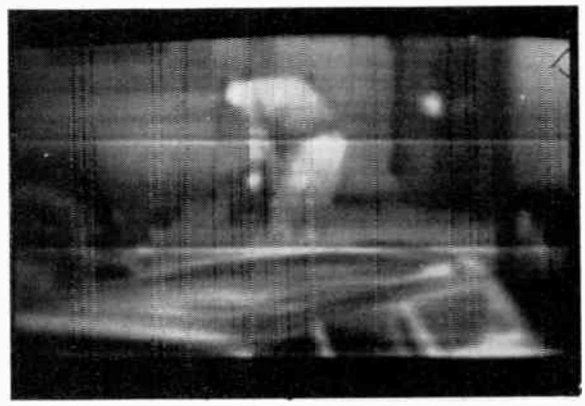


Fig. 23. A typical thermal image from H.H.T.I.

The infra-red scanner assembly is shown in Fig. 22. The detected signal is multiplexed to interface with a miniature c.r.t. which an observer views via an eyepiece. A typical example of the imagery produced is shown in Fig. 23.

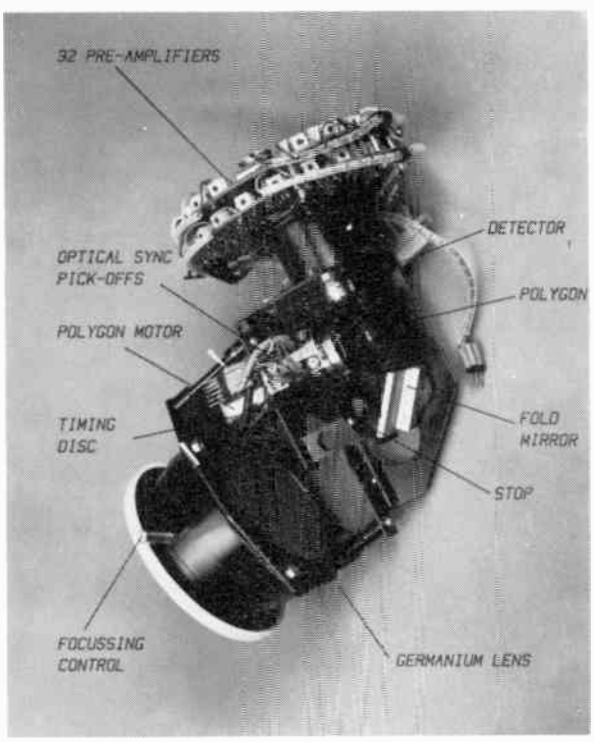


Fig. 22. The infra-red scanning unit of the RSRE H.H.T.I.

Figure 24 illustrates a complete thermal imaging system configured from the class 1 modules produced for the Ministry of Defence Thermal Imaging Common Module Programme by EMI Electronics. The imager is depicted mounted upon an angulation head from the common mounting system manufactured by Marconi Avionics. This imager uses the symmetry of the scanning mechanism to reconstitute a visible analogue of the thermal scene by modulating the light emission from a l.e.d. array in sympathy with the detected thermal signal. An example of the imagery produced by the class 1 direct view equipment is presented in Fig. 25.

The requirement for multiple low-cost displays which can operate remote from the thermal scanner is satisfied by arranging the scanner and its associated processing electronics to provide a composite video output which is compatible with 625 line 50 Hz television. The class 2 modules, produced by Marconi Avionics and Rank Taylor Hobson for the Ministry of Defence Thermal Imaging Common Modules Programme (Fig. 26) furnish imagery with this compatible output. An

Fig. 24. A complete thermal imager using Class 1 modules from the MOD Thermal Imaging Common Modules Programme produced by EMI Electronics.

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Fig. 25. A thermal image from Class 1 TICM.

Fig. 27. A thermal image from Class 2 TICM.

example of the thermal imagery presented upon a television display by the class 2 modules when configured as a complete system is presented in Fig. 27.

The IR18 equipment produced by Barr and Stroud and depicted in Fig. 28 also furnishes 625 line thermal imagery. An example of the imagery produced by IR18 is given in Fig. 29 together with its visual equivalent.

Both the class 2 TICM and IR18 have benefitted by the adoption of TED detectors. Furthermore all the systems presented employ one or more of the signal processing components described in the previous Section.

In conclusion it must be noted that the development of thermal imaging systems using cooled detectors has culminated in a variety of reliable equipments which are about to enter active service. The commercial exploitation of such systems will inevitably follow as equipment costs are eroded by volume production.

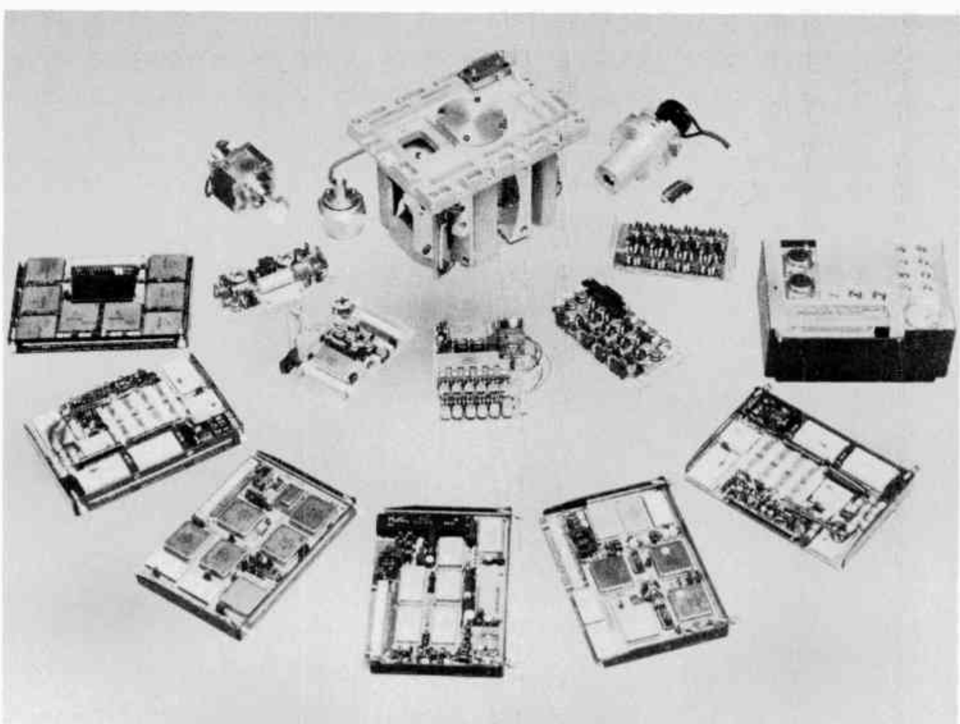

Fig. 26. Class 21 modules from the MOD Thermal Imaging Common Modules.

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Fig. 28. The IR18 thermal imager produced by Barr and Stroud.

7 Acknowledgments

This paper is published by permission of the Director Royal Signals and Radar Establishment Malvern.

The author expresses his thanks for permission to reproduce illustrations within this paper from the following organisations: Barr and Stroud (Figs. 28 and 29), British Aerospace (Figs. 10 and 11), EMI Electronics (Figs. 24 and 25), Marconi Avionics (Fig. 26 and 27), Mullard (Fig. 5) and Rank Taylor Hobson (Fig. 26 and 27).

The kind assistance of several of his colleagues is gratefully acknowledged: in particular, Dr S. Braim for the provision of Fig. 6, Dr J. Warner, A. Foord and M. Thomas for Figs. 21, 22 and 23.

Fig. 29. A thermal image from IR18 and its visual equivalent.

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Indexing Terms: Television recording, Digital systems

Formats for digital video tape recorders

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Based on a paper presented at the International Broadcasting Convention in Brighton in September 1980

SUMMARY

The characteristics required for a studio format digital recorder are considered and variable-speed operation for the Type B and C systems is described. The implication of the picture-in-shuttle techniques are considered and also the reasons for adopting a helical rather than transverse format. Coding systems are then compared in some detail with special reference to error detection and correction and it is concluded that the Miller Squared code is superior to the 8/10 code. Brief comment is made on the adoption of a broadcast digital standard.

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1 Background

In the twenty-four years of professional videotape history, only three mechanical formats have been widely used: the quadruplex that dominated the first twenty years, and the helical B and C formats that are now expanding rapidly. Broadcasters will only change to a new format when it offers a major improvement in their performance per unit cost, and cost includes the capital equipment cost, the operating cost (predominantly tape), and maintenance cost.

A DVTR (digital videotape recorder) must handle much wider bandwidths than its analogue predecessors, and to keep costs comparable it must use little, if any, more tape. Thus, it must handle both high bit-rates, and high packing densities (bits/cm^2).

Digital recording simplifies the use of parallel channels. In theory, therefore, the high bit-rates could be reached by using many parallel channels; but each channel must have a set of read/write electronics, plus its own read/write head. The resulting cost is so high that it eliminates, for example, the 28-track formats found in longitudinal recording. Some form of rotary recording must be used.

In any form of magnetic recording, packing density can be increased either by reducing track width or by reducing the recorded wavelength (i.e. more bits per cm). The s.n.r. in dB is proportional to 10 log T where T is the track width; therefore, doubling the packing density by halving the track width reduces the s.n.r. by 3 dB. In contrast, even neglecting spacing and gap losses, s.n.r. is proportional to 20 log λ where λ is the wavelength, and so decreases 6 dB when the wavelength is halved. This is because the magnetized volume per bit (and, therefore, the number of magnetic particles) is proportional to track width (Fig. 1); when the wavelength is halved, dimensions are reduced not only along the tape, but also the depth of recording into the tape is halved, thus cutting the magnetized volume in four. (This assumes the tape coating thickness is at least one wavelength, which is true of all of today's coated tapes.)

High packing density, therefore, forces the use of narrow tracks. This can be seen from a historical plot of computer disk systems (Fig. 2). A similar trend can be seen in rotary video recorders from the 0·25 mm of the 1956 quadruplex system to the 0·02 mm of the 6-hour VHS system.

2 A Family of Recorders

Assuming that no one recorder can possibly meet every need of the broadcasting industry, six types of recorder can be identified:

1. ENG portable
2. EFP transportable
3. Studio
4. Post production
5. Short segment (less than 6 minutes) cassette player
6. Long segment (1 hour or longer) cassette player.

The ENG portable must be light and rugged, and be battery operated. Some picture quality can be sacrificed but it must be editable without transfer to another format.

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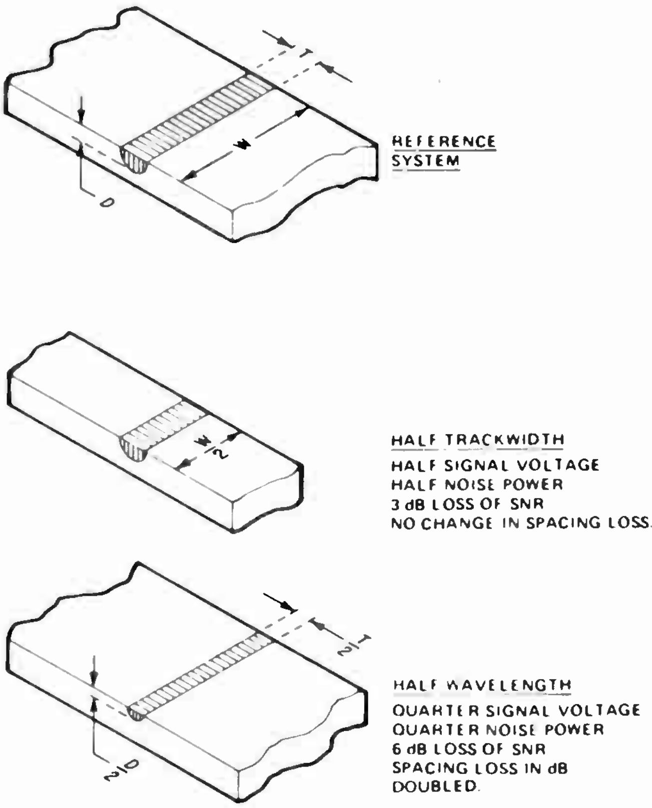

Fig. 1. Two methods of doubling packing density.

The EFP system records the full studio quality but may compromise on some characteristics such as play time and special effects such as slow motion.

The Studio machine is the workhorse of the industry. It provides full quality with all but the most complex special effects, while remaining competitive with today's analogue recorders.

The Post Production machine is less sensitive to size, tape consumption, and cost. For example, it could absorb the addition of a frame store if this gave some additional special effects.

The short segment player is used for news spots, commercials, and for sophisticated editing.

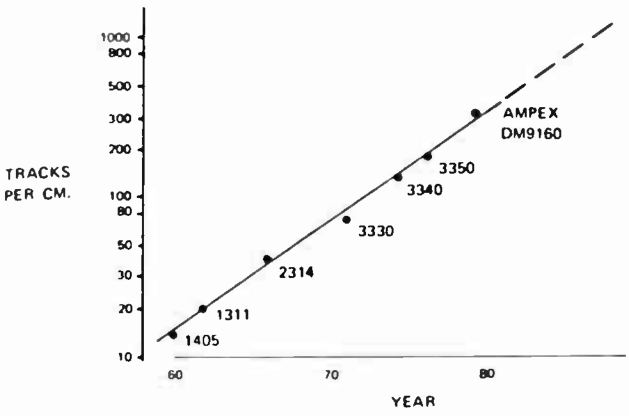

Fig. 2. Increasing packing density for computer disk systems over past twenty years.

The long segment (program) player is the heart of an automated station.

Any format that tried to cover all six would result in a serious compromise at one end or the other of the spectrum. The heart of the broadcast industry is in types 2, 3, and 4, and the first format should be chosen to optimize these. This would then typically cover a broadcast station making its own field productions and doing appreciable amounts of in-studio editing. In countries such as the USA, this includes the financially-important making of local commercials.

3 The Characteristics of the Studio Format

The studio format must combine the advantages of digital recording, both video and audio, with the best features of the analogue formats it replaces. These include independent editing of the video and audio channels, variable speed operation with full quality pictures from reverse through 'freeze' to faster than normal speed forward, usable pictures at the shuttle speeds used in editing, and 'read after write' to provide full confidence.

The improved performance resulting from the digital recording includes more full-quality audio channels (four appears to be a good compromise) and an increased number of generations with what today would be called first-generation quality. How many generations will be usable—or will be wanted—is impossible to say today since it depends on such factors as the quality of future tapes, and the tape consumption selected. Certainly more than ten generations will be provided, but it could be hundreds if packing densities are not pushed to the limit.

Over the last four years, demonstrations have shown a rapid increase in packing densities. All of these have been for simple read/write operations without consideration of interchange and variable speed. In fact, these factors plus the quality of the picture-in-shuttle signal (as described in Sect. 5) will set the practical packing limit to a value two to three times less than that needed for simple playback.

The input to the DVTR in its first version is likely to be a composite signal for NTSC and PAL, and a component signal for SECAM. Later will come digital interconnections. The differences between the composite and component machines will be considerable—for example, in whatever multiplexing system is used to combine the video and audio signals into a single bitstream and in the error correction and concealment techniques. VTRs in which the recorded signal is switched between digitized component and digitized composite will be prohibitively expensive. A temporary expedient may be to use a component recorder with a high-performance—and therefore expensive—PAL or NTSC codec.

Studio machines use a wide range of play times—from the small 20- or 30-minute cassette for EFP to a two-hour continuous recording of a major sports event. It is unlikely that one transport can handle this whole range at reasonable cost, but the format should be suitable

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both for use in a compact casette and for large reel-to-reel systems.

4 Variable-speed Operation in Segmented Formats

Two approaches to variable-speed operation have been developed in analogue VTRs: autotracking systems, and intermittent tape motion with an external field store.

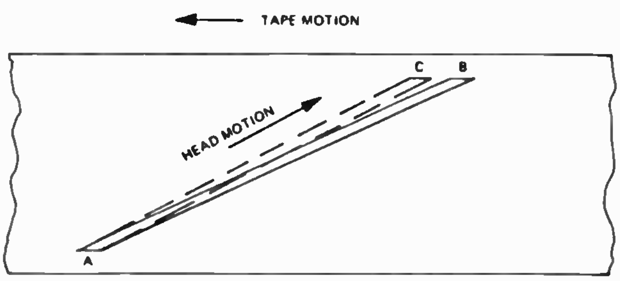

Fig. 3. Motion of video head in Type C autotracking system.

In the Type C autotracking system, the video head is mounted on a bendable arm, so that it can move at right angles to the track. Under normal tape speed conditions a track AB (Fig. 3) is written, the angle being set by a combination of the head speed and the tape speed. If the tape is stopped (for a 'frozen' picture), the head will follow the path AC, BC being the distance the tape moves while the head traverses from A to C. A sawtooth deflection applied to the head then corrects the head motion relative to the tape back to AB.

In a system with intermittent tape motion such as Type B, for, say, halfspeed operation, the system reads Field 1. It then backs up, ready to read Field 2, while Field 1 is read a second time from a field store. The system then reads Field 2 and repeats the cycle. There are many disadvantages to such a system. The intermittent motion makes accurate tracking increasingly difficult on the narrow trackwidths required by DVTRs; in addition, the system becomes impractical for speeds greater than 1, or in reverse because in theory it must then jump a recorded field within the field blanking time.

In analogue VTRs, autotracking systems have required the use of a field-per-scan format. This requires a large (14 cm) diameter scanner even with a 360° wrap; with a 180° wrap, the diameter would be doubled.

Digital systems with their four-times-higher bandwidth must use very narrow tracks (25–50 microns) to give comparable tape usage. These narrow tracks, however, mean that the autotracking system can now jump several tracks.

A DVTR can therefore use certain types of segmented formats with autotracking and this can provide all of the special capabilities and variable speed range of the field-per-scan Type C format with a drum size small enough for a compact portable, and large enough to include preamplifiers and autotracking systems.

5 Picture-in-shuttle

Consider the case where the tape is moving rapidly in the forward direction. Then the head will crosstrack as shown in Fig. 4. The number of tracks crossed, N, is given by

$$N = \frac{V}{u}$$

where V = tape shuttle speed and u = tape write speed. In reverse shuttle, in which V becomes negative, the number of tracks crossed is:

$$N = 2 - \frac{V}{u}.$$

Thus, for any given shuttle speed, two more tracks are crossed in the reverse direction than in the forward.

If one neglects any guardband between the tracks, then for a shuttle speed V, a $(1/N)$ fraction of each recorded track is read. In a multisegment recording with, say, 5 t.v. lines per track, each head will read one t.v. line per track if the shuttle speed is five times normal. (Note, however, that this segment will generally not include a complete t.v. line since the start point is random.) For formats with long recorded tracks, such as the field per swipe, the segment read in shuttle will be much larger; even at ×30 shuttle, over 10 lines will be read in a PAL recording.

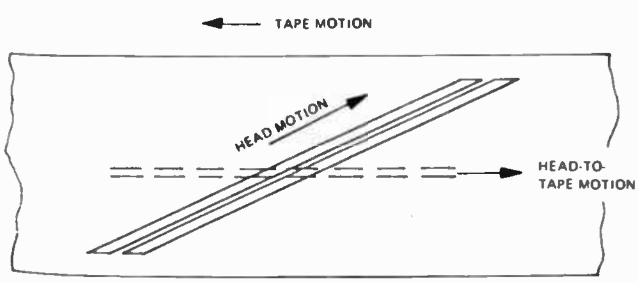

Fig. 4. Motion of picture shuttle.

DVTRs introduce two new problems. As soon as an f.m. signal has adequate s.n.r., its demodulation can start on the next carrier cycle. Providing one knows where it fits within the t.v. picture, useful information is immediately available. The first digital problem is that the digital signal requires a series of synchronizing decisions to be made—by bit, by word, and possibly by block, depending on the format.

The Miller-derived codes require the 101 pattern to phase-lock; the 8/10 codes require a recognizable method of defining the word boundaries. Both need some method of distinguishing audio from video, and of identifying t.v. line number, and t.v. line segment, if whole lines are not recoverable.

Thus, formats with a few t.v. lines per track are limited to low shuttle speeds, unless the lines are further subdivided, with the accompanying overhead for segment identification.

The second digital problem is that the clock rate varies. At the angles found in helical recorders, tape

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speed and head speed are more or less additive. Taking Type C as an example, a shuttle speed of × 30 (760 cm/s) modulates the head-to-tape speed (2·5 m/s) by ±30%. The digital clock rate will therefore change equally.

Picture-in-shuttle therefore increases the required noise margin for two reasons: because a useful signal is needed even as the head starts to crosstrack, and because the clock circuits must follow rapid changes in data rates.

6 Transverse Versus Helical

Transverse formats have several attractive features, especially in narrow track formats: they 'decouple' head and tape motions and, for example, avoid the clock-rate changes in shuttle: they provide the best tracking accuracy under conditions of varying tension, temperature, and humidity; and, in general, because they are two-dimensional formats (as contrasted to the three-dimensional helical), cassette loading systems are simpler and more reliable.

They have, however, two major weaknesses. Track lengths are short—the number of t.v. lines per track is therefore small, and the high-speed picture-in-shuttle problems, as described in Section 5, are very great. For the same reason, the number of tracks per field is too high to be easily covered by an auto-tracking system, and without this, variable speed effects are limited.

7 Helical Problem Areas

Helical formats also have their own weaknesses, of which the most obvious is their limited ability to follow very narrow tracks. Careful attention to tape guiding has produced the very reliable Type C format. However, it would be difficult and expensive to provide the same reliability in a format using 25 to 50 μm track widths.

The second weakness is the coupling of head and tape speeds already discussed in Section 5.

The third is that the three-dimensional format makes the autoloading from a cassette more difficult. This is greatly eased if the wrap is a nominal 180°, rather than the 360° of the Type C format.

8 An Optimum Helical Format

The previous Sections contain the arguments that lead to the following conclusions:

(a) It must be a helical format in which an autotracking head can read a complete field with the tape stationary.

(b) Each track then should hold at least 20 t.v. lines to allow for picture-in-shuttle without having to break the lines into very short segments with the attendant overhead.

(c) The wrap should be less than 360° to ease the automatic tape threading from a cassette. A good compromise is to use 180° with two alternate head stacks for the video: by increasing the wrap 10 or 20° and using both head stacks simultaneously during this time, the audio channels can be added. Simple scaling says that for a video rate of 160 Mb/s recorded in 180°, a further 20° allows for over 17 Mb/s of audio. However, some 30% of this may need to be used for interchannel spacing and for synchronizing each audio channel independently.

(d) By using a high head-to-tape speed of 50 m/s, two parallel channels can record rates up to 160 Mb/s with a linear density of 1600 b/mm, or 200 Mb/s at 2000 b/mm. Given today's tape technology, the optimum linear density lies within this range.

(e) There is a compromise between drum rotational rate, tracks per t.v. field, and scanner size. For example, given a 150 rev/s rotational speed, the 50 m/s peripheral speed gives a drum diameter of 10·6 cm. 150 rev/s with two heads reading or writing at all times, and a 180° wrap gives 12 tracks per 625-line field or roughly 52 t.v. lines per track.

(f) To allow for 'confidence' playback (i.e. read while writing), separate read and write heads must be used. With two heads operating at all times, this gives a total of four read and four write heads mounted on the drum.

(g) A 'write-over' system in which erasure of previous recorded information is unnecessary is highly desirable. Otherwise still more heads must be mounted on an already crowded scanner. To achieve 'write-over' requires using a modulation code with little low-frequency energy even under worst case conditions; this is further discussed in the following Section.

9 Comparison of Miller Squared and 8/10 Block Codes

A considerable amount of experimental work has been performed on the 8/10 and the Miller Squared codes (M^2) and it may be appropriate at this time to compare their characteristics, as they relate to a practical DVTR. All comparisons are made on the basis of equal 'user' data rate, as it is misleading to include the added 20% of the 8/10 code in the packing density figure.

9.1 Signal-to-Noise Ratio Margin

The practical DVTR will require a minimum S/N ratio margin over the well-known failure area (14 to 17 dB) to be able to cope with variations in head and tape conditions, mistracking, etc. This margin must be at least 6 to 10 dB when all other requirements are served. It is therefore imperative that each available dB be obtained. The M^2 has a 3 dB disadvantage when random noise is the cause of errors. The off-tape condition is somewhat different as the dominant noise is in the vicinity of the Nyquist frequency of the code, and the error rate will depend mostly on the response in this area. Since the recorded minimum wavelength of the M^2 is in a ratio of 10/8 to that of the 8/10 code, depth of recording effects will give a 2 dB advantage to M^2.

To that we should add the effects of the inevitable head–tape spacing loss caused by imperfect tape finish, air film, or dead layer build-up at the surface of the transducer. Some of these effects may be beneficial by

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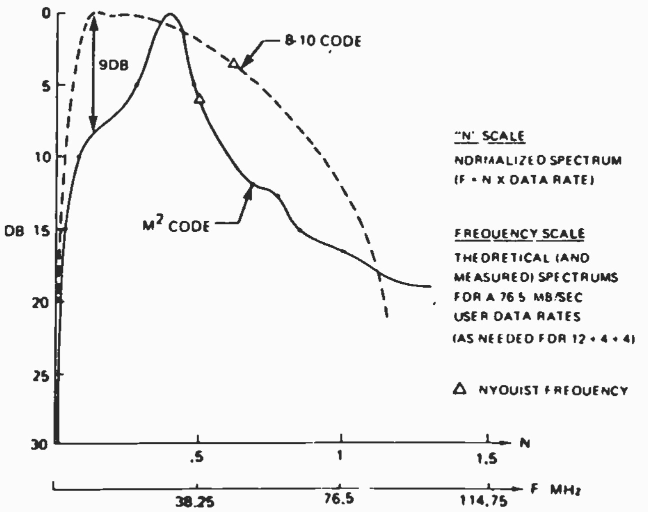

Fig. 5. Relative power spectral density for M^2 and 8/10 codes for equal user data rate.

increasing head life, but their effects on signal performance certainly are not, when wavelengths of the order of 1 μm are considered. Spacing of 0·15 to 0·25 μm are commonly measured. Using 0·2 μm and a useful data rate of 2000 bits/mm, the losses are: $M^2 = 11$ dB, 8/10 = 13·75 dB. The difference, 2·75 dB, added to the 2 dB above, minus the initial 3 dB gives an overall advantage of 1·75 dB to M^2. This may appear trivial, but is equivalent to a 50% track width (or tape consumption) increase.

9.2 Write-over Operation

Of the several factors affecting write-over (record head design, record current shaping, etc.) the most important is the ratio $\lambda_{writing}/\lambda_{recorded}$. The worst case is when writing the Nyquist frequency over the longest period without transition possible with the code. The M^2 is limited to 3 data cells, the 8/10 code to 8 or 10, giving the M^2 up to 10 dB advantage in worst-case erasure efficiency.

The effects on actual error rate will depend on the probability of occurrence of these worst cases. Figure 5 shows the theoretical (and measured) power density spectra of both codes. This can be interpreted as a measure of the probability of occurrence of the various components. 8/10 code shows up to 8 times (9 dB) more low frequency occurrences, with twice (3 dB) the occurrence of the Nyquist frequency to overwrite than the M^2; therefore the M^2 has 16 times less occurrence of worst case—with a 10 dB advantage when it occurs—than the 8/10 code.

9.3 Fringing Effects

Lateral magnetization that decreases the effective guard band is also proportional to the maximum λ. M^2 has a 3 : 1 advantage over 8/10 in this respect.

9.4 Error Detection and Correction

The 8/10 code is capable of 100% single bit and 75% double bit error detection at the block level.[1]

The M^2 simple few rules allow for continuous checking of the 'legality' of the off-tape signal sequences, and permits the detection and a large percentage of correction down to the single bit level.[2]

10 Concealment and Correction

Even the most sophisticated correction systems cannot cope with a long drop-out. For example, a complex system estimated to take about 200 ECL class i.c.s can only handle a drop-out 1080 bits long. At 2000 b/mm this only corresponds to a 0·5 mm drop-out.

On the other hand, the accuracy of a concealment system cannot be expressed mathematically, and its complexity and its success depends very much on the format. An orthogonal format leads to much lower complexity than an interlaced one; a higher sampling rate leads to better concealment.

The final decision must depend on practical tests and especially ones involving repeated edits within a small recorded area. However, an attractive solution is simple error correction using the built-in detection capabilities of Miller Squared combined with a powerful concealment system. Excellent results have been seen with raw error rates 100 to 1000 times higher than are expected on average tape, so that many defect-free multigenerations can be expected.

11 The Broadcast Digital Standard

There has been much discussion, especially within EBU and SMPTE, of a broadcast digital standard. There have been statements that the VTR will for some years limit the standard that can be chosen, and other statements that the achievable densities are increasing so rapidly that it is not a practical limit.

There are five points to be made on this subject:

1. The practical packing density will not be set by simple record/playback; it will be set by operational requirements such as repeated editing within a narrow area, and picture-in-shuttle at high tape speeds.
2. Whatever packing density is possible, tape costs are proportional to bit rate.
3. Similarly, reel size is approximately proportional to the square root of bit rate.
4. Equipment costs increase with bit rate (for example, a field store contains more bits).
5. A bit rate which forces a move from one semiconductor family (such as 10K) into a higher speed family (such as 100K) will have a disproportionate effect on cost, power consumption, and heat dissipation. At present, this will occur at around 80–100 Mbit/s per channel.

12 Conclusions

Assuming that the DVTR must have the features of today's analogue VTRs, then none of the analogue formats come close to meeting its needs. Type C is large and difficult to load from a cassette; Type B cannot provide the slow-motion and picture-in-shuttle performance and the scanner geometry limits the design of a DVTR. Lower performance formats such as U-matic

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have insufficient head-to-tape and shuttle speeds for the bit rates needed for full performance recorders.

Normal speed record/playback is not the limiting factor in setting packing densities and formats. The demands of slow motion and picture-in-shuttle are considerably higher and require an additional 6 to 10 dB of noise margin over that needed for simple playback.

A 180° wrap helical format with two parallel channels provides a good compromise between ease of threading and head costs. Such a system can be built around a 10 cm diameter scanner.

Miller Squared code provides the best match with the DVTR of any of the codes yet proposed. It requires little, if any, increase in bandwidth together with the limited low-frequency energy needed for overwriting.

Increased recorder bit rates will at some point around 80–100 Mbits/s per channel produce a disproportionate increase in cost, power consumption, and heat dissipation.

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Addendum:

When this paper was written there was a prospective agreement on a 160 Mbit/s international standard. This has since been increased to 216 Mbit/s. The one important change in the DVTR is that now minimum cost will occur when more parallel channels are used—probably three or four.

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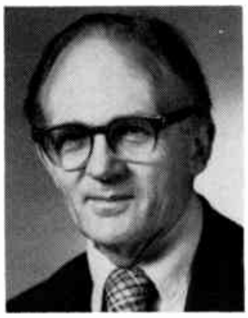

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Indexing Terms: Radio systems, mobile, Co-channel interference, Subjective testing

Determination of a.m. co-channel protection ratio for land mobile signals by means of subjective testing

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SUMMARY

An important parameter in the design of mobile radio systems is the co-channel protection ratio. New measurements, based on realistic subjective testing procedures using speech modulation, are presented for the a.m. case. The critical importance of audible carrier interactions is demonstrated.

Mean values of protection ratio which were graded by users as 'perceptible but not disturbing' decreased from greater than 30 dB to approximately 15 dB when the carrier frequency offset was reduced from 1 kHz to 100 Hz.

Extreme variability between subjects makes reliable experimental evaluation of protection ratio an expensive and time-consuming procedure.

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1 Introduction

In determining the area coverage and grade of service of a land mobile radio system, a critical parameter is the co-channel radio frequency protection ratio.[1] This is the ratio of wanted to interfering signals in the wanted channel necessary to give an accepted grade of service from the wanted signal. Although real land mobile systems are subject to Rayleigh fading and other impairments, a knowledge of the protection ratio required with two constant (wanted and interfering) signals (as experienced in a stationary mobile), sometimes called the absolute protection ratio, is sufficient to permit calculation of required levels for a given grade of service in a variety of fading conditions,[2] including the case of a moving mobile.

2 Measurement of Protection Ratio

When speech-modulated signals interfere, objective methods of measurement are inapplicable, and subjective techniques must be used. This results in greater realism in conclusions, since it corresponds to the real-use situation, but variability of perceptions between different listeners make tests of this kind both expensive and labour consuming.

One approach considered and rejected was to measure articulation scores for the wanted channel in the presence of interference. The technique classical in speech research[5] is to read lists of consonant-vowel-consonant nonsense syllables over the channel. The hearer writes these down as heard and the percentage correct is scored. Well-established literature relates articulation scores to percentage comprehension of random words or connected sentences in major languages. The disadvantage of articulation scoring is that it is generally accepted as having little absolute significance, being most useful to determine whether certain technical changes in a channel have improved or worsened speech transmission. It was also considered that the provision of mobile radio, even of high intelligibility, with obtrusive interference would not be acceptable to users.

For scoring acceptability a number of subjective scales have been used: the most widely recognized is the European Broadcasting Union impairment scale (Table 1), and it was felt that either Grade 3 (definitely perceptible but not disturbing) or Grade 4 (somewhat objectionable) represented the likely lower limit of acceptability for respectively, public radio telephone and 'dispatcher' private mobile radio services.

Attempts to measure absolute protection ratio are very long standing, but for simplicity often depend upon the use of sinusoidal tones modulating both the wanted and interfering signals. For example, the CCIR procedure for protection ratio measurement[3] envisages

Table 1 EBU Impairment Grades

1	Imperceptible
2	Just perceptible
3	Definitely perceptible, but not disturbing
4	Somewhat objectionable
5	Definitely objectionable
6	Unusable

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tone-modulated transmitters used in such a way that the ratio of the wanted signal to all other receiver outputs falls from 20dB to 14dB when the interfering transmission is introduced. Quite apart from the arbitrariness of the decibel figures, it is not clear that measurements with pure tones relate well to practical experience with real land mobile systems. It is apparent from published material[4] that frequency offset between wanted and interfering signals is critical, but it is not taken into account by the CCIR standard.

In the work to be described, absolute protection ratio was determined for the case of a speech-modulated transmitter interfering with another, also modulated by (different) speech. The case of a.m. was considered, because of its particular UK interest, but it is possible to draw conclusions about other modulation systems. The outcome has been to confirm that protection ratio is a function of frequency offset. A substantial improvement in a.m. protection ratio would be secured by tightening frequency specifications.

It must of course, be borne in mind that in a normal mobile radio fading propagation environment these minimum acceptable standards are those encountered at the edges of coverage areas where co-channel interference is most probable. As a consequence they will be improved upon substantially at less extreme ranges, where the wanted signal is stronger.

The design of subjective testing experiments is complex because of the large number of experimental variables which must be covered, including the technical characteristics of the equipments (signal level, degree of frequency offset between wanted and interfering transmissions, degree of speech processing, and so on) and also a number of human factors (operating language, sex, age and experience as radio users of both speakers and hearers, degree of learning of system permitted to subjects before test results obtained, etc). An exhaustive series of experiments, with all factors fully explored and in each test enough subjects to guarantee statistical significance in the results, would be a task of substantial magnitude taking years. It was therefore necessary greatly to simplify.

Preliminary trials gave a rational basis for most of the decisions. Although trials with a.m., f.m. and s.s.b. would have been desirable, only a.m. was used in this series. It was found that signal strengths, provided both wanted and interfering signal were capable of giving 20dB or better SINAD in the receiver, played no detectable part in determining protection ratio, so that as an experimental factor it could be eliminated. The question of speaking voices used for modulating the transmitters was resolved, arbitrarily, by using BBC news broadcasts, recorded off-air, band-limited to the normal 300Hz-3kHz mobile radio range. The only equipment characteristic left was therefore frequency offset between wanted and interfering transmissions, and this was the principal experimental variable.

So far as the selection and preparation of test listeners was concerned, 3 groups, each of 5 persons, were used:

(a) Female and unused to mobile radio
(b) Male and unused to mobile radio
(c) Male and used to mobile radio

In the outcome statistically significant differences between the groups were not observed, and it proved legitimate to merge the results for the three groups. This suggests that neither sex nor familiarity with mobile radio use plays a significant part in a listener's tolerance of co-channel interference.

3 Experimental Procedure

The design of psychological and subjective testing experiments is somewhat involved [5,6] and cannot be summarized here. Two types of experiments were used in the present investigation, interactive and non-interactive, and were alternated with the same listener in each test session.

3.1 The Non-interactive Experiment

This experiment utilized tape recordings, each of ten seconds duration, in which the a.m. receiver output was recorded with wanted and unwanted signal inputs (both modulated by male speech) at known relative amplitudes and frequency offsets. Two blocks of five ten second tracks were administered, then the interactive experiment was carried out, followed by three more blocks of five non-interactive tracks. The duration of the sample was long enough for participants to come to a conclusion, yet short enough to deter reconsideration.

Each block of ten second recordings consisted of five wanted-to-unwanted-signal ratios in Latin square order[7] (5-25dB in 5dB steps). Each block was recorded at an unique frequency offset, but the five blocks, at different offsets, were incorporated in an 'outer' Latin square. The offsets used were: (in Hz) 0, 100, 300, 1000 and 3000. The listener was asked to write down the appropriate EBU grade after each sample.

3.2 The Interactive Experiment

For the interactive experiment the arrangement in Fig. 1 was used. A two-channel tape recorder, each channel providing similar broadcast-quality male speech passages (BBC News), independently modulates two a.m. signal generators at 72MHz, after speech processing designed to reduce the quality to that of land mobile radio. A commercial a.m. receiver designed for 12·5 kHz channel spacing demodulates the combined r.f. output of the two generators.

The output of one generator is fixed at a value near the middle of the receiver dynamic range (giving a high SINAD), but the level of the other can be adjusted by the listener, who is asked to set it so that first one transmission is dominant and then the other. In both

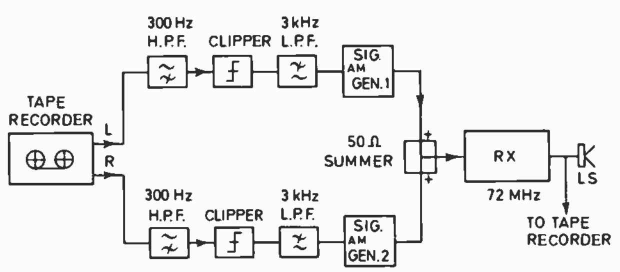

Fig. 1. Block diagram of experimental circuit for the interactive experiment

cases the subject adjusts the level until interference from the unwanted transmission produces the appropriate EBU impairment grade (i.e., 3 or 4, as specified). The protection ratio (under these conditions) is then half the decibel difference between the two output level settings.

It was expected that the interactive experiment would give more accurate results than tape recording grading: indeed a batch of tape groupings was administered before the interactive experiment to give the subject experience in setting standards for the EBU grades. In the event, the differences in outcome between the interactive and non-interactive experiments were not significant and give no grounds for supposing that one technique is superior in accuracy to the other, since the results exhibit similar variability. It should, however, be noted that the interactive experiment gave results with an approximately Gaussian distribution, easily interpolated for percentage acceptance. By contrast the distribution of grades obtained from the non-interactive experiment was markedly non-Gaussian, leading to added uncertainty in interpolations.

4 Results

Individual results from the interactive experiment were classified according to the frequency offset chosen and the EBU grade aimed at (3 or 4). Thirty values were obtained for every frequency/grade class and the mean and standard deviation calculated in each case. In one class (0Hz/Grade 3) two outliers were identified and eliminated, but all other results were included.

Surprisingly perhaps, the interactive experiment gave results which, when measured in decibels, appeared to correspond well to a Gaussian distribution. Application of the chi-squared test to the data was not conclusive. In view of this, a normal distribution has been assumed only in the calculation of 75% and 90% acceptance points. Mean values obtained for the two grades are shown in Fig. 2. In Tables 2 and 3 the same results are presented, together with calculated protection ratios to

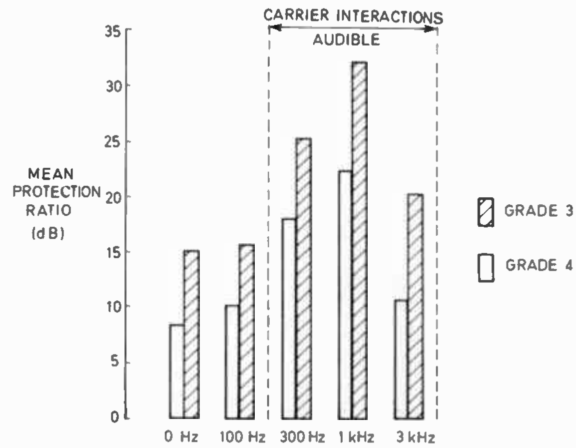

Fig. 2. Mean protection ratios for specified impairment grades as a function of carrier frequency offset (interactive experiment)

give 75% and 90% acceptance at the grade specified. This illustrates the variability of the subjective response evoked: for example at frequency offset 0Hz and 15dB protection ratio, almost half of the sample considered that Grade 3 had been attained ('perceptible but not disturbing'), whereas about 10% graded the signals at 4 ('somewhat objectionable'). One must doubt whether real mobile radio systems can be engineered to the 90% acceptability point; instead it may be necessary to depend upon some degree of acceptance.

The non-interactive experiment gave similar results (Fig. 3). In each case a median protection ratio was computed for the grade and offset (error estimated at 2·5dB).

In all the results significantly higher protection ratios are required for offsets of 300, 1000 and 3000 Hz than for lower offsets. Consideration of the frequency response of the receiver (Fig. 4) (which is typical of commercial a.m. receivers and contains a measure of de-emphasis of higher audio frequencies) suggests that the higher protection ratios at larger offsets arise when

Table 2 Interactive Experiment—Grade 3

Frequency Offset (Hz)	Mean dB	Standard deviation	Standard error mean	Sample No.	75% Acceptance (dB)	90% Acceptance (dB)
0	15·2	4·25	0·8	28*	18·0	20·6
100	15·9	4·69	0·86	30	19·0	21·9
300	25·3	6·06	1·11	30	29·3	32·7
1000	32·2	8·40	1·53	30	37·8	43·0
3000	20·3	8·56	1·56	30	26·0	31·3

* Two outliers omitted

Table 3 Interactive Experiment—Grade 4

Frequency Offset (Hz)	Mean dB	Standard deviation	Standard error mean	Sample No.	75% Acceptance (dB)	90% Acceptance (dB)
0	8·4	4·41	0·80	30	11·3	14·0
100	10·2	3·83	0·70	30	12·7	15·1
300	18·1	7·26	1·32	30	23·0	27·4
1000	22·4	6·47	1·18	30	26·7	30·7
3000	10·8	5·67	1·04	30	14·6	17·7

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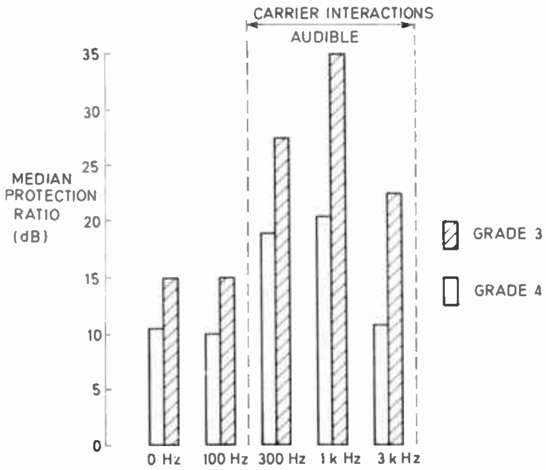

Fig. 3. Median protection ratios for specified impairment grades as a function of carrier frequency offset (from tape gradings)

carrier beats are within the audio passband. Listeners confirm that it is primarily carrier beats which they perceive as interference.

5 Conclusions

It is clear that significantly (e.g. up to 20dB) higher protection ratios are required if large frequency offsets ($\geqslant$ 300Hz) are permitted between wanted and interfering signals. This, perhaps surprising, result is a consequence of the subjectively highly unacceptable character of a continuous tone. By comparison transient interaction between sidebands appears better tolerated.

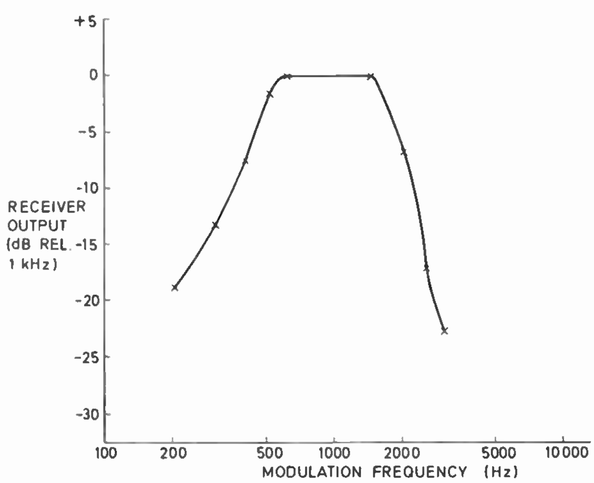

Fig. 4. Receiver modulation frequency response

For example, if the currently permitted tolerance of $\pm$ 1·5 kHz on transmitter frequency applies, the worst case frequency offset, with respect to protection ratio, may often be encountered. Assuming that 75% of the users should find the system acceptable, a protection ratio of 38 dB would be required to establish grade 3 impairment (e.g. for public mobile telephones) and 27 dB for grade 4 (probably suitable for 'dispatcher' type services). By contrast, allowing a frequency tolerance of $\pm$ 50 Hz (which could presumably be extended to $\pm$ 100 Hz with attention to receiver low frequency a.f. reponse) the corresponding figures are 19dB and 13 dB. By contrast the CCIR formula[3] disregards offset yet gives a ratio of 17 dB.

Now that the use of synthesizers is becoming widespread in land mobile equipment, the time may be right to propose tighter standards for frequency stability of equipments, and thus gain the advantage of lower protection ratios. Systems (such as s.s.b.) with suppressed or diminished carrier, but otherwise similar to a.m., could be expected to give protection ratios near the lower end of the range for a.m., i.e. median values around 9dB for grade 4 and 15dB for grade 3.

It is of interest to compare n.b.f.m. with a.m. Since the continuous carrier beat is heard most clearly during pauses in speech, when the unmodulated f.m. and a.m. signals are similar, differences arise principally from receiver characteristics. There is evidence[8,9] for a protection ratio of 15dB to suppress carrier interactions with 12·5kHz channelled n.b.f.m: this is consistent with our results, and suggests that n.b.f.m. and a.m. differ less than sometimes supposed. The recent interesting study by Garner finds little measurable difference between f.m. and s.s.b.[10]

6 Acknowledgments

Without the help of our experimental subjects this research could not have been conducted. One of us (A.L.) wishes to acknowledge financial support from the Science Research Council (a CASE award in association with GEC-Marconi Ltd.).

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Microprocessor controls for limited-function robots

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and
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Based on a paper presented at the IERE Conference on Microprocessors in Automation and Communications held in London in January 1981.

SUMMARY

This paper describes a microprocessor controller for limited-function, special-purpose robots. Both hardware and software for the controller were developed in modular form so that appropriate modules can be selected to suit a particular robot configuration. Two levels of sequence programming, defining the task to be performed by a robot, can be utilized. Low-level sequence programming can be used by a trained operator but is time consuming and error prone. High-level sequence programming can be achieved using a software communications module which prompts the operator so that negligible training is required and sequences can be developed efficiently.

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1 Introduction

The present generation of industrial robots is designed to meet a wide range of applications which require sophisticated mechanical and control system configurations[1–3] so that sufficient flexibility can be obtained. An alternative approach is to develop a number of limited-function, special-purpose robots with associated custom controls. If the development time associated with the special-purpose robots can be minimized, considerable cost savings are possible. Furthermore, if they can be designed to closely match the users' requirements, training time is reduced and valuable floor space will be saved.

A number of limited-function, special-purpose robots have been developed at Loughborough University and have been used successfully in various diverse work-handling applications which has led to current work involving the design of low-cost mechanical robotic forms. Originally some of these robotic devices were controlled with conventional TTL sequence controllers which resulted in limited flexibility. Recently microprocessor-based controls, which provide sufficient flexibility for the control of a wide range of robotic devices but which can easily be customized to suit a particular application, have been developed.

This paper describes the development of these microprocessor-based controls and demonstrates how they can be used to control a number of robotic devices and other sequential machines.

2 A Pick-and-Place Robot

A five-axis pick-and-place robot had previously been developed, the mechanical construction of which is illustrated in Figs. 1 and 2. This was used to evaluate many of the features of the microprocessor controls. All of the axis were actuated by pneumatic cylinders which were controlled by 24V d.c. solenoid operated valves.

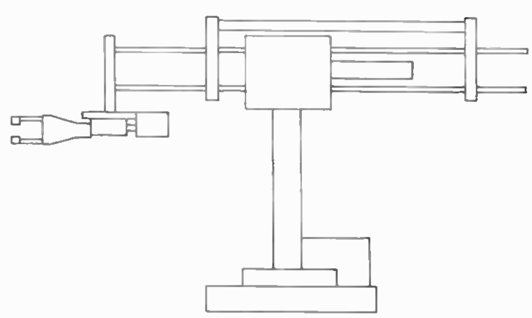

Fig. 1. Outline of pick-and-place robot.

The three major axes, trunk, waist and shoulder, were fitted with magnetic reed-switches to detect the end of travel. Smaller pneumatic pistons were also fitted to these axes to engage or retract mechanical stops; a secondary solenoid and air valve applies restricted air pressure enabling an intermediate position.

The hand gave 90 degrees of rotation to which a range of jaws could be fitted. Table 1 relates axis movement to solenoid actuation and reed-switch closures.

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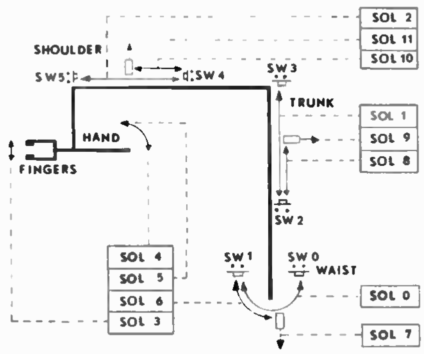

Fig. 2. Axis configuration of pick-and-place robot SW reed-switch SOL solenoid valve.

Table 1

Axis movement, solenoid actuaction, and reed-switch closures.

Axis action	Solenoids energized	Solenoids de-energized	Switch closed
waist clock	—	0, 7, 6	1
waist anti-clock	0	7, 6	0
waist anti-clock midway	7, 6	0	—
trunk down	—	1, 8, 9	2
trunk up full	1	8, 9	3
trunk up midway	8, 9	1	—
shoulder in	—	2, 10, 11	4
shoulder out full	2	10, 11	5
shoulder out midway	10, 11	2	—
hand vertical	4	5	—
hand horizontal	5	4	—
fingers open	—	3	—
fingers closed	3	—	—

3 The Basic Microprocessor Controller

Standard interface modules were produced to facilitate interfacing with the pick-and-place robot (see Fig. 3). An output module was developed to provide sixteen 24V 0·5A d.c. outputs (this module being optically isolated from the microcomputer 5V output ports to reduce problems of earth loops and noise), one of which actuated the axis solenoids of the pick-and-place robots. A d.c. input module which incorporated opto-isolators, was also developed to provide sixteen digital inputs and the robot reed-switches were interfaced using such a module.

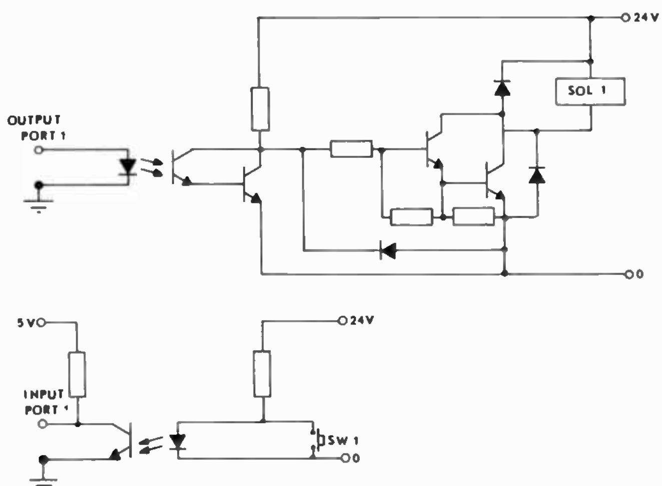

Fig. 3. Interface circuitry for solenoids and switches.
Note: The output and input modules contain sixteen such circuits.

In the development stages of this work, operator communication with the microprocessor controller was achieved via a standard RS232 interface and a computer terminal (Fig. 4). Subsequently a customized control panel was designed (see Sect. 7).

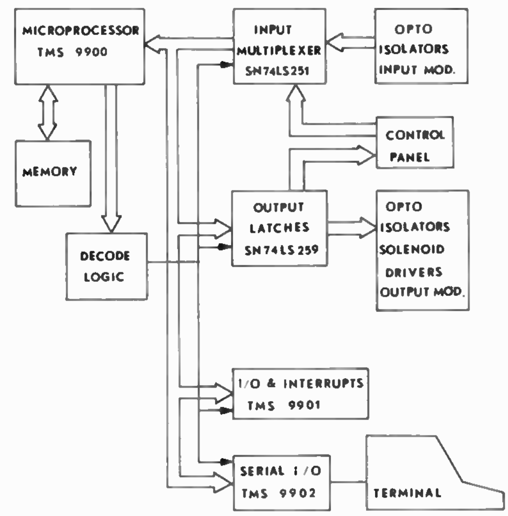

Fig. 4. Overview of microprocessor controller.

When switching on the power supply, the microprocessor controller and robot are forced to automatically re-set with all solenoids in the de-energized state. The microprocessor controller performs a simple diagnostic test of memory, power supplies and serial interface and then all input ports are interrogated for the robot re-set. If this is successfully completed and no error messages are displayed, the operator can choose to action a supplementary test, where the microprocessor controller drives each axis in turn and times the response, displaying appropriate error messages to indicate departures from expected performance.

4 Control Software

Software was developed to provide a basic instruction set which was suitable for the control of the pick-and-place robot. The chosen set of instructions perform the following functions:

Look for input high
Look for input low
Activate output high
Activate output low
Time delay
Jump unconditional
Stop
Jump on input port high } decision instructions
Jump on input port low }

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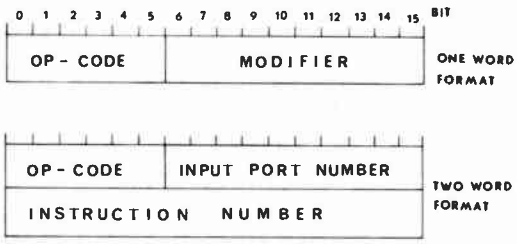

Fig. 5. Instruction code formats.

Each instruction is defined by a routine, written in assembly language, and a 16-bit format was adopted for all instructions except the two concerned with decisions which are represented by two 16-bit words—(see Fig. 5). The format includes an operation code (op. code) and modifier; the op. code describes the type of action to be performed (e.g. time delay, jump, etc.) and the modifier is an address or data (e.g. for input/output instructions it is a port address, whilst for a time delay the value is taken as the number of milliseconds). Considerable expansion of the basic instruction set is possible, the maximum number being 64, a large number of instructions being required for the control of more complex robotic devices and other sequential machines.

The user can choose appropriate instructions to form a sequence program which defines the task to be performed by the robot. This is stored in random access memory (r.a.m.) so that changes to the sequence can be performed on the shop floor. The microprocessor controller sequentially interrogates this user memory area and performs the instructions by branching to the related assembly level routine.

The input routines incorporate an 'antibounce' time delay loop, and a single-step switch is interrogated within the output routines to ease validation of the program.

Table 2
Instruction Codes

1 Energize a solenoid—format 1NNN (base 16)
where NNN = solenoid number (in the range 0 to 1023).
e.g. 1004 energizes solenoid four (Sol 4)

2 De-energize a solenoid—form at 2NNN
where NNN = solenoid number.

3 Test micro-switch closed—format 3NNN
where NNN = micro-switch numbers.
e.g. 3000 test micro-switch zero (SWO)
and continues testing until switch closes

4 Test micro-switch open—format 6NNN
where NNN = micro-switch numbers

5 Time delay—format 4NNN
where NNN = time delay in hexadecimal and
relates to a base time of 0·1 s.
e.g. 43E0 causes a delay of $3EO_{16} \times 0{\cdot}1$ s $= 99{\cdot}2$ s.

6 Jump—format CNNN
where NNN = instruction number
e.g. C009 moves unconditionally to the 9th instruction
in the user program.

7 Stop—format 8000 stops the program

8 Jump on input high—format DNNN
MMMM
where NNN = input port number
MMMM = instruction number

9 Jump on input low—format ENNN
MMMM
where NNN = input port number
MMMM = instruction number

5 Code Programming

Although the software described so far is rudimentary it is sufficient to allow an operator, who has received a moderate degree of training, to develop sequence programs. This is illustrated by Tables 2 and 3. In Table 2 the instruction codes are given and in Table 3 a short sequence program is shown.

The sequence of operations performed by the robot can be changed by an external event. This can be actioned in two ways; the operator can use a conditional jump instruction; or the external event can cause a priority interrupt so that the microprocessor performs a specific branch to a new sequence program. The principles of robot decision making are considered in greater detail in Ref. 4.

Table 3
Example sequence program

Instruction code hexadecimal	Instruction	Robot action
1005	output high 5—energize solenoid 5	Hand horizontal
400A	time delay 10 × 100 ms	
2005	output low 5—de-energize sol. 5	
400A	time delay 10 × 100 ms	
1002	output high 2—energize solenoid 2	Shoulder out full
3004	input low 4—switch 4 closed	
4006	time delay 6 × 100 ms	
8000	stop	

6 Operator Assistance

Programming the robot, using codes describing each instruction, is not a difficult task if the sequence program is short but for more complex sequences many errors can be made and the time required to 'prove' a sequence may be long. For general machine control the manufacturers of programmable controllers have attempted to aid sequence programming by allowing the sequential movements of the machine to be described in the form of a relay ladder diagram or by using Boolean algebra.[5,6] This approach is not appropriate here with conceptual problems of relating the movement of axes to relay or Boolean algebraic symbols.

The approach adopted is similar to that for manual data input for machine tool control. An interactive software module was developed to provide a conversational link with the operator. This software module customizes the basic instruction set for the pick-and-place robot providing prompts to the operator concerning the programming possibilities. This allows

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the operator to input statements in the form

'move waist clockwise'

Such a statement results in a number of instructions (from the basic instruction set of the robot) being loaded into the user area of r.a.m. and the operator is saved unnecessary and error-prone work.

Table 4 shows the listing of a sequence program development session using the interactive software. Operator communication is achieved using a standard v.d.u. or teletypewriter.

The microprocessor controller prints out a request for an instruction followed by the alternative answers. Only the first letter of the reply is typed by the operator and the microprocessor controller completes the work. If an illegal letter is entered an error message is given and the question repeated. This approach was found to be most successful with all users. However, as a user gained experience in sequence programming it was found that many of the prompts were unnecessary. Thus a facility was provided to allow the operator to change to 'short form' print-out with error messages retained in an unabbreviated form.

Table 4
High-level sequence programming—example terminal session

ROBOT CONTROL
PLEASE INPUT YOUR INSTRUCTION NUMBER 0000 (MOVE, JUMP, DELAY, STOP, END)
MOVE
WHICH AXIS (WAIST, TRUNK, SHOULDER, HAND, FINGERS)?
HAND
VERTICAL OR HORIZONTAL
HORIZONTAL
PLEASE INPUT YOUR INSTRUCTION NUMBER 0001 (MOVE, JUMP, DELAY, STOP, END)
MOVE
WHICH AXIS (WAIST, TRUNK, SHOULDER, HAND, FINGERS?)
TRUNK
UP OR DOWN
DOWN
PLEASE INPUT YOUR INSTRUCTION NUMBER 0002 (MOVE, JUMP, DELAY, STOP, END)
MOVE
WHICH AXIS (WAIST, TRUNK, SHOULDER, HAND, FINGERS?)
SHOULDER
IN OR OUT
OUT
PLEASE INPUT YOUR INSTRUCTION NUMBER 0003 (MOVE, JUMP, DELAY, STOP, END)
DELAY
6 NUMBER OF 100 MILLI SEC?
PLEASE INPUT YOUR INSTRUCTION NUMBER 0004 (MOVE, JUMP, DELAY, STOP, END)

Further software facilities have recently been added to assist the user which are:

(i) Edit. The user can modify, list, and dump sequence programs, and
(ii) Instruction Decode. Instructions are decoded and grouped to form high level statements of the type used in the interactive terminal sessions

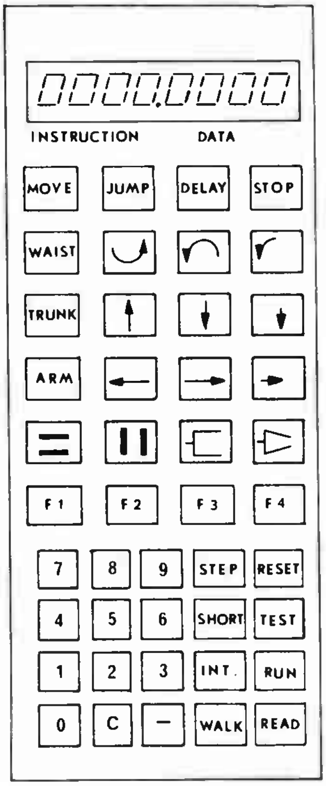

Fig. 6. Customized programmers panel.

7 A Programming Panel

If the 'short form' print-out option of the interactive programming facility is used, sequence programming can be achieved by using a small hand-held visual display unit and keyboard. By interfacing via microprocessor controller input/output ports and making minor modifications to the software structure a customized programming panel can be used. Figure 6 illustrates such a programming panel. The panel uses illuminated push button switches with a legend placed on each. The operator is guided when the microprocessor controller illuminates the switches which can be pressed in answer to the current prompt. The decimal read-out, together with a numeric keypad, is used for delay and jump instructions. The operator can also use recall facilities to read through sequence programs.

8 Current Developments

The microprocessor controller is currently being enhanced to achieve customized controls for other special purpose robots. The instruction set for a robot can now be selected from a wider range of assembler routines. Furthermore additional hardware modules have been developed to allow interfacing for hydraulic servos; both digitizer and potentiometer feedback signals can be catered for. By selecting an appropriate instruction set and suitable hardware modules, the microprocessor controller has been used to control other limited function robots, two such robots allowing point-to-point positioning in up to three axes. High-level programming facilities are being developed to allow interactive sequence pragramming for both robots. The structure of this software is attracting particular interest,

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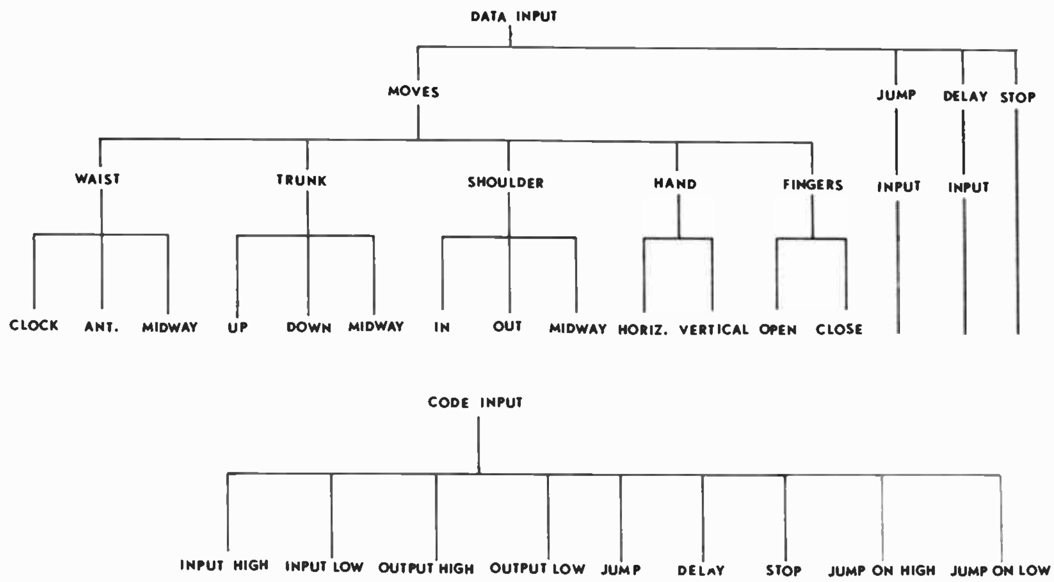

Fig. 7. Software structure for the pick-and-place robot.

'common' and 'specialized' software modules being identified so that future high-level interactive programming facilities can be efficiently developed to suit any robot form.

9 Conclusions

By adopting a modular approach to both hardware and software design, a microprocessor controller has been developed which can service a range of special-purpose robotic devices (Fig. 7 illustrates software modularity for one of these robots). Two levels of sequence programming are available. At a low level, a trained operator can use basic instructions (each corresponding to a real-time control assembler routine) to form a sequence of handling operations for the robot. Low-level sequence programming is similar for robots with diverse forms although each robot will have a particular set of instructions and addresses (relating to axis actuators and feedback devices) which must be known to the programmer. Generally, however, as the robot becomes more complex, then sequence programming at this low level becomes more difficult. Interactive software was thus developed to give computer assistance at the robot so that a conversational link with the operator provides a high-level sequence programming facility which greatly reduces the need for training. Unfortunately, however, this interactive software is very much dependent on the robot type as it must provide prompts which relate specifically to the axis nomenclature, axis actuator and feedback mechanisms, allowable operating modes, allowable position and velocity ranges, etc. Current work concerns the development of interactive software which can be easily tailored to various types of special purpose and industrial robots. In parallel work, 'teach' software is also being developed which will make a further optional sequence programming technique available to the operator to facilitate the efficient generation of handling sequences for robots in a wide range of work-handling applications.

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Indexing Terms: Microwave devices, Switches, Attenuators, Detectors, Couplers, Mixers, Planar integration.

A survey of planar integrated mm-wave components

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An extended version of a paper presented at the Military Microwaves Conference held in London in 1980.

SUMMARY

Different approaches for the integration of mm-wave components have been presented recently, suggesting image line or shielded microstrip line for example. A very promising attempt employs quasi-planar structures, like fin-line, and related line configurations for this purpose. The paper gives a survey of various components being developed in the frequency range from 18 to 170 GHz using this approach.

Broadband p-i-n-attenuators achieve an insertion loss below 1 dB and an isolation better than 25 dB covering either one or two entire waveguide bands. Narrowband resonator-type attenuators need only one diode to achieve similar results. At 94 GHz the attenuation of such a device can be adjusted between 1·5 and 35 dB. Fin-line detectors have been built between 18 and 170 GHz, with minimum sensitivity ranges from 400 to 100 mV/mW, depending on frequency. The conversion loss of a planar balanced mixer developed for Ka-band (26·5–40 GHz) amounts to 5 dB in a narrowband version and to 6–8 dB in a broadband, octave-wide version (18–40 GHz). For 60 GHz, a conversion loss down to 6·5 dB has been achieved. The unique advantage of the fin-line technique is demonstrated by a completely integrated Ka-band receiver front end, containing p-i-n-s.t.c., mixer and local oscillator. Fin-line couplers necessary for other integrated circuits have shown coupling factors up to crossover operation with full waveguide bandwidth.

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1 Introduction

The demand for inexpensive, but quality satisfying and reliable mm-wave components has encouraged the development of fin-line technology in recent years. Various papers have been published, dealing with fin-line based planar integrated mm-wave components.[1–8]

This paper summarizes design criteria and performance data of various fin-line components, such as p-i-n attenuators and switches, detectors and mixers, as well as directional couplers. Additionally, in order to demonstrate the outstanding potential of fin-line techniques with respect to the integration of different components, an entirely integrated receiver front-end is shown.

2 p-i-n-Switches and Attenuators

Two entirely different types of diode controlled mm-wave fin-line attenuators and switches can be distinguished, depending on the installation of the p-i-n-diodes: shunt-type and series-type circuits. The distinct designs, shown in Fig. 1, exhibit entirely different characteristics. Thus the type of fin-line attenuator may be chosen according to the application requirements.

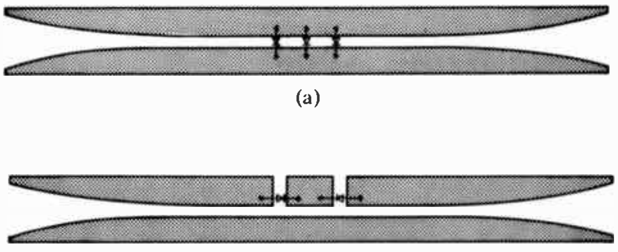

Fig. 1. (a) Basic set-up of a shunt-type p-i-n attenuator (b) Basic set-up of a series-type p-i-n attenuator.

Figure 1(a) displays the layout of a shunt-type p-i-n-diode attenuator. Devices of this kind can be built for frequencies up to approximately 100 GHz. At 94 GHz an insertion loss of 1·5 dB with an isolation of 35 dB can be achieved (Fig. 2). Two beam-lead p-i-n-diodes have been employed, spaced three quarter wavelengths (94 GHz) apart, to achieve such a high isolation.

By reducing the diode spacing to a quarter wavelength at midband either one or two entire waveguide bands can be covered. Figure 3 shows the characteristics of such a device with three diodes. The attenuation can be adjusted between 1 and 25 dB respectively.

The realization of such an octave-wide component requires a special metal housing, e.g. for an 18–40 GHz device, the waveguide cross-section in the vicinity of the shunted diodes must have the width of Ka-band (26·5–40 GHz) waveguide, while the output flange should mate with K-band (18–26·5 GHz). This was accomplished by tapering the waveguide width.

Employing transmission line theory, the p-i-n-diode capacitances in the off-state (low attenuation) are compensated to reduce the insertion loss. In the application of such a device, the decreased bandwidth is

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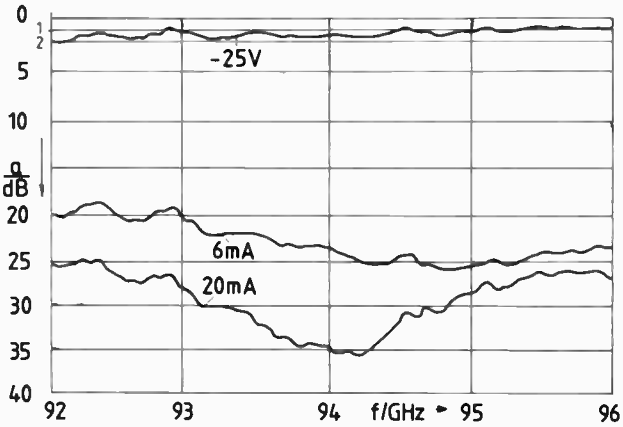

Fig. 2. Attenuation of a two-diode shunt-type p-i-n attenuator for 94 GHz application.

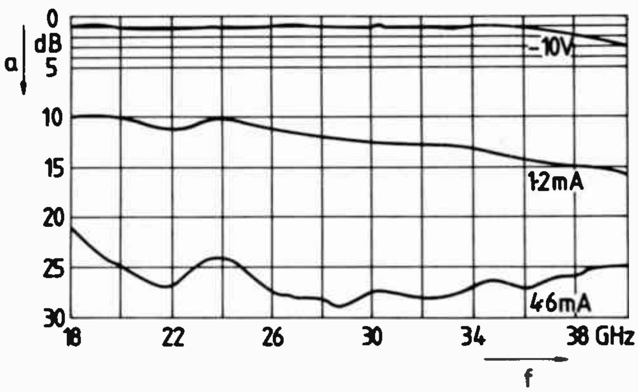

Fig. 3. Attenuation of a three-diode shunt-type p-i-n attenuator for octave wide bandwidth utilization.

an advantage. Insertion loss values of below 0·8 and 1·6 dB have been achieved at 39 and 60 GHz respectively, with minimum isolation of 25 dB for a two-diode device. The corresponding bandwidth amounts to 3% (10% bandwidth for devices exhibiting insertion loss below 1·5 and 2 dB respectively).

The alternative approach for the design of fin-line attenuators and switches is given in Fig. 1(b). The parallel resonance of the short-circuited slot-line stub and the p-i-n-diode's inductance in the forward biased state is exploited to reflect the incoming power, representing the ON-state (high attenuation) of the switch. In the OFF-state, the p-i-n-diode is reversely biased, the lead inductance and the capacitance of the p-i-n-diode now form a series resonance, and thus the stub is shorted. The performance of such a device for 60 GHz application is given in Fig. 4; the attenuation can be adjusted between 1 and more than 35 dB. A bandwidth of about 2% can be achieved by incorporating two p-i-n-diodes; for an increased bandwidth of 5% the switching dynamic range decreases to about 20 dB.

The parallel resonance of the shorted slot-line and the diode inductance exhibits a high Q-factor, corresponding to a narrow bandwidth. Due to the thin film technique employed, this resonance has a good reproducibility. The series resonance of the diode capacitance and inductance depends on the semiconductor parameters. Fortunately production spreads do not critically influence the switching behaviour, because this resonance has only a low Q-factor, corresponding to a broader bandwidth. p-i-n attenuators and switches of the

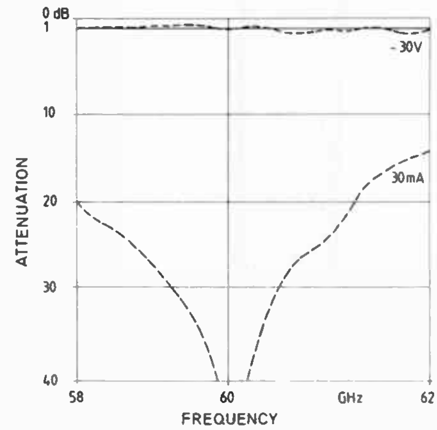

Fig. 4. Attenuation of a two-diode series-type p-i-n attenuator for 60 GHz application.

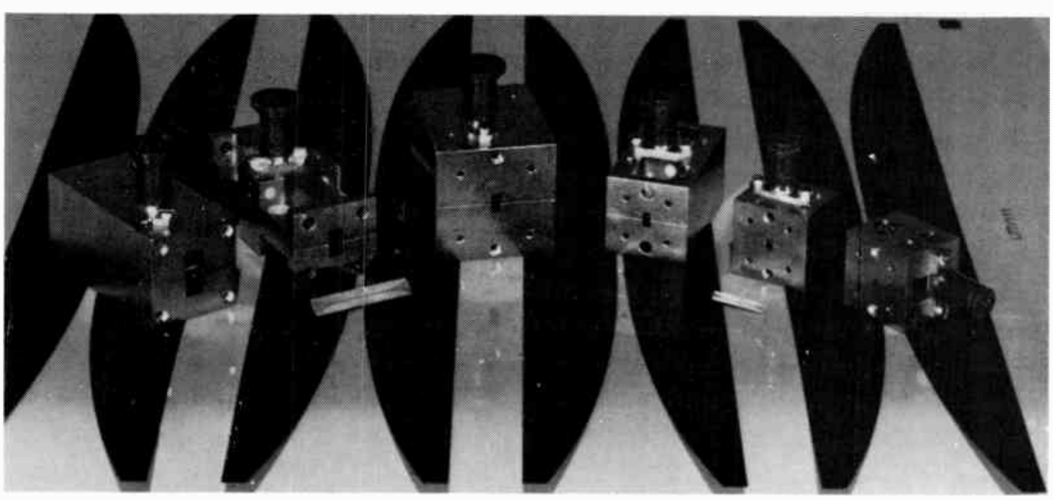

Fig. 5. Several fin-line p-i-n attenuators and switches produced for different waveguide bands, starting (left) with K-band (18–26·5 GHz) and ranging up to 100 GHz.

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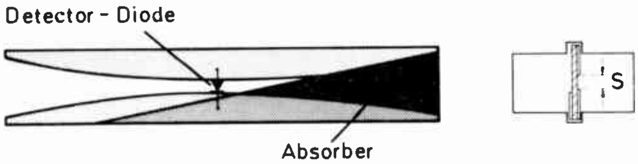

Fig. 6. Basic set-up of a fin-line detector.

described type can be built for frequencies as high as 100 GHz. A 90 GHz device which is under development at the present time, can be adjusted between 2 and 35 dB.

It should be mentioned that in Reference 7 another series-type attenuator has been described. The application of that device is limited in frequency due to the diode parasitics. These difficulties have been overcome with the inversely working type of series p-i-n-attenuators presented here. Combining two p-i-n-attenuators—parallel or series type—by means of a Y-type series fin-line junction, as described in Reference 2, double-through p-i-n-switches can be built. These devices can be used as Dicke-switches in radiometers, for example; they exhibit nearly the same performances as the two-port devices, only the insertion loss is slightly increased.

Due to the semiconductor behaviour the switching speed of p-i-n-diode controlled mm-wave switches is limited to a minimum of about 50 ns. A solution to overcome this limitation is the application of Schottky-barrier mixer-diodes as switching elements. This approach was described previously in detail.[5] Rise- and fall-times below 300 ps have been achieved.

Several p-i-n attenuators and switches for various frequencies between 18 and 100 GHz have been built, some of which are shown in Fig. 5.

3 Detectors

For detector applications in the mm-wave range commercially available zero-bias beam-lead diodes have been utilized.[9] Figure 6 shows the construction of a fin-line detector. On the upper side of the substrate the fin-line circuit, containing the semiconductor device, is etched, while absorber material is painted on the back side of the substrate. A good transition from waveguide to the semiconductor device can be achieved, using an optimized fin-line taper.[2] The v.s.w.r. of the entire detector unit is 2 : 1. Several units have been set up for

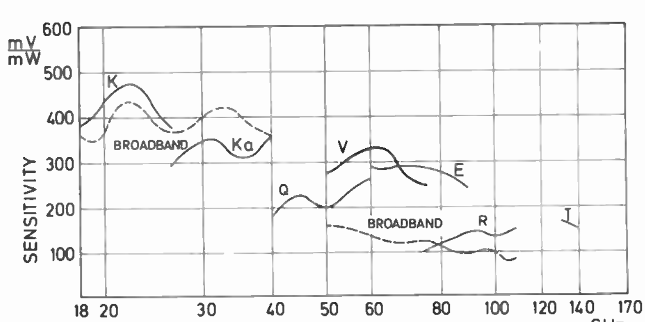

Fig. 7. Sensitivity of fin-line detectors for different waveguide bands.

different waveguide bands between 18 and 170 GHz. Minimum sensitivity ranges from 400 to 100 mV/mW (Fig. 7), and excellent broadband behaviour could be achieved. Units with bandwidths of more than an octave have been built, the flatness being below ±1 dB over one or two entire waveguide bands. The transfer characteristics (voltage output versus input power) are shown in Fig. 8 for 35, 90 and 132 GHz respectively; good square law dependence can be seen.

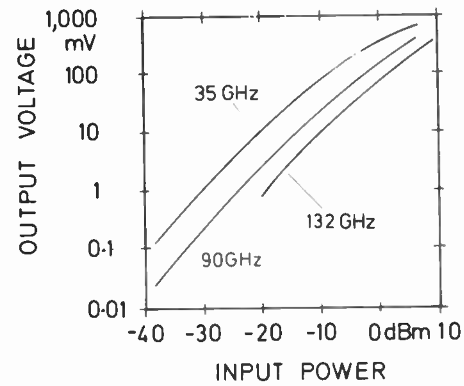

Fig. 8. Transfer characteristics of different fin-line detectors.

4 Directional Couplers

The design of more complex mm-wave systems, e.g. coherent pulse Doppler radars or monopulse radars, has the need for directional couplers. Therefore fin-line couplers, employing two coupled slots, have been investigated. High coupling factors up to cross-over operation can be achieved. Figure 9 shows the measured coupling factor of a directional two-slot coupler at 40 GHz as a function of the slot distance *s*. In Fig. 10, the transmission between the input and the direct, the coupled and the decoupled port as well as the input reflection coefficient of a 3 dB Ka-band fin-line coupler are plotted.

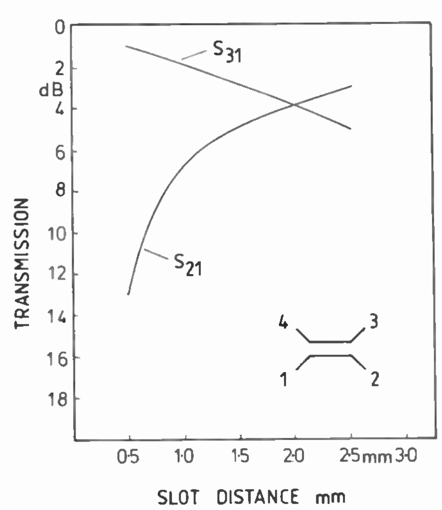

Fig. 9. Coupling factors of a directional fin-line coupler at 40 GHz as a function of slot distance.

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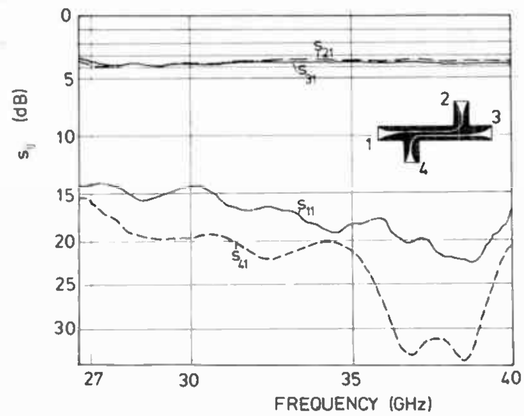


Fig. 10. *S*-parameters of a 3 dB-directional fin-line coupler at Ka-band (26·5–40 GHz).

5 Mixers

Different approaches to the design of a balanced mixer have been reported recently.[10-12] Figure 11 shows the layout of a balanced fin-line mixer. The local-oscillator power is fed to the beam-lead mixer diodes via a transition from an asymmetrical fin-line to a coplanar line, whereas for the signal port a unilateral fin-line is chosen. In this way, a frequency independent 180° hybrid is formed which gives the basis for wideband operation. A microstrip low-pass filter connects the mixer with the i.f. output.

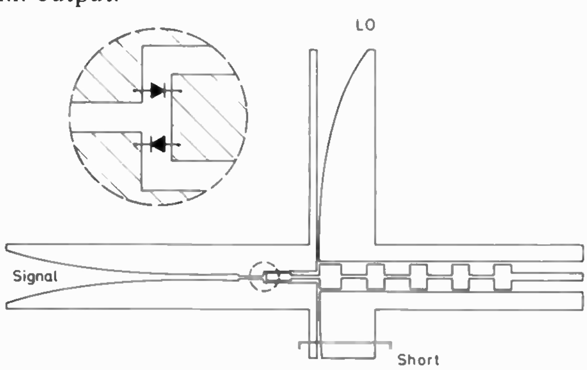


Fig. 11. Basic set-up of a balanced fin-line mixer.

The transition from fin-line to coplanar line works in a similar way to that of a common 'probe-type' transition from waveguide to coaxial line. For proper operation, a short is placed a quarter wavelength away from the transition. Quarter-wave transformers provide a suitable impedance match for the diodes.

Figure 12 shows the conversion loss of such a mixer from 18 to 40 GHz. The l.o. was fixed at 29 GHz. The ripple between 20 and 27 GHz is due to a provisional transition from K-band waveguide to the mixer itself. In this case, the i.f. is limited to 9 GHz because the i.f. signal interferes with the waveguide-fin structure due to the low cut-off frequency of the fin-line. For high intermediate frequencies, the waveguide dimensions in the region of the mixer have to be reduced.

Figure 13 gives results of a mixer optimized for 38 GHz (F_{LO} = 38 GHz). A minimum conversion loss of 5 dB is achieved; this value, however is achieved only for narrow-band operation due to the diode parasitics.

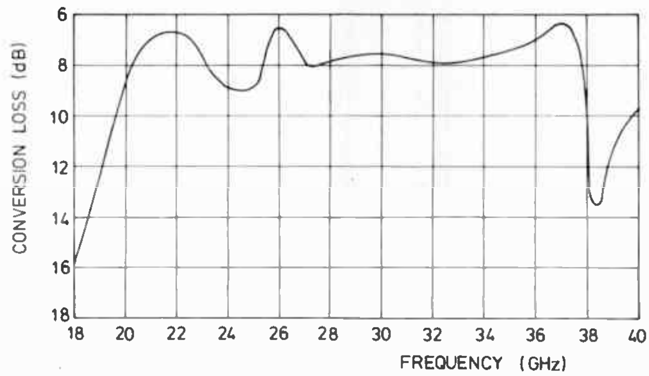


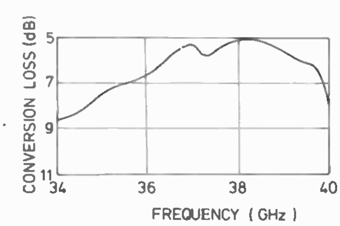
Fig. 12. Conversion loss of an octave bandwidth fin-line balanced mixer for a fixed frequency local oscillator at 29 GHz.

The d.s.b. system noise figure of the mixer lies between 6 and 7 dB, including an i.f. noise figure between 1·6 and 2·6 dB.

L.o.-to-signal isolation is greater than 30 dB for a matched pair of diodes.

In the same technique, a mixer for 60 GHz has been built giving a conversion loss between 6·5 and 8 dB.

Fig. 13. Conversion loss of a fin-line balanced mixer optimized for 38 GHz utilization.



6 Integrated Receiver Front-end

One goal of the fin-line technique is the integration of different components into subsystems. Figure 14 shows the basic layout of a completely integrated Ka-band (26·5–40 GHz) receiver front-end in fin-line technique.[13] The receiver consists of a Gunn oscillator, a balanced

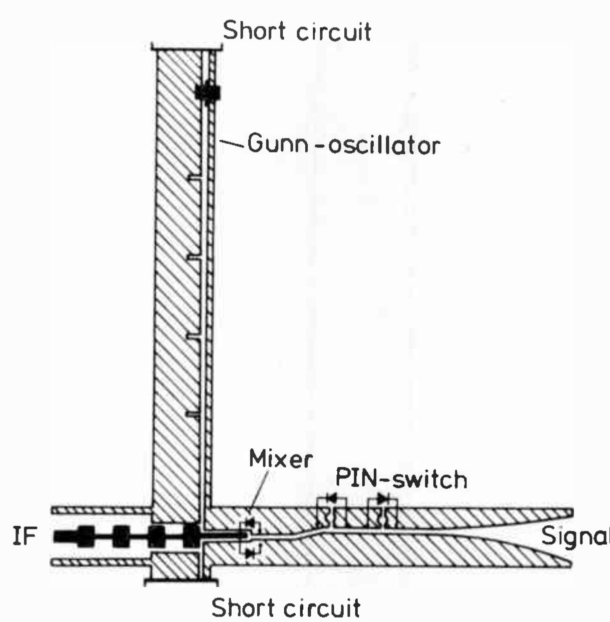


Fig. 14. Basic set-up of an integrated Ka-band (26·5–40 GHz) receiver front-end.

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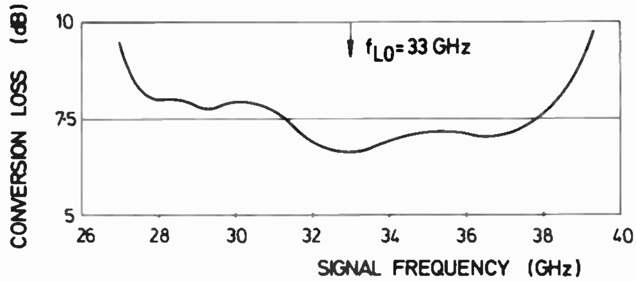

Fig. 15. Conversion loss of the integrated Ka-band (26·5–40 GHz) receiver front-end.

mixer, a p-i-n-diode switch and a low-pass i.f. filter. A taper from fin-line to waveguide enables the connection to an external circuit (e.g. antenna).

The Gunn oscillator consists of a Gunn diode mounted in the broad wall of the waveguide and an asymmetric fin-line with a periodic grating which determines the frequency of operation and the impedance match of the Gunn diode.[14] A short circuit terminates the oscillator at the rear, allowing a final frequency adjustment.

The mixer corresponds to that of Section 5 of this paper, and the p-i-n-switch to that of Section 2. The p-i-n-switch is inserted between signal port and mixer input and serves as a sensitivity time control in radar applications or as a simplified noise reference in radiometer applications.

The conversion loss of the receiver (including p-i-n-switch) amounts to 6·5 to 8 dB between 28 and 38 GHz (see Fig. 15) for f_{LO} = 33 GHz, and a d.s.b. system noise figure between 6·5 and 7 dB (i.f. noise figure 1·6 to 2·6 dB) was found.

7 Conclusion

The components presented in this paper employ fin-line technique, which demonstrates its feasibility for integration. Complete modules or sub-assemblies can be realized on one substrate, e.g. a Doppler radar module or, as presented, a complete mm-wave front-end. In addition, this technology is easy and inexpensive to fabricate. It is believed that this technology will be widely employed for applications up to 100 GHz; in some cases even above.

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13 Menzel, W., Callsen, H., Adelseck, B. and Sicking, F., 'An integrated Ka-band receiver front-end', 11th European Microwave Conference, pp. 361–4, Amsterdam 1981.

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Conferences, Courses and Exhibitions, 1982-83

The date and page references in italics at the end of an item are to issues of *The Radio and Electronic Engineer (REE)* or *The Electronics Engineer (EE)* in which fuller notices have been published.
The symbol ★ indicates that the IERE has organized the event.
The symbol ● indicates that the IERE is a participating body.
An asterisk * indicates a new item or information which has been amended since the previous issue.

Further information should be obtained from the addresses given.

JANUARY

Computers *19th to 22nd January*
The Which Computer Show, to be held at the National Exhibition Centre, Birmingham. Information: Clapp & Poliak Europe Ltd, 232 Acton Lane, London W4 5DL (Tel. 01-747 3131)

Microelectronica *27th to 29th January*
Second Annual European Microelectronics Congress produced by Golden Gate Enterprises will be held at the Philips Centrum in Eindhoven, The Netherlands. Information: Microelectronica, P.O. Box 482, Los Altos, California 94022 (Tel. (415) 979-6920)

FEBRUARY

Assemblies *2nd to 4th February*
Electronic OEM Assemblies 82—an exhibition organized by Trident International Exhibitions, is to be held at the Royal Horticultural Halls, Elverton Street, Westminster. Information: Trident International Exhibitions, 21 Plymouth Road, Tavistock, Devon PL19 8AU (Tel. (0822) 4671)

Data Communications *9th February*
A one day Symposium entitled "A Better Way to Communicate?—Methods of Data Communication in the 1980's" organized by the NCUF and the IEE, to be held at the IEE, Savoy Place, London WC2. Information: Eric Howe, Chairman, NCUF, c/o The National Computing Centre Ltd, Oxford Road, Manchester M1 7ED (Tel. (061)228 6333.

Solid State *10th to 12th February*
International Solid State Circuits conference, organized by the IEEE, to be held at the Hilton Hotel, San Francisco, California. Information: Lewis Winner, 301 Almeria Avenue, Coral Gables, FL 33134 USA. (Tel (305) 466-8193).

***Sound '82** *23rd to 25th February*
Annual three day exhibition of professional public address, sound reinforcement and communications equipment organized by the Association of Sound and Communications Engineers, to be held at the Cunard International Hotel, London W6. Information: ASCE, 4 Snitterfield Farm, Grays Park Road, Stoke Poges SL2 4HX. (Tel. 0753-39455)

MARCH

★ Fibre Optics *1st and 2nd March*
First IERE International Conference on Fibre Optics, its technological progress and future applications in Defence, Industry, Commerce and Marine Engineering. To be held at the I. Mar. E. Conference Centre, London. Information: Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ (Tel. 01-388 3071).

Electrex '82 *1st to 5th March*
Eleventh International Electrotechnical Exhibition, sponsored by the Association of Supervisory & Executive Engineers (ASEE) will be held at the National Exhibition Centre, Birmingham. Information: Electrex '82 Wix Hill House, West Horsley, Surrey KT24 6DZ (Tel. (0483) 222888)

PEP 82 *2nd to 6th March*
The 2nd International Production Engineering and Productivity Exhibition, sponsored by the Gauge and Toolmakers' Association and the Institution of Production Engineers, to be held at Olympia, London. Information: Clapp & Poliak Europe Ltd, 232 Acton Lane, London W4 5DL (Tel. 01-995 4806)

Manufacturing *2nd to 6th March*
Second International Conference on Manufacturing Matters, organized by the Institution of Production Engineers, to be held during the International Production Engineering & Productivity Exhibition at Olympia, London. Information: The Manager, Conferences & Exhibitions, The Institution of Production Engineers, 66 Little Ealing Lane, London W5 4XX (Tel. 01-579 9411)

● Digital Communications *9th to 11th March*
Seventh International Zurich Seminar on Digital Communications, organized by the IEEE Switzerland Section with the association of IEEE Societies and EUREL, to be held at the Swiss Federal Institute of Technology with the theme 'Man-machine interaction.' Information: Secretariat 82 IZS, Miss M. Frey, EAE, Siemens-Albis AG, CH-8047, Switzerland.

MT '82 *15th to 18th March*
Materials and Testing Exhibition, to be held at the National Exhibition Centre, Birmingham. Information: John Payne, Hampton Mill, Evesham, Worcestershire

***Computers** *16th to 18th March*
The Scottish Computer Show, will be held in the Albany Hotel, Glasgow. Information: Beverley Dellow, Couchmead Ltd, 42 Great Windmill Street, London W1V 7PA. (Tel. 01-437 4187)

APRIL

Control Systems in Medicine *5th to 7th April*
Meeting on Control Systems, Concepts and Approaches in Clinical Medicine, organized by the Institute of Measurement and Control, to be held at the University of Sussex, Brighton. Information: Mr M. J. Yates, Deputy Secretary, Institute of Measurement and Control, 20 Peel Street, London W8 7PD (Tel. 01-727 0083/5)

Electronics *19th to 21st April*
The All-Electronics/ECIF Show, sponsored by the Electronic Components Industry Federation, to be held at the Barbican Centre, City of London. Information: 34–36 High Street, Saffron Walden, Essex CB10 1EP (Tel. 0799 22612 Telex: 81653).

★ Recording *20th to 23rd April*
Fourth International Conference on Video and Data Recording, organized by the IERE with the association of AES, IEE, IEEE, IoP, RTS and SMPTE, to be held at the University of Southampton Information: Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ (Tel. 01-388 3071) *EE, 18th June, p. 2.*

●Communications '82 *20th to 23rd April*
Conference organized by the IEE in association with the IEEE and the IERE, to be held at the National Exhibition Centre, Birmingham. Information: IEE Conference Department, Savoy Place, London WC2R 0BL (Tel. 01-836 2441).

Sound Systems *29th April to 30th May*
Third National Sound and Electronic Systems Conference, organized by the Electronic Industry Show Corporation, to be held in New Orleans. Information: David L. Fisher, 222 S. Riverside Plaza, Suite 1606 Chicago, Ill. 60606, USA (Tel. (312) 648-1140).

***●Acoustics** *29th to 30th April*
International conference on Spectral Analysis and its use in Underwater Acoustics, organized by the Underwater Acoustics Group of the Institute of Acoustics in association with the IEE, IERE, IMC, IMA, ASA and the IEEE to be held at Imperial College, London. Information: Dr T. S. Durrani, Department of Electronic Science & Telecommunications, University of Strathclyde, Royal College, 204 George Street, Glasgow G1 1WX. *(Papers by 18th February 1982)*

MAY

Acoustics, Speech & Signal Processing *3rd to 5th May*
International Conference on Acoustics, Speech & Signal Processing, sponsored by the IEEE, to be held in Paris. Information: Prof. Claude Gueguen, Département Systemes et Communications, Ecole Nationale Superieure des Telecommunications, 46 Rue Barrault, 75634 Paris, Cedex 13 France.

***Insulation** *10th to 13th May*
Fourth International Conference organized by British Electrical & Allied Manufacturers Association in association with the EEA to be held at the Brighton Metro pole Hotel. Information: BEAMA Publicity Department, 8 Leicester Street, London WC2H 7BN. (Tel. 01-437 0678)

Security Technology *12th to 14th May*
1982 Carnahan Conference on Security Technology sponsored by the University of Kentucky, IEEE (Lexington Section and AESS) to be held at Carnahan House, University of Kentucky, Lexington, USA. Information: Sue McWain, Conference Coordinator, Office of Continuing Education, College of Engineering, University of Kentucky, 533S. Limestone Street, Lexington, Kentucky 40506. (Tel. (606) 257-3971). *(Papers by 10th February 1982)*

Multiple Valued Logic *25th to 27th May*
12th International Symposium on Multiple valued logic sponsored by the IEEE Computer Society, to be held in Paris. Information: Michel Israel, Symposium Chairman, IIE-CNAM, 292 Rue Saint Martin, 75141, Paris Cedex 03, France (Tel. 271 24 14 ext. 511)

Electro *25th to 27th May*
Conference and Exhibition organized by the IEEE, to be held at the Boston Sheraton Hotel, Hynes Auditorium, Boston, Mass. Information: Dale Litherland, Electronic Conventions Inc. 999 N. Sepulveda Blvd., El Segundo, CA 90245 (Tel. (213) 772-2965).

Consumer Electronics *30th May to 2nd June*
Consumer Electronics Trade Exhibition sponsored by BREMA together with ICEA and RBA, to be held at Earls Court, London. Information: Montbuild Ltd. 11 Manchester Square, London W1M 5AB (Tel. 01 486 1951)

JUNE

SCOTELEX '82 *8th to 10th June*
The 13th Annual Scottish Electronics Exhibition and Convention, organized by the Institution of Electronics, to be held at the Royal Highland Exhibition Hall, Ingliston, Edinburgh. Information: Institution of Electronics, 659 Oldham Road, Rochdale, Lancs. OL16 4PE (Tel. (0706) 43661).

● Reliability *14th to 18th June*
The fifth European Conference on Electrotechnics, EUROCON '82, sponsored by EUREL, to be held in Copenhagen. Information: Conference Office, (DIEU), Technical University of Denmark, Bldg. 208, DK-2800, Lyngby, Denmark (Tel. 45 (0) 882300)

Fisheries Acoustics *21st to 24th June*
Symposium on Fisheries Acoustics organized by the International Council for the Exploration of the Sea with the collaboration of the United Nations Food and Agriculture Organization, to be held in Bergen, Norway. Information: General Secretary, ICES, 2-4 Palaegade, 1261 Copenhagen K, Denmark
(Papers by 31st March 1982)

★ Microelectronics *29th June to 1st July*
Conference on The Influence of Microelectronics on Measurements, Instruments and Transducer Design organized by the IERE in association with the IEE, IEEE,

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IProdE, IOP, IMC, IQA and BES, to be held at the University of Manchester Institute of Science and Technology. Information: Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ (Tel. 01-388 3071)
(Papers by 31st January 1982)

JULY

Simulation *19th to 21st July*
1982 Summer Computer Simulation conference will be held at the Marriott-City Centre, Denver, Colorado. Information: Lawrence Sashkin, 1982 SCSC Program Director, The Aerospace Corporation, P.O. Box 92957, Los Angeles, California 90009. (Tel. (213) 648-5934)
(Papers by 15th March 1982)

Control *19th to 21st July*
Conference on Applications of Adaptive and Multivariable Control, sponsored by the IEEE in association with the University of Hull, to be held at the University of Hull. Information: G. E. Taylor, University of Hull, Dept. of Electronic Engineering, Hull (Tel. (0482) 46311 Ext 7113).

● **Image Processing** *26th to 28th July*
Conference on Electronic Image Processing, organized by the IEE in association with the IEEE and the IERE, to be held at the University of York. Information: IEE Conference Secretariat, Savoy Place, London WC2R 0BL (Tel. 01-836 2441).

SEPTEMBER

ICCC '82 *7th to 10th September*
Sixth International Conference on Computer Communication, sponsored by the International Council for Computer Communication, to be held at the Barbican Centre, London. ICCC '82 PO Box 23, Northwood Hills HA6 1TT, Middlesex.

***Wescon '83** *14th to 16th September*
Show and Convention to be held at the Anaheim Convention Centre and Anaheim Marriott, Anaheim, California. Information: Robert Myers, Electronic Conventions Inc. 999 North Sepulveda Boulevard, El Segundo CA 90245.

● **Broadcasting** *18th to 21st September*
The ninth International Broadcasting Convention, IBC '82, organized by the IEE, and EEA with the association of IERE, IEEE, RTS and SMPTE, will be held at the Metropole Conference and Exhibition Centre, Brighton. Information: IEE, 2 Savoy Place, London WC2R 0BL (Tel. 01-836 2441)

★ **Electromagnetic Compatibility** *20th to 22nd September*
Third conference on Electromagnetic Compatibility, organized by the IERE with the association of the IEE, IEEE, IQE and RAeS, to be held at the University of Surrey, Guildford. Information: Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ (Tel. 01-388 3071)
(Papers by 1st February 1982)

Man-Machine Systems *27th to 29th September*
Conference on Analysis, Design and Evaluation of Man-Machine Systems sponsored by IFAC in association with the IFIP/IFORS/IEA, to be held in Baden-Baden, Federal Republic of Germany. Information: VDI/VDE-Gessellschaft, Mess-und Regelungstechnik, Postfach 1139, D-4000 Dusseldorf 1. (Tel. (0211) 6214215)

OCTOBER

Defendory Expo '82 *11th to 15th October*
The 4th Exhibition for Defence Systems and Equipment for Land, Sea & Air, organized by the Institute of Industrial Exhibitions in association with the Defence Industries Directorate of The Hellenic Ministry of National Defence to be held in Athens, Greece. Information: Mrs Duda Carr, Westbourne Marketing Services, Crown House, Morden, Surrey SM4 5EB (Tel. 01-540 1101)

● **RADAR '82** *18th to 20th October*
International Conference on Radar, organized by the IEE in association with the IEEE EUREL, IERE, IMA, RAeS and RIN, to be held at the Royal Borough of Kensington and Chelsea Town Hall, Hornton Street, London W8. Information: IEE Conference Department, Savoy Place, London WC2R 0BL. (Tel. 01-836 2441)
(Abstracts by 29th January; Papers by 31st May)

● **Military Microwaves '82** *19th to 22nd October*
Third International Conference and Exhibition organized by Microwave Exhibitions and Publishers, to be held at The Cunard International Hotel. Information: Military Microwaves '82 Conference, Temple House, 36 High Street, Sevenoaks, Kent TN13 1 JG

Pattern Recognition *19th to 22nd October*
Sixth International Conference on Pattern Recognition, sponsored by the IEEE in association with the IAPR and DAGM, to be held at the Technical University of Munich. Information: Harry Hayman, P.O. Box 369, Silver Spring, MD 20901 (Tel. (301) 589-3386).

Broadcasting *19th to 21st October*
Conference on Broadcasting Satellite Systems organized by the VDE(NTG) with the association of the specialized groups of the DGLR and the IRT. Information: Herrn Dipl. Ing. Walter Stosser, AEG-Telefunken, Gerberstrasse 33, 7150 Backnang *(Abstracts by 22nd February, Papers by 28th June)*

NOVEMBER

Electronica '82 *9th to 13th November*
The 10th International Trade Fair for Components and Sub-Assemblies in Electronics, organized by the Munich Trade Fair Corporation, to be held at the Munich Trade Fair Center. Information: Postfach 12 10 09, D-8000, Munchen 12 (Tel. (089) 51 07-1)

DECEMBER

***Mesucora '82** *6th to 11th December*
Eighth International Exhibition, organized by the French Physical Society, to be held in Paris in the Exhibition Hall of the Porte de Versailles. Information: SEPIC-MESUCORA – 40, rue du Colisee, 75381 Paris Cedex 08 (Tel. 359.10.30)

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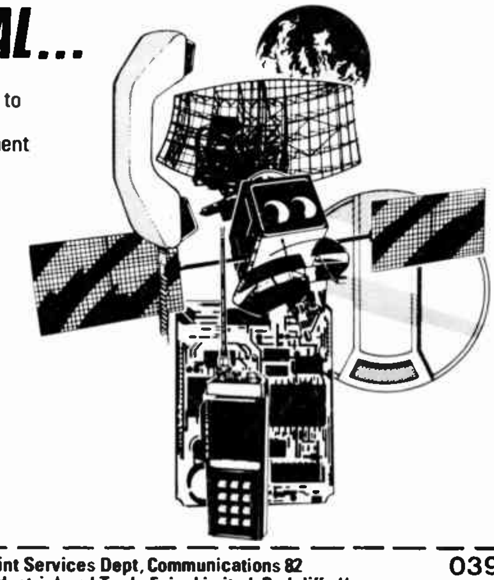

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