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The Radio and Electronic Engineer

Journal of the Institution of Electronic and Radio Engineers

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TOM McCANN and **DAVID FINDLAY** (Genrad)

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D. F. BOND (Formerly Wayne Kerr)

The complexity of present day electronic systems calls for increased technical knowledge on the part of all involved. This paper considers in particular the needs of technicians involved in the stages from research through production to service. The complementary role of the technical college is emphasized.

Radar Engineering

Principles of independent receivers for use with co-operative radar transmitters **93**

J. G. SCHOENENBERGER and **J. R. FORREST** (University College London)

Bistatic and multistatic radar systems are shown to have certain operational advantages and the paper describes the various techniques for achieving synchronization reference signals and for computing target range and learning information in real-time.

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Volume 52 No. 2 February 1982

The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

The Engineering Profession Surveyed

EVERY two years since 1966 the Council of Engineering Institutions has made a survey of the engineering profession, setting out its vital statistics such as income, qualifications, field of work, location, trade union membership and a number of other factors. The range of questions asked has expanded over the years and the eight surveys provide a fascinating view of the profession of chartered engineers.

The 1981 Survey,* published at the end of November, was based on some 18,600 questionnaires returned by Chartered Engineers and 2,124 by Technician Engineers (from a 1 in 6 random sample), completed in both cases between May and September. It suffers in its aim of providing the usual comprehensive cross-sectional report of our profession by the refusal of three institutions (IEE, I Prod E and I Mun E) to distribute questionnaires to their members because of a group of questions which asked for opinions rather than for factual information. These questions were therefore not analysed for the published survey but, more important, the absence of, potentially, several thousand sets of answers from the main part of the survey makes some deductions and comparisons difficult.

Nevertheless it is clear that in the last two years salaries in the engineering profession have no more than kept pace with those in other industries. By 1979, salaries in the industry had declined some 25% relative to other industries in the UK since 1966. The Chairman of the Steering Committee for the Survey, Mr. Bryan Hildrew (Chairman of CEI for 1981) suggests that in the present recession it is unlikely that either the public or the private sector will move to rectify this steady decline in real income. The apparent reluctance of some young people to train for the engineering profession may well be influenced by the limited reward and thus the technology base which is fundamental to the health of the nation will continue to deteriorate until this inequity is rectified.

Study of the forty-odd tables in the Survey reveals interesting and, sometimes, thought-provoking statistics. The remuneration of engineers in the manufacturing industries continues generally to be lower than for those in those industries which are of a 'service' nature. The categories with which the majority of electronic and radio engineers will be concerned are 'Electronic or telecomms apparatus', 'Computer technology' and 'Postal services, telecomms, broadcasting': the median annual incomes are, respectively, £10,100, £11,200 and £13,228. (A similar order of figures was noted two years ago.) Interestingly, the average ages for these three industries are respectively 45, 40 and 46 years. Technician engineers in these industries receive £8,500, £9,265 and £10,700 with average ages of 43, 39 and 42.

Specific overall figures of salaries for members of the IERE itself are not included in the Survey as published. However, referring to trade union membership, for the 21·1% of IERE members in the private sector who are in a union, the average income is £10,518 which is about £600 higher than the average for this category of all Chartered Engineers (£9,938), while for the 71·6% of those in the public sector who belong to a union the income of £11,738 is just greater than the average of £11,471 for all Chartered Engineers. The proportion of IERE members in unions is within a few percentage points of the average for all Chartered Engineers. The table for methods of determining salary shows that those IERE members in both public and private sectors whose salaries are determined by collective bargaining are some £500–£600 above the average for all Chartered Engineers; those members depending on 'personal representation' or 'periodic adjustment by employer' do appreciably less well than the average engineer by between £600 and £1,300. An odd consequence of this is that the minority of IERE members who have to rely on 'personal representation' are apparently still several hundred pounds better off than their colleagues! The age related remuneration table shows that IERE members under 35 receive salaries significantly above the average (£1,200 for those under 30 and £400 between 30–34), but their elders, according to the present Survey, are still paid about £1,000–£1,500 below the average.

Continuing to note the earnings related tables of the Survey, the 'Qualifications by Institution' statistics indicate that, while the 47% of IERE members who are non-graduates are at £10,942 nearly £700 below the average for non-graduate Chartered Engineers, a graduate IERE member (41%) is on £11,268 compared with £10,946, while the 12% of post-graduates earn £11,751 compared with £12,622. The IERE still has an appreciably larger proportion of non-graduates than the average Institution (23%) and its proportion of post-graduates is below the 19% for all Institutions.

Turning now to the details across the board, the contractual working week has moved appreciably towards lower hours: 44·1% of the Chartered Engineers group and 45·4% of Technician Engineers now enjoy a basic working week of less than 37½ hours compared with 17·9% and 20·2% respectively in 1979 while, looking at all of the questionnaires returned, it

* 'The 1981 Survey of Professional Engineers'. Council of Engineering Institutions, 2 Little Smith Street, London SW1P 3DL. Price £10

seems that 35·5% of engineers in the private sector work an average week of 37½ or more hours compared with 25·8% in the public sector. The information given in the Survey shows that shorter contractual and average working weeks have led to little change in the pattern of overtime working by Chartered Engineers. The number reported as working no overtime has increased from 26·7% in 1979 to 31·7% this year while a further 22·1% indicated that they worked seven and a half or more hours overtime each week compared with 24·5% in 1979. Overtime worked by Technician Engineers has, however, dropped to an appreciably greater extent. Chartered Engineers cease to be paid overtime when their salary is in the region of £10,250; there is no such clearly defined level for Technician Engineers.

In the current economic climate there will obviously be interest in the statistics on Unemployment in the Survey. The percentage of Chartered Engineers who had been unemployed at some time during the year has risen from 2·2% in 1979 to 2·9% in 1981. Just a half of the sample were only unemployed short-term (1–8 weeks) whilst the numbers experiencing long-term unemployment (over 20 weeks) have, rather surprisingly, fallen from 26·4% to 19·2%. This may be explained by increasing numbers accepting early retirement.

As far as conditions of employment are concerned, annual leave has been analysed by class of employment and it is apparent that whilst the private sector is less generous than the public sector, 96% of all engineers now enjoy four weeks or more annual leave. The number of Chartered and Technician Engineers in the public sector not in a pension scheme is now extremely low (~1% compared with 9% two years ago), whilst in the private sector the figures show only minor reductions—to about 8% from 10%. There would also appear to be a steady reduction in retirement age—probably an accelerating feature in the present recession.

Whilst the proportion of engineers undertaking further full-time or part-time training has fallen dramatically compared with earlier surveys, a considerable proportion have taken short courses, i.e. less than 40 hours tuition in total. Apart from 'Foreign Languages', the short courses far outnumber full and part-time courses. The numbers undertaking courses in 'Safety' are available for the first time and here again the 'Short Course' predominates. About 20% have had some training in this important area.

The Survey contains much detailed information on the fields of work (i.e. industry), class of employment (public or private sector etc.), current occupations (job area), and location of employment. An interesting deduction made in the review section of the Survey relates to the number of Chartered Engineers working in Design which shows that overall the downward trend has continued. It may be that the development of Computer Aided Design is steadily reducing the numbers of those directly involved in this occupation but it still remains the occupation with the lowest age group and the lowest salaries.

Simultaneously with the publication of the Survey, the organization which conducted it for CEI, Remuneration Economics, published their 'Salary Survey of Engineering Functions'*. This is intended primarily for those responsible for deciding how much they should pay their engineer employees and it takes into account such factors as sales turnover of the company, number of employees, the industry concerned, the function of the employee, area of work (broadly speaking, the discipline involved), geographical location, age and qualifications and various fringe benefits. Against these categories are given the upper and lower quartile, median and average salaries, as well as number in sample, average age and average length of service, for the whole range of zones of responsibility. These are: Engineering Director, Divisional Manager, Head of Function, Section Manager, Principal Engineer, Senior Engineer, Engineer, Junior Engineer.

This Survey, which was compiled with reference to 1st July 1981, was based on questionnaires to managements of over 100 industrial companies and organizations who were asked to give information against criteria established by R E in consultation with other organizations including CEI. Its applicability to engineers' salaries may be gained from the following quotation from its Foreword:

'Questions are frequently raised, invariably with some degree of scepticism, concerning the general level of pay for professional engineers. Are current structures compatible with the specialized training undertaken and the skills acquired? Is the pay sufficiently competitive with the alternative professions to attract a full share of able individuals capable of attaining high levels of creative skills? The suggestion inherent in these questions is that they are not.'

In expanding on the last sentence, R E compare salaries paid at the various levels in the Engineering, Personnel and Financial hierarchies, for national samples and based on their own similar surveys. If one looks at the top position and the lowest positions in each hierarchy, the following comparisons emerge—in each instance average salaries are shown, together with average age indicated in brackets.

Engineering Director £22826 (49)	Personnel Director £24265 (45)	Financial Director £27618 (47)
Engineers £8026 (37)	Personnel Officer (Senior) £9053 (38)	Senior Accountant £9312 (37)
Engineers (Junior) £6788 (28)	Personnel Officer (Junior) £6885 (30)	Accountant (Junior) £7775 (32)

The two Surveys cannot easily be used to compare particular data as the original bases are different—rather they can be regarded as complementary guides to the remuneration of engineers.

With the points which have been brought out in this article in mind, and in particular the comparative table just given, the last word can be given to Mr. Hildrew, who ended his review of the CEI Survey thus:

'Our country is now facing major changes in the techniques of design and production. The Council of Engineering Institutions through the Engineering Registration Board has over the past 15 years endeavoured to ensure that the education and training of Chartered and Technician Engineers would enable the profession to meet such changes. The newly formed Engineering Council will undoubtedly strive further to improve the quality of the professional engineer and thus ensure the future health of our industries and of our country. In parallel it will be necessary to ensure an adequate reward in order to attract and exploit the potential of the profession for the benefit of the nation.'

F.W.S.

* 'Salary Survey of Engineering Functions, Autumn 1981'. Remuneration Economics Ltd, 51 Portland Road, Kingston-upon-Thames, Surrey KT1 2SH. Price £60

ANNOUNCEMENTS

New Specialized Group on Information Technology

Members will be interested to learn that the Council has decided, on the advice of the Professional Activities Committee, to form a new group to further the development of computer science within the Institution. The Computer Group and the Microprocessor Group have been disbanded and merged into a new group which has the title of 'Information Technology Group'.

Its areas of interest are to be as follows:

- The architecture of computer, microprocessor and other intelligent systems;
- Equipment technology;
- Program technology;
- Software engineering;
- Distributed systems;
- Dispersed information processing: networking;
- Information security;
- Design automation of computer electronic systems;
- Appropriate applications.

The first Chairman of the Information Technology Group Committee is Professor K. G. Nichols (Fellow) of the University of Southampton and twelve members, most of whom were previously on the disbanded committees, have agreed to serve.

'John Betts' Research Studentship

Many members, particularly those having links with the University of Southampton or who are concerned with communications systems will have learned with sorrow of the recent tragic death in a motor car accident of Professor J. A. Betts.

John Betts had occupied the Chair of Communications in the Department of Electronics at the University since 1976. Following his graduation from the University of Nottingham in 1955, he held several appointments in industry as well as at the Royal Naval Engineering College, Greenwich, before going to Southampton as a Lecturer in 1965. His work during the past 16 years was summed up in an obituary note in *The Times*:

'He did much to help establish the reputation that the department now enjoys and he will be sadly missed by his friends and colleagues there as well as in the profession at large. He will be remembered for his many contributions to his subject, not least for the design and development of JAGUAR, a very advanced microcomputer-controlled system for monitoring telephone-exchange traffic. This equipment has recently been installed in the university's private exchange and will also be supplied to a number of other universities.

'Recognized as an outstanding teacher of his subject, he was also author of two widely-used textbooks, "High Frequency Communications" and "Signal Processing, Modulation and Noise".

'John Betts was an eminent engineer, being one of this country's leading experts in radio communications techniques and systems, and was responsible for introducing important developments involving digital-signal processing.'

Wishing to perpetuate his name, his former colleagues have set up a Memorial Fund with which it is proposed to endow a Research Studentship. Members who wish to support the Fund are asked to send donations to Mr R. S. Broom, Department of Electronics, University of Southampton, Southampton SO9 5NH.

Membership Elections and Transfers

In the list of elections and transfers to membership approved by Council which was published in the January 1982 issue (page 13), indications showing that three of the 'Direct Elections to Member' were 'Subject to Mature Candidate Regulations' were omitted. The members (all from Great Britain and Ireland) were: TINK, Kenneth Robert (April). HUNTER, Timothy Robert (August). SHERRY, Leslie Arthur (October).

Corrections

The following corrections should be made in the paper 'Electric forces', published in *The Radio and Electronic Engineer*, **51**, no 2, November/December 1981.

Page 555. The second line above equation (6) *should read* 'acceleration or higher-order. . .'

Page 558, right-hand column. Line 17 *should read* '. . .equations (1) and (2). . .'

Page 559, left hand column. Line 17 *should read* '. . .$(u^2/\rho)/(1-u^2/c^2)$.'

Standard Frequency and Time Service

(Communication from the National Physical Laboratory)

Relative Phase Readings in microseconds
NPL—Station
(Readings at 1500 UT)

OCTOBER 1981	MSF 60 kHz	GBR 16 kHz	Droitwich 200 kHz*
1	−3·3	13·6	75·4
2	−3·1	13·5	75·4
3	−3·1	13·1	75·5
4	−3·3	13·6	75·6
5	−3·5	14·0	75·7
6	−3·3	13·6	75·8
7	−3·3	12·6	75·9
8	−3·5	12·8	76·0
9	−3·3	14·2	76·0
10	−3·5	12·8	76·1
11	−3·6	13·1	76·2
12	−3·7	13·6	76·3
13	−3·9	13·7	76·3
14	−4·1	12·3	76·3
15	−4·3	12·6	76·5
16	−4·5	12·1	76·5
17	−4·3	11·9	76·6
18	−4·3	11·5	76·7
19	−4·4	12·6	76·9
20	−4·3	12·0	76·9
21	−4·4	12·5	77·0
22	−4·4	14·3	77·0
23	−4·6	13·6	77·1
24	−4·6	12·3	77·1
25	−4·6	12·0	77·2
26	−4·6	12·6	77·2
27	−4·6	12·8	77·4
28	−4·8	35·0†	77·5
29	−4·8	34·8	77·5
30	−4·8	34·8	77·6
31	−5·0	34·9	77·7

Notes: (a) Relative to UTC scale (UTC_{NPL}–Station = +10 at 1500 UT, 1st January 1977.

(b) The convention followed is that a decrease in phase reading represents an increase in frequency.

(c) 1 μs represents a frequency change of 1 part in 10^{11} per day.

* It may be assumed that the satellite stations on 200 kHz at Westerglen and Burghead will follow the day to day changes in these phase values.

† A phase shift of +22 μs occurred between 0855 and 0938 UT on 28th October.

What is a Profession?

There have been many attempts to define precisely 'a profession' and its place in a democratic society. In a recent article published by Professional Administration, *Mr John Phillips, C.B.E., a former Secretary and a President of the Institute of Chartered Secretaries and Administrators, has produced a very clear definition of a profession. The permission of the Institute and* Professional Administration *to reprint part of Mr Phillips' article is gratefully acknowledged.*

What is a profession? Notoriously difficult to define, a profession nevertheless has certain clear characteristics. Professional service and responsibility is individual and personal. It calls for the application and exercise of a body of knowledge of specialized character, intellectual rather than manual. That body of knowledge, constantly being refreshed and replenished, must be capable of being learned and taught, and must therefore be normally the subject of organized systems of study and practice, and examination under the guidance and control of leading members of the profession, elected by their peers for that purpose. But perhaps the most important ingredient of a profession is the essential dedication to a code of conduct—of honourable and fair dealing with one's fellow men—that transcends the requirements of law.

The profession in our form is a peculiarly British concept. The more intimate association with mainland Europe brought about by the entry of the UK into the EEC highlighted the fact that professional bodies so long established in the UK and in effect based upon the voluntary association and self-regulation of practitioners had no real counterpart elsewhere except in those countries which had received and accepted the basic principles of English law and practice. There were and are, of course, practitioners who generally derived their academic qualification from a University course and degree of high quality—and associations of practitioners voluntarily subscribing to standards of skill, practice and conduct; but this differs fundamentally from the British concept of a self-governing body of practitioners prescribing syllabuses and courses of study, holding examinations, specifying periods and standards of practice, and above all administering disciplinary provisions including the power to expel the member from the society; all this being recognized by, and supported and enforced by, the law of the land.

The question is sometimes raised as to whether an employed person can properly be regarded as a professional man—does he not owe a duty to his employer which may be in conflict with the duty that he owes—of independence and integrity—to his profession? The question is rather academic, since the overwhelming majority of professional people are in employment; and, fundamentally, there is no difference in the standard of service one owes to one 'client' (one's employer) or a plurality. The Royal Commission on Legal Services (Oct 1979 Cmnd 7648), in commenting on estimates of the numbers of barristers and solicitors in legal posts in commerce, finance and industry, said that the estimates suggested that 'there are nearly as many barristers known to be working in salaried legal posts as there are in private practice' and that 'It is in the public interest that those who are employed in a legal capacity in the national or local government service and in business should be subject to the same discipline, rules of conduct and professional standards of integrity and independence as lawyers in private practice'.

A particular aspect of the British professional body is the fact that the leading and senior professional bodies are incorporated by Royal Charter and in one or two cases by statute. This, too, gave rise to some concern and confusion in EEC circles on Britain's entry. The corporation aggregate is, of course, as well understood and accepted outside the English system of law as within it; but it is generally based on statutory provision. The chartered body in the UK owes its creation and existence not to Parliament at all but directly to the Crown acting through the Privy Council. It is a form of 'legislation' which is earlier than Parliamentary statutes and comes directly from exercise of the Royal Prerogative which, although eroded by the exercise of Parliamentary powers, still exists in this area of professional incorporation.

The 'moral' of all this is that the professional man, and not least the member of a chartered body has the opportunity and the duty to provide the highest standard of service to his fellow men in his chosen specialist field.

Involvement and Interaction: The SERC Report for 1980/81

In his Foreword to his last report* as Chairman of what was the Science Research Council and is now the Science and Engineering Research Council, Sir Geoffrey Allen, FRS, identifies the two important trends underlying most of the activities of the Council. These are: the increasing involvement of UK academic scientists and engineers in international activities, and interaction with British industry.

International activities

'The idea of going to work in a foreign laboratory has been part of the lifeblood of basic research for a century or more' Sir Geoffrey writes. International collaboration 'by circumstance and choice' is now even more important to SERC's affairs. Geographical and climatic factors have compelled UK astronomers to think internationally; sheer expense has led to European collaboration in particle physics; the UK is one of three partners in the Institut Laue-Langevin which is used by our chemists, physicists and materials technologists; while the involvement of a wider group of European partners was a key factor in planning for the UK synchrotron radiation and neutron sources.

Although Sir Geoffrey is introducing a Report which spans the financial year April 1980 to March 1981, examples of such co-operation cover a longer period. The SERC/ZWO partnership for example, was signed in June of this year and will result in the Netherlands providing 20% of the manpower and costs of construction and operation of the 4·2-metre, the 2·5-metre and the supporting 1·0-metre optical telescopes and the 15-metre radio telescope—all due to be completed on La Palma by 1986.

Sir Geoffrey emphasizes that 'the advancement of science and engineering depends on people and that the Council is very conscious of the increasing importance of involving UK workers with science and engineering in Europe and elsewhere'. Among SERC support schemes in this area, he mentions the Visiting Fellowship which 'continue to provide a

* Annual Report of the Science and Engineering Research Council 1980–81, available from Government Bookshops, price £4

flow of visitors bringing vital ideas and new techniques from overseas' and the European Short Visit Grants which give UK workers the opportunity to initiate collaboration with their European counterparts. Highlighted in his report is SERC involvement in the work of the European Science Foundation and particularly his initiative to improve scientific interactions with Japan.

Involvement with industry

Sir Geoffrey has always maintained the importance of the academic world playing a vigorous role in helping industry explore new technologies both in the training and retraining of scientists and engineers as well as through the research programmes. He describes schemes SERC has developed for stimulating research appropriate to the needs of industry and for increasing the interaction of academic engineers and scientists with the industrial world. Computer-aided engineering and satellite telecommunications are examples of the part played by SERC programme directors and co-ordinators in areas once relatively neglected by the academic world or where an immediate need for an increasing and integrated effort was identified.

'The scheme for co-operative awards in science and engineering, in which a research student is jointly supervised by an academic and an industrialist, has grown rapidly in recent years and now accounts for 30% of all research studentships awarded both in science and engineering' writes Sir Geoffrey. All CASE awards were fully taken up in 1980/81.

The fastest growing scheme is that of co-operative grants in which a research group in industry joins forces with a research group in academe in a collaborative project. This growth 'is all the more remarkable because in these times of economic difficulty industry has proved willing to shoulder its fair share of each project'. A total of £2·7M has been committed on 79 collaborative projects up to the end of the period of the Report. The number of projects now is 101 to a total value of £3·6M. The availability of finance is the only constraint on a successful scheme.

Successful though such schemes have been, Sir Geoffrey thinks more needs to be done to increase collaboration with industry and with parts of Government to make 'UK Research Ltd.' internationally more competitive. 'The special directorates' for example, 'are now at a stage where they should move further towards industrial commitment in order to release SERC money and manpower for other projects at this interface. Our schemes for the provision of highly trained manpower can only progress if industry, too, recognizes the importance of such training and provides the appropriate career opportunities. It is especially important that our current experiments in continuing education quickly turn into an effective postgraduate presence in this field. I am confident that the Council has now established the firm base for interaction between academe and industry that is essential for the future of our economy'.

EMC: ERA Reports on Radio Interference

Ten special reports on aspects of radio interference have been published by ERA Technology Ltd, the independent contract research organization. Seven of these contain an edited selection of papers issued over the last ten years to sponsors of ERA's radio interference research programme, Project 3031. The others (Numbers 80–150R to 80–152R) are based on ERA's 1980 radio interference research programme.

RADIO INTERFERENCE PROBLEMS WITH SMALL MOTORS contains 22 individual papers and covers investigations and tests carried out on commutator motors, including universal motors, permanent magnet motors and thyristor controlled motors. Investigations into the effect of brush grade, spring pressure and lubrication are included. (*Report No. 80-1R*)

RADIO INTERFERENCE MEASURING EQUIPMENT comprises 14 papers on interference measuring equipment and their characteristics. A general survey of equipment in use in the UK is given, together with specific evaluations of individual equipment. (*Report No. 80-2R*)

RADIO INTERFERENCE MEASURING TECHNIQUES examines the techniques necessary to measure radio interference. It includes some general papers on techniques for measurements in the range 30–300 MHz, and a paper on the design of an artificial mains network in the range 10 kHz–30 MHz. (*Report No. 80-3R*)

RADIO INTERFERENCE FROM SEMI-CONDUCTOR CONTROLS investigates the problems of interference generated by various types of semiconductor control used for motors, lamp dimmers and other circuits using thyristors and transistors. (*Report No. 80-4R*)

RADIO INTERFERENCE FROM MOTOR VEHICLE IGNITION SYSTEMS contains seven papers on the problems of radio interference generated by the ignition system of a motor vehicle. It includes general comments on the problem and the results of measurements made to establish the magnitude and nature of the radiation. It also gives a comparison of the performance of induction plug cap suppressors with conventional resistive suppressors. (*Report No. 80-5R*)

RADIO INTERFERENCE FILTERS AND COMPONENTS looks at the performance and effectiveness of a range of suppression components including toroidal core chokes, inductors and filters. (*Report No. 80-6R*)

RADIO INTERFERENCE FROM CONTACT DEVICES covers interference generated by thermostats and time switches and includes notes on the testing of appliances containing contact devices. (*Report No. 80-7R*)

RADIO INTERFERENCE—EQUIPMENT CONTAINING COMMUTATOR MOTORS deals with radio interference generated by universal motors, which are incorporated in a wide range of domestic appliances and industrial equipment. The investigations have concentrated on the suppression measures necessary to achieve compliance with current national and international radio interference limits by the use of both conventional and more novel techniques. (*Report No. 80-150R*)

RADIO INTERFERENCE—EQUIPMENT CONTAINING CONTACT DEVICES: Thermostats and energy regulators can produce high levels of interference particularly when they are used to control inductive loads. The interference generated by such contact devices has been examined in magnitude and characteristic nature for a number of loads, both resistive and inductive. (*Report No. 80-151R*)

RADIO INTERFERENCE—FILTERING AND SUPPRESSION TECHNIQUES: The development of optimized filter and suppression circuits, particularly for more complex equipment which can contain several different sources of noise, can be relatively unrewarding if the results of radio interference voltage measurements are not interpreted correctly. This report provides guidelines for the procedures necessary to obtain the optimum solution as rapidly as possible and offers guidance on the use of particular suppression components and their siting within the equipment for maximum effect. (*Report No. 80-152R*)

All ten reports have been compiled for members of ERA's Technical Services Scheme and, as such, are only available to members (Class A). Companies interested in joining the Scheme and receiving copies of the reports should contact Robert Stafford, Client Liaison Manager, ERA Technology Ltd, Cleeve Road, Leatherhead, Surrey KT22 7SA. Telephone: Leatherhead (03723) 74151 Ext 292.

Members' Appointments

NEW YEAR HONOURS

The Council has sent its congratulations to the following member whose name appeared in Her Majesty's New Year Honours List.

MOST EXCELLENT ORDER OF THE BRITISH EMPIRE
To be an Ordinary Officer of the Civil Division (O.B.E.)

Gerald Crofton Briggs (Graduate 1969). Mr Briggs is Sales Director of Marconi Instruments, St Albans.

CORPORATE MEMBERS

D. J. Batten (Member 1970, Graduate 1964) has taken up an appointment as Engineering Manager with Powernetics in Loughborough. Since 1966 he had been a Senior Development Engineer with Thorn Automation, Rugeley.

Cdr S. M. Bruce, RN (Member 1969, Graduate 1963), after gaining promotion in June, has graduated from the RAF Staff College and has now taken up an appointment at the Admiralty Surface Weapons Establishment, Portsdown.

S. J. Fox, B.Sc. (Member 1981, Graduate 1975), Instrument Engineer for the UK with Horizon Exploration International since 1977, has been appointed Senior Electronic Engineer, Australia, for the Company and is now based in Perth.

M. H. W. Gall, M.A. (Fellow 1971) who was formerly Managing Director and more recently consultant to H. Tinsley & Co, has taken up an appointment as Managing Director of Precision Varionics, Cheltenham. He is a member of the Measurements and Instruments Group Committee.

A. Gothard (Member 1975, Graduate 1971) who was a Senior Lecturer in Electronics at Riversdale College of Technology, Liverpool, is now Principal Lecturer for Staff Development at Stoke-on-Trent College.

Wg Cdr M. J. Gregory, M.A., M.Sc., RAF (Member 1969) has completed a tour of duty in the Ministry of Defence Procurement Executive and has been posted to HQ RAF Support Command, Brampton, in connection with test equipment maintenance.

R. W. Knowles (Member 1973) who has been 1st Engineer (Telecomms) with the Central Electricity Generating Board, has been promoted to Senior Engineer (Telephony and Data), Telecomms Project Team in the Transmission and Technical Services Division.

Professor D. W. Lewin, D.Sc. (Fellow 1974, Member 1960, Graduate 1957) has been appointed first holder of the Anglia Television Chair in Electronics at the University of East Anglia; since 1974 he has been Head of the Department of Electrical Engineering and Electronics at Brunel University. Prof Lewin is a past member of IERE Council, Papers Committee and Computer Group Committee and he is also a member of the National Electronics Council and of the Electrical and Systems Engineering Committee of SERC. He is author of several books on computers and has contributed numerous papers to the Journal.

T. Lomas, E.R.D. (Member 1963) has been appointed Deputy Director of Major Systems Procurement, British Telecom. For the past four years he has been Deputy Controller of Contracts.

A. J. Lowne, B.Sc. (Member 1976) who has been a Senior Scientist with Kodak Research Laboratories in Harrow, has transferred to Eastman Kodak Research Laboratories, Rochester, New York, as a Research Physicist to work on the design of the Ektachem blood analysis instrumentation.

R. G. White (Member 1975, Graduate 1970) who has been with the International Harvester Company since 1978, has been promoted to the new post of Manager, European Telecommunications and will be based in Doncaster. Since 1980 he has been Manager Telecommunications of IHGB.

Sqn Ldr R. L. Wilson, RAF (Member 1973, Graduate 1969) has been posted to HQ Strike Command to join the TACEVAL Team. For the past three years he was the Senior Engineering Officer on No 92(F) Squadron at RAF Wildenrath.

NON-CORPORATE MEMBERS

P. M. St. J. Cambell-Carr (Associate Member 1981) has taken up an appointment as Sales Engineer with E.B. Horsman & Son in Vancouver. Since 1974 he has been a Test Engineer with Fa. Willy Vogel AG, Berlin.

J. Netherton (Associate Member 1972) who has been with Cable & Wireless since 1969, latterly as Engineer in Charge of the Microwave/Coaxial Station in Tortola, has taken up an appointment as Station Engineer based in Riyadh and is assigned to the company's communications project with the Saudi National Guard.

B. Watt, B.Sc. (Associate Member 1980) has been promoted to P&TO II and is now a Project Officer in the Ministry of Defence, Procurement Executive, concerned with procurement of new radar and spares to support existing radar.

Airborne Radar Remote Sensing Experiment

A specialized computer system designed by System Designers Ltd sponsored by the Department of Industry and located at the Royal Aircraft Establishment, Farnborough, has produced the first digitally processed radar images as part of an international remote sensing experiment using airborne radar. The Department's National Maritime Institute is undertaking an assessment of this type of radar picture for marine traffic monitoring in the Dover Straits.

The remote sensing experiments involve some 100 research institutes throughout Europe collecting radar imagery for the detection, mapping and monitoring of features related to resource and environment problems on land and at sea. The experiment has been jointly organized by the European Space Agency and the Joint Research Centre of the EEC. It is centred on the Convair 580 aircraft owned by the Canadian Centre for Remote Sensing and based at the Royal Aircraft Establishment, Bedford.

The aircraft used in the project has a detection system consisting of a unique three-frequency radar to provide high resolution radar imagery of the synthetic aperture type. The data produced by the radar is then processed by the Department of Industry's specialized computer system.

During June and July data have been collected over some 40 land and sea test areas all over Europe – from Greenland to Southern Spain. Studies will include mapping of sea-ice and icebergs, classification of agriculture field types, investigation of a proposed motorway, research into geological mapping and mineral prospecting and the effects of pollution both on forests and in the Mediterranean Sea. The analysis and evaluation of remotely sensed radar data is expected to contribute to the planning and preparation of the European Space Agency's ERS-1 satellite which will carry a similar type of radar system.

The radar system makes the following information available: a 'quick-look' image immediately after the flight, a specially processed image that can be used for photo-interpretation and digital tapes so that data can be analysed using a computer. Before the data is ready for interpretation a series of rather complex pre-processing procedures must be followed.

This work will be done at the Royal Aircraft Establishment, Farnborough in the UK and at other technical centres in Germany, Canada and USA.

Obituary

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

William Norman Bruce (Fellow 1949, Member 1944) died on 1st October 1981 aged 73, as the result of a motoring accident.

Born in Edinburgh, Norman Bruce was educated at George Watsons Boy's College and received his education at Caledonian Wireless College and at Heriot Watt College, Edinburgh.

From 1931 to 1933 he ran his own wireless retail and repair shop and then in 1933, he was appointed Officer-in-Charge of Police Wireless, Edinburgh—he continued with this Force until his retirement in 1961 with the rank of Chief Inspector. For much of this period he was Technical Adviser to the Scottish Home Department on wireless matters and on retirement he took up an appointment as Communications Officer with the Department.

In his capacity as Officer-in-Charge of Police Communications, Norman Bruce was responsible for the introduction of mobile m.f. transmitters in the 1930s and later on the introduction of a local v.h.f. scheme on 80 and 128 MHz. He designed and tested a new system of radio control for unattended relay stations.

His duties as Technical Adviser to the Home Department involved co-ordination of police, fire, ambulance and civil defence schemes and when he became Communications Officer at the Home Department this called for a full-time job with the responsibility for the whole of Scotland. He retired from the Home Department in 1974 with the title of Chief Adviser on Radio Communication to the Secretary of State for Scotland. He was awarded the British Empire Medal in the New Year Honours List for 1949.

Norman Bruce served on the Scottish Section Committee, of which he was a founder member, for many years. His service included two years as Chairman (1952–54) and three years as Vice Chairman (1949–52), and at the time of his death, although he had retired seven years ago, he was still an active serving member on the Committee. His colleagues on the Committee and members of the Section will sadly miss his genial presence and sound guidance.

Arthur George Hacker (Fellow 1970) of Maidenhead, died on 30th September 1981, aged 71.

Arthur Hacker and his brother Ronald were well known in the British domestic radio and television receiver manufacturing industry, having founded their own company, Dynatron Radio, in 1927 which had a reputation both before and after the war for high quality equipment. During the war, the firm produced radar equipment and afterwards, in addition to domestic equipment, made electronic equipment for the UK Atomic Energy Authority. During this time Arthur Hacker was Joint Managing Director and Technical Director. In 1959 the company was bought by E.K. Cole and five years later Arthur Hacker and his brother left to re-start an existing small company, Hacker Radio which continued the manufacturing policy of the original Dynatron Radio. In 1973 it was awarded a Royal Warrant for the supply of radio gramophones and receivers to Her Majesty The Queen and another in 1976 for Her Majesty The Queen Mother. Following the oil crisis however, and the impact of increased VAT, the company encountered serious cash flow problems and was taken over. Mr Hacker and his brother remained with the company until 1978 in order to protect the interests of long serving staff and he then retired.

Hubert Kenneth Hadley (Member 1966, Graduate 1963), of Nuneaton, died on 25th August 1981, aged 60. He joined the British Thomson Houston Company as an electrical tester in 1940. He remained with the company until 1959, ultimately becoming engineer responsible for tenders and contracts for electrical equipment for steel works. In 1959 he entered technical education as a Lecturer in Electrical and Electronic Engineering at Nuneaton Technical College.

Lieutenant Commander David Robert Gordon Johnson, RN (Rtd) (Member 1948, Associate 1947, Student 1944) of Beccles, died on 25th August 1981, aged 61. After leaving school in Norwich, Cdr Johnson served an electrical engineer apprenticeship with Laurence, Scott and Electromotors. In 1944 he entered the Royal Navy as an Electrical Officer. For most of his service career he was concerned with air radio, radar and electrics and his appointments included that of Senior Electrical Officer at the Royal Naval Air Station at Lee-on-Solent.

Oswald Bainbridge Kellett, M.B.E. (Fellow 1938, Member 1931), of Newcastle-upon-Tyne, died on 17th July 1981, aged 75. After some years with the radio industry in the Manchester area, Mr Kellett joined the staff of the Manchester Police Regional Wireless Station in 1936 as an Engineer. In 1939 he moved to what subsequently became the Home Office Directorate of Telecommunications and he served at various regional wireless stations throughout the country before being appointed Regional Wireless Engineer in charge of the Home Office Wireless Department at Marley Hill, Co. Durham in 1945. He was made an M.B.E. in 1969 and retired in 1972.

Mr Kellett served on the Committee of the North Eastern Section of the Institution for nearly 25 years and for several years was Honorary Treasurer.

Erik Johan Arthur Larsen Kongshaug (Member 1953, Associate 1957) of Oslo died during summer of 1981, aged 79. Mr Kongshaug was, before his retirement, Director of the Norwegian radio manufacturing company of Arktik.

James Lyons (Graduate 1963) of Lisburn, Co. Antrim, died during the summer of 1981, aged 51. Mr Lyons was formerly with the Civil Aviation Authority.

Frederick Bernard Salt (Member 1941) of Hinwil, Switzerland, died recently, aged 75. Before his retirement through ill-health some twenty years ago, Mr Salt was concerned with the cinema industry in South East England.

Henry James Shaw (Member 1961) of Carshalton, died on 22nd June 1981 after a long illness, aged 72. Henry Shaw joined the General Electric Company in 1929 as an Assistant in the Technical Sales Office of the Radio Service Department which dealt with a wide range of radio communication and sound equipment installations. After the war, Mr Shaw was in charge of the Technical Sales Department and during this period he served on trade association and BSI committees. In 1961, on the re-organization of GEC, Mr Shaw went to New Electronic Products as Laboratory Administrator and Works Manager. Soon afterwards, the company was taken over by Honeywell Controls and for the next ten years he was with the company's medical division as Contracts Engineer. From 1972 till 1975, when he suffered a series of severe strokes, Mr Shaw was with Medisco, a company formed by a group of former colleagues to carry on work started at Honeywell who had discontinued this activity. His work involved the engineering aspects and consultancy in connection with medical electronic equipment.

Alfred Laurence Spring (Associate 1949, Student 1941) of Ickenham, died last summer, aged 69. Mr Spring entered the radio industry in 1930. He served in the Royal Ordnance Corps during the war and on demobilisation returned to work for Radio Rentals where he was Assistant Divisional Controller.

Peter John Welton (Member 1980, Graduate 1968, Student 1964) of Willoughby, N.S.W., died during last summer, aged 35. Mr Welton received his technical education initially at Norwood Technical College, obtaining the Diploma in Telecommunication and Electronic Engineering, and later at the University of Wales Institute of Science and Technology where he obtained an M.Sc. degree in electronics. For the next three years he was an electronics engineering consultant with P.A. Management Consultants, Cambridge.

In 1973, Mr Welton took up an appointment as a teacher of electronics at North Sydney Technical College, New South Wales. In 1978 he was appointed a Lecturer in Electrical Engineering at Darling Downs Institute of Advanced Education, Toowoomba, Queensland, the post he held at the time of his death.

Alfred Walter Ray Woods (Member 1946) of Johannesburg, died in July 1981, aged 65. Born and educated in South Africa, Mr Woods joined the South African Broadcasting Corporation in 1937. After five years service as a Wireless Operator/Air Gunner in the South African Air Force, he returned to the Corporation in 1945 where he continued until his retirement in 1977.

Mr Woods was a founder member of the South African Section and served as a member of its Committee for more than twenty five years; for seven years he was Chairman of the Section.

Europe's Space Programme

While the United States and the Soviet Union still lead the world in space technology, other countries, especially Japan and certain European countries (notably France, Germany and Britain), have developed space programmes, particularly exploiting satellites for scientific research and telecommunications.

The European Community has no space programme as such, but eight of its member states are members of the European Space Agency (ESA). Furthermore, the European Community's research and development programme has closely followed and exploited Earth research aspects of space exploration.

Europe's latest space achievement, the successful launching in June 1981 of the ESA's third *Ariane* rocket from the French launch pad in Kourou in Guinea, carried the second *Meteosat* satellite, which should provide information about the Earth's weather for the nations of Western Europe.

The EEC and space research

Through arrangements with NASA (the US National Aeronautics and Space Administration) the EEC has made use of American satellite data to measure agricultural conditions in Europe, and plans to make increasing use of Europe's own satellites (of which over 30 have been placed in orbit since 1960) and tracking stations to expand this programme into such areas as natural resource detection, diagnosis and forecasting of agricultural problems, and the instantaneous detection of pollution.

An 'own initiative' report by the European Parliament's Energy and Research Committee on European Space Policy gives a résumé of Europe's space achievements and calls for the development of a 'great design', 'which will enable Europe to maintain its future presence in space and consolidate its competitiveness in world markets'.

The European Space Agency (ESA)

Of ESA's total membership of 11 states, eight are also members of the EEC (Luxembourg and Greece are not members). ESA's three other member states are Switzerland, Spain and Sweden. In addition, Austria and Canada are associate members and Norway is an observer.

ESA, whose headquarters are in Paris, was founded in May 1975 to coordinate the activities of Europe's two previous space institutions: The European Space Research Organisation (ESRO) which was concerned mainly with satellite programmes, and the European Launcher Development Organisation (ELDO) whose purpose was to develop a European launch vehicle.

According to ESA's charter, its prime purpose is to 'provide for and promote, for exclusively peaceful purposes, cooperation among European states in space research and technology, with a view to their use for scientific purposes and for operational space applications systems'. ESA's activities can broadly be divided into two categories:

Compulsory programmes These are mainly 'scientific' programmes which are financed (along with the general budget) by contributions from the member states calculated as a percentage of their GNP and decided upon by the Council on the principle of one country, one vote. Contracts are distributed on the basis of the 'fair return' rule with a minimum of 80%.

Optional programmes These are financed by contributions decided upon by the member states and the most important so far have been *Ariane* and *Spacelab*, which accounted for 27% and 24% of the total budget for 1980.

Thus the breakdown of national contributions to ESA's total budget varies enormously from member to member. For instance in 1980 it was as follows: France 29%, Germany 22%, UK 11%, Italy 9%, Netherlands and Belgium 3% each, Switzerland, Sweden and Spain 2% each, Denmark 1% and Ireland, Norway, Austria and Canada 1% between them. The remaining 15% came from 'other income'.

ESA's greatest achievement has undoubtedly been the development of the *Ariane* programme and *Spacelab*.

Ariane

Ariane's development as Europe's foremost launch craft was spearheaded by the French government which has paid some 63% of *Ariane's* total budget which is administered by ESA. A consortium, known as Arianespace, of some 50 aerospace companies from the ESA member states which hold two-thirds of the shares with the French national space agency, CNES, holding the rest, has now been established to produce and sell *Ariane's* services. Countries with satellite ambitions but no launcher will be able to 'book a place' on an *Ariane* launch which at between £13M and £25M a time will provide a lucrative source of income for the consortium. As an example, *Ariane III* launched an experimental communications craft built by the Indian Space Research Organisation.

Spacelab

Spacelab is Europe's biggest space project after the *Ariane* launcher. It is a re-usable cargo bay, designed to fly aboard the American Space Shuttle Orbiter, and consists of three basic parts:

- a pressurized cabin module within which scientists may conduct their experiments.
- a non-pressurized instrument platform or pallet (made by British Aerospace) where telescopes, sensors and experimental devices can have free access to the view and vacuum of space.
- a tunnel that provides systems and human access from the lab module to the cabin of the Orbiter.

The module and pallet sections are made up of segments that may be added or subtracted according to the needs of a particular mission which gives the project its main attractions of versatility and each part being re-usable, economy.

The prime contractor for the lab's construction is VFW-Fokker/ERNO, the German aerospace company. Over 30 other European firms have, however, contributed subsystems or parts.

European national programmes

While ESA's role in space activities is mainly in the field of research and development, national aerospace industries in Europe continue to pursue their own programmes, either independently or in cooperation with those industries of other EEC member states or elsewhere. Under the *Galileo* programme for instance, Germany is cooperating with the US in the exploration of Jupiter, while France is involved in an extensive programme with the USSR which includes the exploration of Venus, a space probe to study Halley's Comet, and medicine and material physics programme in *Salyut* stations. The UK is also cooperating with the US in the field of X-ray astronomy.

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Videotex display technology:
the immediate past and the likely future

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This paper reviews, on a world-wide basis, recent developments in Videotex display technology. Three possible paths for future development are identified. These are a merger with word processing, a merger with computer graphics and a merger with digital television techniques. The writer tentatively suggests that the last is most likely.

1 Introduction

It is now six years since British Telecom Research Laboratories (BTRL)—then the Post Office Research Department—brought Videotex display technology into the world with the publication of Fedida's original paper on Viewdata. The world's reaction was at first a little varied. The television industry, who were already preparing to move into the digital era by incorporating broadcast Teletext circuits into their receivers, saw it as an opportunity to enter the potentially lucrative business and computing markets and reacted enthusiastically. The computer community were somewhat uninterested, and saw little new in what they regarded as a cut-price display connected to a down-market time-sharing system. The communication authorities of the world were startled. They recognized at once the potential of the new technique but were bemused by a number of radical innovations that distinguished viewdata from their existing services.

In the following years this range of reactions crystallized into an almost world-wide enthusiasm. Viewdata was implemented in the United Kingdom under the trade name of Prestel and was exported to Germany, Holland, Austria, Switzerland, Italy and Hong Kong, while competing videotex systems emerged in France, Canada and Japan. This competition manifested itself both commercially and in the international standards forums where it took the form of rivalry in display technologies. In the writer's view this total emphasis on display technology is wrongly placed since the major problems, real costs, and main profit opportunities are to be found in the operation of the data-base and its associated computer software. However, display technology is important because of its impact at the man-machine interface and because, as videotex salesmen say, 'the systems sell themselves at the screen'. With these points in mind, this paper will outline the recent history of videotex display technology and will offer some informed conjecture on its likely future. (Readers not already familiar with the terms should note that Teletext is a broadcast data service, but Teletex is the new CCITT standardized message service.)

2 The Display of Text

The first information to be displayed was based on the Roman alphabet and Arabic numbers without provision for accented characters or diacritical signs. The original viewdata experiments used ASCII because of the availability of small-scale integrated circuits for character generation. When UK viewdata merged with broadcast Teletext a slightly different code set known as an application-oriented version from standard ISO 646 was implemented. This standard deserves more than passing mention because of its inadequacies. It contains several options with ambiguous wording to guide the system designer on their modes of use. In the writer's view the international strife that followed can be blamed to a degree on these ambiguities.

An early task for the international standardization committees was to define a method of providing characters with accents and diacritical signs. One method is to utilize the so-called 'national variant' codes in the ISO 646 code table, but the provision of a large repertoire requires a more sophisticated technique. The first problem is to decide on the range of characters to be provided. The initial assumption was that the major purpose of defining a polyglot standard was to facilitate working across national boundaries. More recently the requirements of multi-lingual communities and minority groups have been quoted as a major factor in the determination of the character set. The problem here is the utter diversity of the languages involved. If it were desirable, or politically possible, to limit the scope to 'indigenous' minority languages (Welsh, Gaelic, Friesian etc) the problem would be severe but manageable, but immigration has given rise to language combinations such as English/Urdu and Swedish/Greek which are truly formidable in terms of the character combinations that they produce.

If one limits the problem in the first instance to Roman-based languages, two methods of code extension for special characters were proposed. One was the direct method in which a second set of characters would be defined to contain the accented letters and special characters. The second set would have allocated to it the same range of transmission codes that are used for the unaccented repertoire and the terminal would distinguish between the two sets by the receipt of shift characters. It was not found possible to accommodate the range of characters required even by this method and so the composite method was devised whereby a complete character (e.g. é) would be transmitted by the code sequence ⟨e⟩ ⟨backspace⟩ ⟨shift⟩ ⟨´⟩, or by a variant thereof. Within an electronic terminal the backspace character is used to form a compound character from the accent and the letter. Other alphabets such as Greek, Hebrew and Cyrillic can be accommodated by shifting into separate repertoires, but since other languages also have their equivalent of accents and breathing marks (in the case of Greek up to four per letter) the problems have not yet been completely solved to the satisfaction of all the linguists concerned.

The Viewdata transmission codes are shown in Table 1. In addition to letters and numbers, other characters ranging from music symbols to mathematical signs have also been requested. The best current reference for videotex character repertoires is standard CCITT S.100.

All early videotex character generation used a predefined repertoire stored in read only memory (r.o.m.) in the terminal. A major advance was made by Sargent who suggested the concept of dynamically redefinable character sets (d.r.c.s.) as

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0033–7722/82/020059+08 $1.50/0

Table 1
Viewdata transmission codes

bits	$b_7b_6b_5b_4b_3b_2b_1$	Row \ Col	0	1	2	2a	3	3a	3b	4	4b	5	5b	6	6a	7	7a
	b_7		0	0	0		0			1		1		1		1	
	b_6		0	0	1		1			0		0		1		1	
	b_5		0	1	0		1			0		1		0		1	
	0 0 0 0	0	NUL	DLE	Sp		0			@		P		—		p	
	0 0 0 1	1	SOH	Cursor On DC1	!		1		Set Verify Mode(1)	A	Alpha^n Red	Q	Graphics Red	a		q	
	0 0 1 0	2	STX	DC2	"		2		Set Verify (2)	B	Alpha^n Green	R	Graphics Green	b		r	
	0 0 1 1	3	ETX	DC3	£		3		Set Verify (3)	C	Alpha^n Yellow	S	Graphics Yellow	c		s	
	0 1 0 0	4	EOT	Cursor Off DC4	$		4		Set Programme Mode	D	Alpha^n Blue	T	Graphics Blue	d		t	
	0 1 0 1	5	ENQ	NAK	%		5		Tape Pause on Playback	E	Alpha^n Magenta	U	Graphics Magenta	e		u	
	0 1 1 0	6	ACK	SYN	&		6		Tape Start	F	Alpha^n Cyan	V	Graphics Cyan	f		v	
	0 1 1 1	7	BEL	ETB	'		7		Tape Stop	G	Alpha^n White	W	Graphics White	g		w	
	1 0 0 0	8	Cursor ← BS	CAN	(		8			H	Flash	X	Conseal Display	h		x	
	1 0 0 1	9	Cursor → HT	EM	)		9			I	Steady	Y	Contig Graphics	i		y	
	1 0 1 0	(A) 10	Cursor ↓ LF	SUB	*		:			J	End Edit	Z	Separated Graphics	j		z	
	1 0 1 1	(B) 11	Cursor ↑ VT	ESC	+		;			K	Start Edit	←		k		¼	
	1 1 0 0	(C) 12	Cursor Home & Clear FF	SS2	,		<			L	Normal Height	½	Black Background	l		‖	
	1 1 0 1	(D) 13	Cursor ← CR	SS3	—		=			M	Double Height	→	New Background	m		¾	
	1 1 1 0	(E) 14	SO	Cursor RS Home	.		>			N		↑	Hold Graphics	n		÷	
	1 1 1 1	(F) 15	SI	US	/		?			O		#	Release Graphics	o		▮	

applied to Videotex. Chambers had previously pioneered the concept in broadcast Teletext. In addition to the r.o.m. for the basic character set a random access memory (r.a.m.) is provided in the character generator. The bit patterns defining any set of characters can be loaded into this r.a.m. from the videotex computer and can then be used as many times as required. This technique provides a very economic way of obtaining a wide range of characters. Its prime use will probably be textual extension but it can also be used for the extension of graphics.

Another concept best introduced in a discussion of text, but equally applicable to videotex graphics, is that of character attributes. Whereas most traditional v.d.u.s provided rows of similar monochrome characters, videotex is rich in colour and other visual devices. Character shapes may be in a variety of colours, referred to as the foreground colour. They sit upon individual spaces the colour of which, (i.e. the character background colour), may be varied. In turn the individual character spaces can be regarded as overlaying a colour common to the row. Row defined colours can be regarded as overlaying a whole screen background colour, normally perceived only as a border to the usable display area, but conceptually applicable to any character position for which the row and character backgrounds are not defined. Finally, the possible existence of a broadcast television picture, visible when whole screen, row and character backgrounds are not set, gives a fifth layer. For each layer of colour other 'attributes' may be added. For example, a displayed feature may be called upon to flash, it may be concealed from view pending the receipt of a 'reveal' command or it may be displayed at half intensity. (At this point it should be noted that it is desirable for videotex logic designers (usually in the semiconductor industry) occasionally to consult the e.h.t. and power circuit designers in the television industry for videotex sets have been destroyed by the unwitting invocation of a sequence of commands such as, 'set whole screen white, flash'.) A major debate has centred on how these attributes should be coded, stored in memory, and interpreted. A brief and somewhat simplified outline of this debate follows.

3 Serial Attributes

UK viewdata uses what are known as serial attributes. The attributes for any character are coded in digital form and stored in the same memory as the characters themselves. This memory is 7 bits wide (excluding parity bits) and attribute descriptions such as 'red foreground' set the display mode such that red letters are displayed until another attribute code is encountered. Since the attribute is stored in the same memory as the displayed characters, a space can appear on the screen at the point where the attribute is stored. The space need not be black because background colour can be invoked, but it is not possible to change the colour of each letter in a word without artificial spaces appearing between the letters. For the display of textual information this limitation is not serious, for there is evidence to suggest that changing the colour of each letter of a word decreases its legibility substantially. However, videotex displays are not limited to the display of textual information. They can also be used for the display of stylized pictures by utilizing the alphanumeric character spaces for the display of 2×3 element mosaic characters. When such pictures are being created the appearance of spaces in the picture becomes more serious. The difficulty can be averted by the use of a command known as 'hold graphics' which inserts into the would-be space a copy of the previously displayed mosaic character, but this technique is not elegant and poses some limitations on the pictures that can be created.

Two distinct concepts emerge from the above. The attribute, being stored in the same memory as the displayed characters, gives rise to a space and this is a disadvantage, but the fact that the attribute is applied to a series of characters is an advantage because by changing that single attribute the appearance of many displayed characters can be changed simultaneously.

4 Parallel Attributes

The second videotex system to emerge on the world scene was the French Teletel. It shares a coding scheme with French broadcast teletext called Antiope and employs parallel attribute coding. Eight additional data bits are associated with each stored character making a total of 16. Eight are used to define the character and eight for the definition of its attributes. These 16 bits are addressed simultaneously. The advantage is that the attribute definition never interferes with the display. Three disadvantages have been cited against parallel coding. The first is that the size of the memory has been doubled from 1 Kbyte to 2 Kbytes. With the gradual fall in the cost of memory this disadvantage has become less significant than it was although the current state of the videotex residential market still indicates that designers should be cautious about any costs that they add to the price of a television set. A full discussion of the second disadvantage is beyond the scope of this paper for it relates to the propagation, reception and decoding of broadcast teletext signals. The British teletext system is synchronous and has an addressing structure that has a one-to-one relationship with the sequence of horizontal synchronizing pulses in the television signal. This gives greater immunity against errors, but dictates that the number of characters associated with each broadcast television scan line should be equal to the number of display characters in a row on the screen. This restriction militates against the use of parallel attributes because the number of characters required can, and usually does, exceed the number of characters in a row. The French system is free format and can accommodate parallel attributes in a simple manner. The writer is not an expert in broadcast propagation and on this point can only advise the reader to observe the relative penetrations of the two main contending broadcast teletext systems in the international market.

If the first two criticisms cited against parallel attributes are either contentious or of diminishing importance, the third has recently received substantial impetus. This relates to the number of characters that need to be transmitted to a videotex terminal to create a picture. The problem for the parallel system arises partly from the omission, in the original designs, of the facility to change certain attributes on a serial basis and partly from artificial limitations imposed by standard ISO 2022. It is not possible in most cases to reset the 16 bits of a parallel attribute terminal character space simply by transmitting the values of those 16 bits in two consecutive 8 bit characters. The use of a number of bit combinations is prohibited because they are allocated for computer and telecommunications control purposes. This has the consequence that in many situations it is necessary to resort to the so-called 2 character and 3 character 'escape sequences' to change a single character attribute bit. These rules also apply to serial attribute terminals but they hit the parallel terminal much harder because the information content of the store is higher.

This phenomanon was first recognized in research work by Sargent, already described by the writer.[1] Figure 1 shows how the count of transmitted characters for Antiope pages can rise sharply. For those on Prestel they correspond closely to the normal distribution and cut-off at just below 1,000 characters. This work aroused little interest when it was originally published and was almost certainly regarded in many quarters

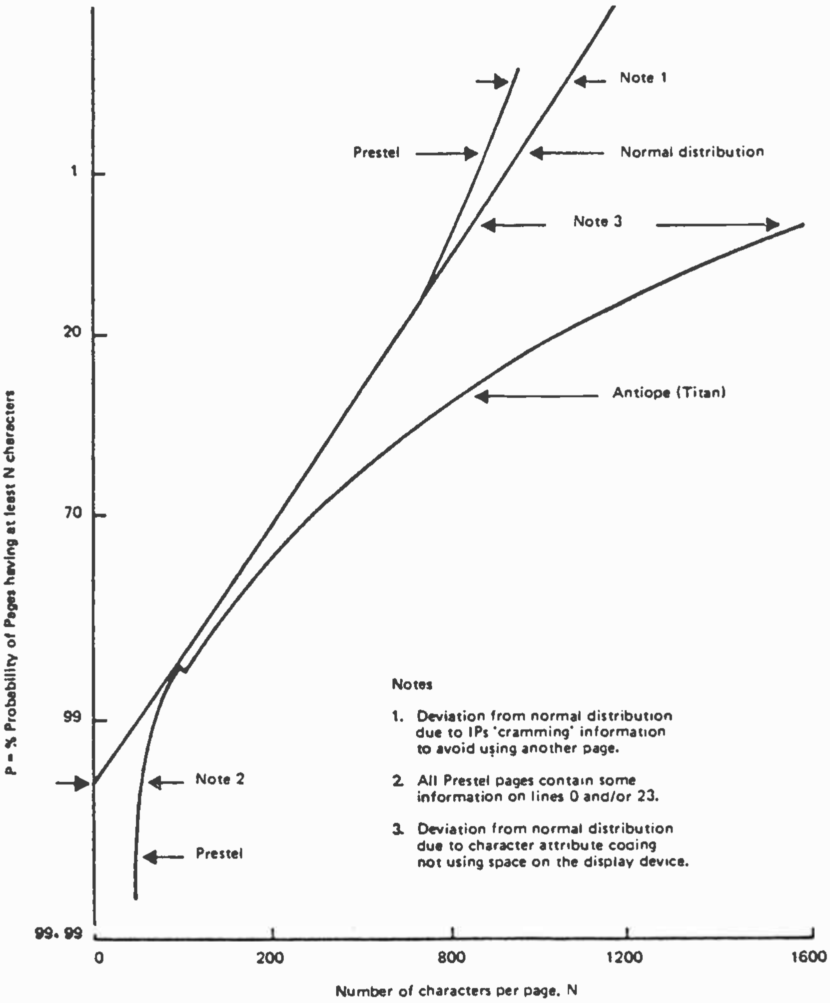

Fig. 1. Analysis of Prestel and Titan pages.

as a rather artificial piece of propaganda for Prestel, which had just started bulk production using l.s.i. The climate of this debate changed when the Bundespost in the Federal Republic of Germany began experimenting with their Gateway system. Under this scheme a customer would access Bildschirmtext (the German videotex system) in the first instance but would then be referred onwards to a third party or host computer for specialist transactions. These transactions could be highly interactive in nature. They include financial transactions performed on computers owned by banks and the telephone age equivalent of 'mail order'. The customer needs a clear visual indication of when he has completed entries in a data field correctly and the obvious way to do this is to change the background colour of the field. This brought into a sharp commercial lime-light the importance of changing attributes using a minimum number of transmitted characters. German contributions to CEPT showed that Sargent's curve for parallel attributes converged on 16 000 characters (to create a single page in the worst case). Thus the concept of serial attributes became suddenly respectable even if the space on the screen in the original British system did not.

5 Non-Spacing Serial Attributes

The UK response to these events was known as Prextend and was due to Childs[2] seeing that there was no necessary correlation between terminal internal architecture and the transmission coding scheme. Childs proposed the use of non-spacing serial attributes. His terminal would have a memory that was 16 bits wide, as in the French case, and the additional memory width would be used to ensure that the attribute controls did not interfere with the perceived display, but the attributes would be serial in their effect. Thus the space on the screen has disappeared, but the low character count has been retained. Prextend had one further characteristic of considerable commercial significance. By the judicious use of the backspace command it was possible to construct pictures that could be displayed with a high degree of acceptability on existing Prestel decoders. Downwards (or backwards) compatibility was thus obtained.

6 The European Standard

A new European videotex standard is now agreed and draws heavily on British, French and German thinking. The advent of microprocessor-controlled terminals coupled with hard work by the technical experts of CEPT have made it possible to accommodate both the British and French systems and to cater for the additional needs of the Germans. The proposed standard has considerable advantages for the United Kingdom, because we will benefit from the low-cost decoders that will result from production for the larger European market and yet our investment in Prestel will be preserved. The chief problem in defining such a coding scheme relates to the assignment of relative priorities to the serial and parallel attribute codes. This problem is not too severe when one considers static frames, in which the screen is cleared and a block of characters filling the screen from the top to bottom is transmitted leaving the cursor at the bottom of the screen. However, the data field application described above and animated frames require the movement of the cursor along complex crossing paths. This makes the definition of attributable priorities at any one character position much harder. The eventual solution, known as the time dependent model, does this by allocating priorities according to the time at which various characters were received. The method was due to the CCETT research institution at Rennes in France.

Terminal architecture is discussed above in terms of either 8 or 16 bits, but the new standard does not preclude the design of terminals with memories that are 24 bits wide, indeed there is a school of thought that maintains that 24 bits are likely to be the more common implementation. Provision is also made in the new standard for d.r.c.s. and for the production of accented characters using the composition method. The commercial importance of this European agreement cannot be overstated.

7 Alpha-geometric Coding

Under this method graphical information is encoded and transmitted in cartesian and/or conic form. For example, a circle would be transmitted by the coordinates of its centre and its radius. The technique is well known in computer graphics (see Sutherland[3]) and was introduced to videotex by the Canadians when they announced Telidon in 1979. It is usually demonstrated using 'bit plane memories' of some 40 kilobytes in which the data to be displayed over the entire area of a screen are represented on a dot by dot basis rather than being created by a character memory and character generator. Two major advantages were initially claimed for this technique. The undisputed advantage for terminals with large memories is that much finer pictures, in terms of diagonal lines and circles, can be created. It is also claimed that alpha-geometric coding has a degree of 'terminal independence' that is absent in other coding schemes. This claim is debatable, for Childs' work has shown that the terminal independence concept is equally applicable to alpha-mosaic coding schemes, although the Canadians should receive due credit for first identifying this approach to videotex coding. Apart from the cost of the memory, two problems arise with the use of alpha-geometric coding. Whereas mosaic information providers (IPs) require only an additional keyboard for use in conjunction with a videotex television receiver, alpha-geometric editors need a local dedicated computer. Apart from the adverse effect that this has on the economics of information provision, it has the undesirable effect of concentrating that activity into the hands of larger organizations and skilled operators. The second disadvantage relates to the use of microprocessors in the terminal. The software routines necessary to decode the picture description instructions can be time consuming and it is possible for the rate of transmission of data to the terminal to exceed that which it can process. This means that the terminal must have the ability to instruct the computer to stop transmitting data until it has processed that which it has already received. This gives rise to a more complex line protocol than is necessary with alpha-mosaics and the perceived picture build-up time is increased. Alpha-geometric videotex systems have been implemented by CCETT in France, by the Open University in Britain ('Cyclops') and by Finland and the IBA in Britain (on an experimental basis). The coding schemes used in each case differ slightly from those used by Telidon. An alpha-geometric system has also been adopted by the AT & T Company in the USA.

8 Photographic Techniques

Two such systems have been announced so far. These are the CAPTAINS system from Japan and Picture Prestel from the United Kingdom.[4]

The videotex situation in Japan is of considerable economic and technical interest. The basic Japanese requirement is the display of some 3000 kangi idiographic characters. This precludes the use of Western character generators and, for a nation that is dependent on the day to day use of such characters probably rules out the use of d.r.c.s. as well. Several early videotex systems emerged in Japan including one called Video Reference System and another called CIRCLE, described elsewhere by the writer.[4] More recently CAPTAINS has emerged as the main Japanese offering to the world videotex market. It is of commercial interest to note that although CAPTAINS uses picture coding techniques (which they describe as 'pattern transmission') for kangi characters, it has been designed to incorporate character generators as well because 'these are suitable for European and American countries'. Little has been published on the crucial point of data entry for CAPTAINS but it is probably done by a dedicated computer not dissimilar to that used for Telidon. The image is then scanned on a line-by-line basis and packets of data relating to the bit pattern that represents the image are transmitted to the videotex centre and stored on disk. Before it is transmitted to the terminal at either 2·4 Kbits or 3·2 Kbits per second a data compression technique known as run length conversion is applied to the data in order to minimize transmission time. It is perhaps an indication of computational problems involved that the traffic handling capacity of their computer is 70 erlangs,† which compares with the 200 erlangs on an unenhanced Prestel computer and this will have an adverse effect on the price the customer pays to use the service. The picture coding technique adopted by the Japanese also gives them a graphic capability equivalent to Telidon. Because of the need to minimize page transmission time the colours provided are limited to 8—black, blue, red, magenta, green, cyan, yellow and white. Thus CAPTAINS graphics retain a highly stylized appearance.

Work by Prestel staff in Britain had indicated that there was indeed a substantial market for pictures in the next generation of videotex provided that they were not stylized. Meanwhile, in a different branch of communications engineering, progress was being made in the coding of television pictures for applications susch as teleconferencing and surveillance. In this work an analogue signal is digitized and then subject to complex data compression algorithms. Differential pulse code modulation (d.p.c.m.) and transform coding are typical examples. The processed signal can then be stored and/or transmitted. An inverse of the appropriate processes is carried out at the terminal. The effect of this sophisticated coding is to reduce substantially the number of bits required to create high-quality pictures.

In 1979 it was observed by Fenn and Nicol[5] that falling microprocessor and storage costs had placed these techniques within the range of videotex designers. The importance of this is that still picture transmission can be used on present-day low-bandwidth videotex systems, and the same techniques can be exploited further when telephone exchanges such as System X make 64 Kbit/s switched facilities widely available to the subscriber. An experiment to exploit these techniques for videotex was commenced by the Viewdata and Visual Telecommunications Divisions of BTRL and resulted in 'Picture Prestel'.[4]

The first system was implemented using d.p.c.m. and used picture inserts covering 1/9th of the total screen. The IPs photograph is placed beneath a conventional television slide scanner and is then converted into its luminance (Y, using conventional television terminology) and two colour difference components (U and V). It may then be reduced by a digital filtering process on the television signal. D.p.c.m. is then used

† A unit of telephone traffic equivalent to a circuit fully loaded for one hour.

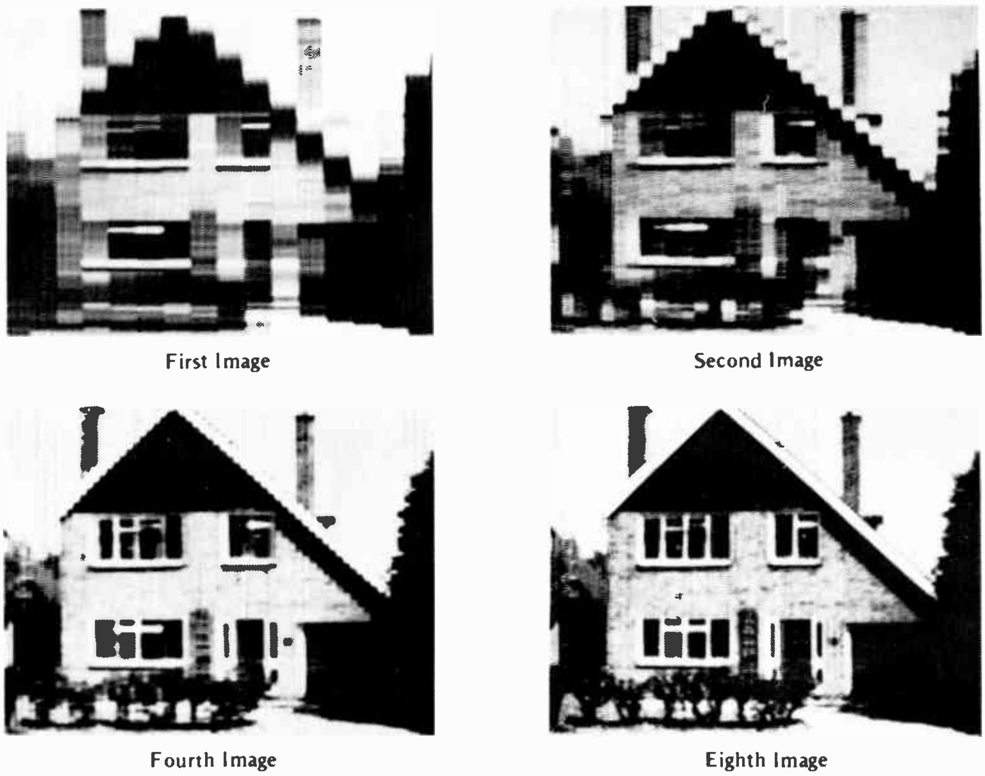

Fig. 2. Build-up of a picture using the transform coding technique.

to digitally code the luminance and chrominance components to 4 bits per sample. This achieves a data compression of 2 : 1. The luminance and chrominance signals are then multiplexed for storage at the Prestel centre and transmission to the customer's receiver. The header frame which contains the information describing the page that surrounds the picture is transmitted first. This is a conventional Prestel page except that a series of start insert codes are used to indicate the points in the line of 40 characters at which the picture insert starts. The start insert code is ESC (as taken from standard ISO 646) followed by the binary character 0/14. The picture creation process is fully automatic and no manual composition is required of the IP other than to position his picture on his page, another important advantage over all forms of stylized graphics. About 8 Prestel pages are required to contain the picture data. The computer software requires very little modification when the data pages are used for picture data. At present two speeds have been implemented for the transmission of the picture to the customer, 1·2 and 4·8 Kbit/s. 1·2 Kbit/s is the transmission speed of many videotex systems so if this speed were used no additional computer ports would be required. The picture takes about 1 minute to build up using d.p.c.m. and 1·2 Kbit/s. This is somewhat slow but could be acceptable where the customer has a definite information requirement. At 4·8 Kbit/s, which will be obtainable at reasonable cost on the existing telephone network, build up takes about 15 seconds and this is quite acceptable. The Integrated Services Digital Network (ISDN) service in the UK (based on System X) starts in 1983 and will offer 64 Kbit/s switched circuits and will thus allow the choice between build up times of about 1 second or larger pictures. (The coding technique may change for these higher speeds.)

The main components that are not found in a conventional videotex television receiver are the control card, the microprocessor and the 24 Kbyte picture store. 8 Kbytes are allocated to the chrominance and 16 Kbytes are allocated to the luminance. Using this amount of store a picture that is typically $\frac{1}{3}$ screen height and $\frac{1}{3}$ full screen width is obtained although the aspect ratio of the picture insert may be varied at the IP's discretion to permit, for example, the depiction of a tower. Furthermore, the picture display area need not be contiguous and the picture display area could be used for the display of 3 or 4 small photographs. The envelope surrounding the picture can be varied in shape giving rise to, say, L-shaped pictures although the editing techniques required in such cases are more complicated. An error concealment algorithm that is activated by looking at two parity bytes (one for luminance and one for chrominance) at the end of each television line ensures acceptable picture quality at error rates approaching 1 in 1000. 256 levels of brightness are achieved.

Complete compatibility between broadcast teletext and videotex has been maintained throughout the development of Prestel and picture coding technique can also be used for inserting pictures in broadcast teletext frames. Experiments have been carried out in conjunction with the Independent Broadcasting Authority in the United Kingdom. In broadcast mode one frame containing the start insert codes is sent. A series of following frames contains the picture data. Collaboration with the BBC whose research work has been described by Chambers[6] is also taking place.

Using d.p.c.m. the picture is built up vertically on a line by line basis. The use of transform picture coding techniques permits the rapid transmission of a low-definition image, the resolution of which is then gradually improved. This would enable the customer to reject irrelevant pictures quickly, in addition the use of transform coding will ultimately reduce the number of bits required for the transmission and storage of pictures by a factor of about 3. 1/9th area Prestel pictures could then be stored in 2 or 3 conventional Prestel pages. Figure 2 illustrates the picture creation using transform coding. This technique has been demonstrated by BTRL, and produces a very attractive effect.[7]

9 Applications of Picture Prestel

9.1 Mail Order

The first announcement of videotex aroused considerable interest from mail order companies who were disappointed to find that it did not permit them to cease or reduce the publication of their printed catalogues. Useful cost savings could be achieved by using the videotex response pages for ordering but the customer would still require a catalogue to examine pictures of the products. This led to the investigation of other methods for reproducing the pictures on the screen, and to propositions for hybrid schemes using video disk. A complex and rather expensive terminal would contain a television set with videotex facilities and a video disk unit. The mail order company would despatch a video disk containing the picture data to be mounted on the video disk unit. Indexing information would be held on the videotex data bank and would be used to access the required picture information from the disk via purpose-built logic. The ordering process could then be executed using videotex response frames. Such solutions are ingenious and may indeed by cheaper than printed catalogues but the production and distribution of the disks could not be carried out very frequently. Picture Prestel overcomes this difficulty and enables the picture information to be inserted and altered at a central location, thus giving the IP the same flexibility of use that he has with other forms of videotex data. Figure 3 shows an example of this application.

9.2 General Advertising and Product Pictures

The advertising of consumer and industrial products of all kinds will be enhanced substantially by the addition of pictures. This is true of both videotex and broadcast teletext. This applies not only to goods, it is equally applicable to the advertisement of services such as restaurants, plays and the cinema (where the display of photographs outside the premises is an old tradition). In view of the interest in Prestel by the travel trade the display of hotel and resort pictures for the sale of holidays is likely to be of particular importance. The display of house and commercial property pictures by estate agents has already aroused interest in the UK.

9.3 The Display of Portraits

Several possible applications are apparent. Many managers maintain photographic files of their staff and the automation of this data would be convenient. Computer dating is a flourishing industry and has found it profitable to distribute videotapes to customers. In the field of social welfare, adoption prospects are increased by the use of photographs. We are already witnessing the use of videotex for general journalistic purposes and the insertion of a small photograph of the author could play an important part in convincing the customer that the copy has been originated by a human rather than a computer.

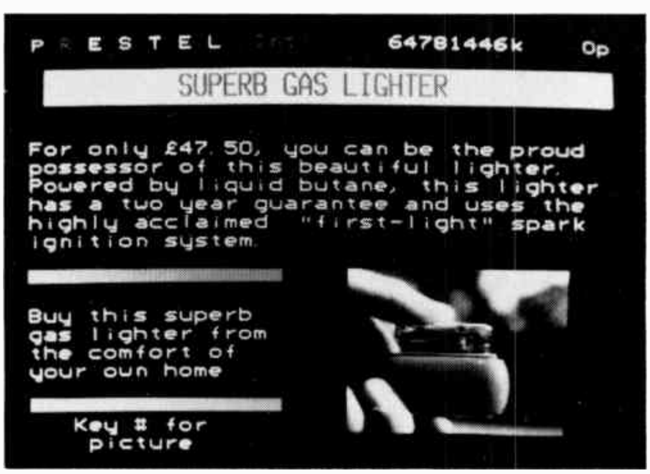

Fig. 3. Example of 'Picture Prestel'.

9.4 Signature Verification and Security Applications

Picture Prestel can be used to display the signatures of, say, credit card holders and this could be associated with a photograph of the card holder. A powerful aid to security is thus achieved.

9.5 Education

Both specialist educational pages and the more general videotex encyclopedia would be enhanced by the provision of photographic pictures.

9.6 Business Information

Picture Prestel can be used for the display of graphs and pie charts, an application area often quoted as requiring alpha-geometric coding.

10 Some Conjecture on the Future

When considering the future of videotex display technology the writer has in mind a sequence similar to Fig. 4. Videotex as we know it today can proceed in a number of directions and each direction has associated with it a school of technical and academic thought advocating that course. Three of these steps may be seen as going forward and one, slightly provocatively, can be depicted as going backwards.

11 Compatibility with Existing Terminals

Let us consider the 'backwards step' first. The argument runs as follows. The main component of a videotex system is not its display technology at all, but its database. In the introductory paragraph of this paper the writer gave some recognition to this point, but it is given an even greater weight by one body of opinion, concentrated largely in the traditional computer time-sharing market. According to this school the operators of videotex databases should do all possible to make them accessible to the large population of existing computer terminals. These consist of teletypes, 'glass teletypes' and v.d.u.s in many forms. According to this argument, the videotex operators should modify their central software to accommodate this motley army. One objection to this course is that this is not easy to do, because the existing population of terminals is completely unstandardized. They differ in the number of characters per line, in their character repertoires, in the number of characters on a row, in the number of rows on a screen, and in their transmission schemes and protocols. They lack many of the features such as colour and graphics that are common to all videotex systems and have served to carry videotex from the realms of computerized information retrieval into those of electronic publishing. Moreover, the current explosive growth in the market for private videotex systems is likely to ensure that videotex terminals will predominate over all other types in the future.

12 A Merger with Teletex, Word Processing and the Electronic Office

These areas are seen by many as the next rapid growth area in computer technology and communications. If, as has occurred, the early penetration of videotex is in the business rather than

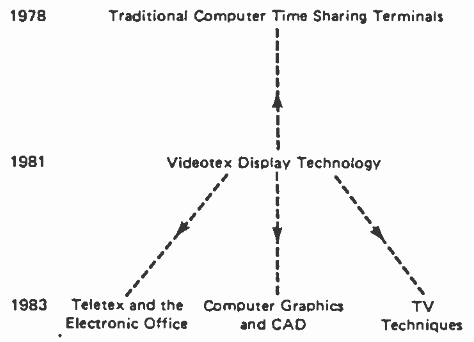

Fig. 4. Possible future development of videotex display technology.

the residential market, should not videotex be seen as tending to merge with the electronic office? Good progress has been made in defining standards for Teletex and the author has no doubt that the future will see considerable interworking between videotex and Teletex services. Since the Teletex and electronic office standards are mainly concerned with text, there is little problem here. Standards conversion could be achieved at gateways between services or even, with falling microprocessor costs, in the terminals themselves. The biggest problem is the difference between line lengths, with videotex at 40 characters and most word processing machines at 80 characters or greater. For most applications this presents few problems, although tabulated data would suffer when transferring from teletex to videotex. However, the manufacturers of office equipment have so far shown less interest in colour or graphics than videotex designers. The Prestel evidence is that these features are important in both ergonomic and commercial terms, even in the business market, and for this reason the writer sees videotex as maintaining a separate identity. The Teletex standards are designed to allow for the incorporation of signatures at the bottom of documents and of business logos at the top, on the assumption that these could be transferred by facsimile techniques. This indicates a profitable future for photographic videotex techniques in this area.

13 A Merger with Computer Graphics

This school is strong in Canada, the home of alpha-geometric coding techniques, but also finds a response amongst the traditional computer graphics fraternity and in many university departments of computing science. Without doubt alpha-geometric videotex frames are rich in graphics and they thus meet this requirement even better than mosaic systems. However, the pictures that they produce remain highly stylized and this is not what publishers want. Most books or magazines contain much text, the occasional stylized picture (usually a weather map or cartoon) but many photographs in both the advertising and editorial sections. Alpha-geometrics do not meet this need and the technical reason for employing alpha-geometrics may soon no longer apply. Alpha-geometrics are a sophisticated method of data compression reducing the number of bits that need to be stored in the computer and terminal, and transmitted on the telephone line. The development of optical disks, and of 64 Kbit/s telephone lines and the continuing fall in the cost of memory in the terminal will probably render these data compression techniques less necessary.

14 Photographic Techniques

Photographic techniques will provide publishers with the photographs that they are used to and will benefit from the technical trends mentioned above. Apart from their intrinsic technical merits these techniques will benefit commercially from the fact that the Japanese are forced to employ them for the production of their own idiographic characters and this is likely to give a major commercial impetus to this approach on the world market.

Of course this is a simplified view of the future. There is no reason why videotex technology should be homogeneous and many variants are likely to emerge. The probability is that we will see all three variants exploited to a greater or lesser degree and hybrid systems drawing on two or three of them are equally possible.

15 Second-generation Videotex in the United Kingdom

This is to be associated with the introduction of the ISDN in 1983. Discussions are currently taking place with the UK IPs and equipment manufacturers to formulate the specification exactly, but at present the following features appear probable—

- Picture Prestel, using much larger pictures than at present and quite possible extended to the full screen.
- High resolution stylized graphics. These will be provided and Prestel is studying closely developments in Europe relating to d.r.c.s. and in Canada relating to alpha-geometrics.
- A full range of accented characters by the composition method.
- Serial and parallel attributes to the new European standard.
- Data encryption, to provide greater security for the users of closed user groups.
- Prestel operating concurrently with speech on the telephone line, so that both facilities can be used at once.

16 Acknowledgments

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The views expressed on the future of videotex display technology are those of the writer and do not commit either British Telecom or Prestel to the commercial provision of the facilities mentioned.

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Microprocessor product design: the role of the development system

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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

The technical and financial success of a microprocessor based design project can be profoundly influenced by the performance of the development system. This paper reviews types of system commonly in use today, and establishes some approximate measures of performance. Then follows a review of the features and facilities which a good, stand-alone system should include, i.e. text-editor, assembler, linker, debugger, in-circuit emulation and logic analyser, including a brief discussion of different ways of implementing some of these features and the consequent impact on system performance.

Finally an attempt is made to establish criteria whereby the performance of a development system may be evaluated in terms of its intended application.

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Why use microprocessors?

The first commercially available microprocessor was introduced less than ten years ago. Today it is virtually impossible for any city dweller to go for a single day without in some way or other having dealings with a microprocessor. The self-service petrol pump, the cash registers in supermarkets, as well as traffic lights, the word-processor in the office, our washing machine and possibly even microwave oven, are all controlled by microprocessors.

All these applications have one thing in common; they are all in areas where the cost or performance of the particular equipment concerned is of prime importance. These then are the two main reasons for the rapid acceptance of microprocessors: cost and performance.

The microprocessor replaces a large number of other types of component in electronic circuits. This leads to cost savings both in direct component costs and indirectly through cheaper packaging such as smaller printed circuits, smaller enclosures and power supplies, and also via simplified product testing and repairs.

Other cost savings are possible through easy modification of product performance, and a potentially lower initial design cost because hardware designs with microprocessors are simpler and more uniform than non-microprocessor designs.

Using microprocessors also opens up tremendous possibilities in improved product performance. A reduced component count almost automatically leads to improved reliability, as there is a very strong correlation between reliability and the number of interconnections in an electronic circuit. Also, by their very nature, microprocessors can be programmed to perform 'clever' or 'intelligent' functions which are very expensive to achieve using more traditional techniques.

Designing with Microprocessors

The process of designing a microprocessor-based product differs markedly from what we are used to in traditional electronics, or indeed traditional computer applications. The electronics engineer turning to microprocessors for the first time soon discovers that the software (programming) of the microprocessor is the key to product performance, whilst the computer programmer frequently discovers that the interaction between hardware and software assumes a degree of importance far beyond anything he has ever encountered before. It is safe to say that in the near future a new kind of professional will emerge, and be recognized as such, who combines the two older disciplines. Let us call this new breed a 'microprocessor engineer'.

What steps, then, must the microprocessor engineer perform in order to design a microprocessor based product?

Product Definition

Seen in relation to conventional electronics, the product definition phase is very much the same as before, except that there is considerably more flexibility due to the programmable nature of microprocessors. For example, whilst the performance of, say, a machine controller

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made with conventional circuitry is closely defined by the details of the circuitry, and so must be fully specified at the outset, if a microprocessor is used it is possible to defer decisions about performance details to much later in the design cycle.

Trading Hardware against Software

A completely new set of decisions must however be made early in the design cycle, namely those of hardware versus software trade-offs. An example of this is a design which incorporates a numeric display. Should the display digits be multiplexed using software multiplexing to save hardware, or should the burden of controlling the display be placed on the electronics, so as to reduce programming time and make more of the microprocessor's time and memory available for more important functions?

Hardware Design

Once the hardware versus software trade-off decisions have been made, the detailed hardware design can be started. In general microprocessor-based hardware designs are all very similar: a microprocessor, some memory, address-decoders and a number of peripheral circuits for communicating with the outside world. Although the latter can vary considerably in complexity and design technique, the main core of the hardware, the microprocessor and associated circuitry, can be designed using a small repertoire of standard techniques. On a whole, then, designing the hardware will be easier and cheaper using a microprocessor.

Software Design

The ultimate performance of a microprocessor-based design is dependent on the software, or program, which instructs the microprocessor in what steps to take in order to achieve the desired result.

Software undoubtedly accounts for the major proportion of the cost of most microprocessor-based designs. This has led to a common misconception that design costs with microprocessors are therefore higher than with conventional electronics. The fact of the matter is, at least in the authors' opinion, that software is generally cheaper to design than hardware which will perform the same function. In other words, the seemingly high cost of software development is related to the fact that microprocessors are frequently used in applications which would be prohibitively expensive to contemplate with a purely hardware solution. Also, there is a tendency to include in software costs much of the work related to product definition rather than just the implementation costs.

The cost of writing software is hard to determine even after a project is completed, let alone predict before it is started. In the computer industry, an oft-quoted rule-of-thumb is that software costs around $20 per line of code to generate, including initial planning, flowcharting, coding, debugging and testing. This figure is said to hold true whether the actual programming is done in a high-level language or in assembly language. If we start with this figure as a basis for microprocessor programming, and assume that each line of code in assembly language generates an average of two bytes of final program code in p.r.o.m., we are forced to conclude that it will cost about $20,000 to produce a prototype 2K p.r.o.m. in a typical microprocessor-based design.

In the authors' experience, this figure is, fortunately, wildly pessimistic. On two separate microprocessor programming projects, where a detailed record was kept of times spent, the cost per byte of final code, based on a labour cost of $25 per hour, came out at $1·10 and $1·50, including all preliminary work such as flowcharting etc. This is equivalent to $2250 and $3070 respectively for a 2K program, a much more acceptable figure. The first (cheapest) program was a complex word processor using a Z80 microprocessor, whilst the dearer one was a relatively simple logic controller using SC/MP. In both cases the coding was done by aiming at minimum programming time rather than a highly optimized program size or execution speed. Both projects were performed using stand-alone, disk-based development systems, though the system used for the Z80 project was superior. This factor is reflected in the disparity between program complexity and cost.

Testing and Debugging

Although a considerable amount of testing and debugging can be performed on hardware and software separately, the major portion of microprocessor design debugging needs to be performed with the software interacting directly with the prototype hardware. This is particularly true in the case of software debugging; the whole purpose of the software is to assimilate input data from the hardware, manipulate it in some way or other, and then supply transformed output data back to the hardware. Under such circumstances, it is most unreasonable to expect to be able to debug the software properly without having a realistic representation of the hardware for it to interact with.

It is dangerous to attempt to lay down hard and fast rules for how best to proceed with hardware/software debugging. One general guideline however, is that it pays to debug the hardware first, at least to the point of verifying that it is functionally sound, before trying to run the software in the prototype hardware. Software should be debugged in small blocks, so the integrity of one block is ensured before it in turn is used to debug other blocks. If software debugging starts with those portions which directly communicate with the hardware, e.g. I/O drivers, the microprocessor engineer will gain additional confidence in his hardware at the same time.

The actual point in the debugging process where hardware and software merging or integration starts is in practice highly dependent on the tools available to the microprocessor engineer. As a rule, the better the tools he has available, the sooner the microprocessor engineer will be able to start integration and start to identify hardware and software errors which could prove very costly to track down later on in the cycle.

The Development System

As we have seen, microprocessor product design consists of something old and something new. The 'something old' consists of elements drawn from two previously separate fields, electronics and computer programming, while the 'something new' is related to the interaction between these. What then are the tools which a microprocessor engineer should employ in order to perform his job as efficiently and economically as possible?

Many solutions to this problem have been tried out over the few years that microprocessors have been in existence. Some have been extremely effective, whilst others have worked, but only with an excessive expenditure of time and effort.

In theory, a microprocessor engineer equipped with only the barest of essentials in the way of equipment, say an oscilloscope and a p.r.o.m. programmer, can manage to complete a microprocessor-based design. In practice however, the time taken to complete any non-trivial design would be excessive, and the cost prohibitive. It follows then that the reason for giving him better tools is to save time and money, and the savings must be commensurate with the investment we make in better equipment.

Types of Design Aid

Let us review briefly some of the design aids which are in common use today.

Evaluation Kits and Low-cost Development Systems

These consist usually of a microprocessor, some memory, a calculator-style keyboard and a six- or eight-digit hexadecimal display. A small program contained in r.o.m. allows the user to enter programs in machine code, the most primitive of programming codes, and then debug them in the system's own hardware. Normally some facilities exist for the user to add hardware of his own design to the system, so he can interface the system to the real world. These devices are adequate for educational, hobbyist and microprocessor evaluation purposes, but are generally regarded as inadequate for designing all but the simplest products economically.

The main limitation of these systems is that they provide absolutely no assistance in generating software.

Large Computers

Many large computer installations have available programs which can be of considerable assistance in generating microprocessor software. These programs are called cross-assemblers, cross-compilers and cross-simulators. The 'cross' prefix indicates that the program is written to run in a host computer which is of a different type to the target computer (in our case target microprocessor).

Using such cross-software, it is possible to write a microprocessor program with relative ease, and also to debug it partially using the large computer to simulate the microprocessor. However, this simulation is only a simulation, and cannot execute the program in real time, nor can it take into account interactions between the user's program and the actual hardware of the prototype microprocessor based design.

Logic Analysers

Logic analysers are a class of instrument which have appeared in recent years, in response to the need for equipment suitable for troubleshooting bus-oriented circuitry, such as minicomputers. These units are hardware-oriented, giving high-speed data capture and display capability on as many as 32 signal lines simultaneously. Some models are capable of displaying the data in symbolic microprocessor assembly-language format, and as a result have been applied to the task of debugging microprocessor hardware and software.

However, while logic analysers are a powerful tool for monitoring the operation of a microprocessor, they provide little or no means of controlling program execution, nor any method for generating and altering software.

Integrated Development Systems

Over the last 6 or 7 years, a new class of equipment has evolved, which is aimed specially at the needs of the microprocessor engineer, a unit which combines all the facilities which are needed for economic development of microprocessor based designs. So as to distinguish these from the low cost development systems outlined above, one is tempted to coin a new name such as Integrated Development System; however, the simple term 'development system' is commonly accepted as referring to a fully fledged system, whilst terms such as 'design aid', 'evaluation kit' or 'low cost development system' are normally used when referring to the simpler type of equipment discussed earlier.

A microprocessor development system is neither a computer nor an electronic instrument, rather it is a synthesis of the two. The development system includes and integrates facilities addressed primarily at the three main phases in the development process: software generation, hardware testing, and integrated hardware/software debugging. One of the most important characteristics of a well-designed development system, and one which sets it apart from a collection of individual, special purpose equipments, is that all the facilities in the development system are smoothly integrated into a coordinated whole.

As stated earlier, the main purpose in investing in a development system must ultimately be to save money, and the development system achieves this by saving the microprocessor engineer time. In a competitive commercial environment the development system can also increase profits by permitting new products to be marketed earlier, and by giving the microprocessor engineer the tools he needs to make his design perform better and so capture a larger market. Let us therefore review the various features of development systems with view to assessing their contribution towards achieving these objectives. To illustrate the various points, the GenRad/Futuredata Advanced Microprocessor Development System (AMDS) will be used. However most other good systems include facilities similar to those described.

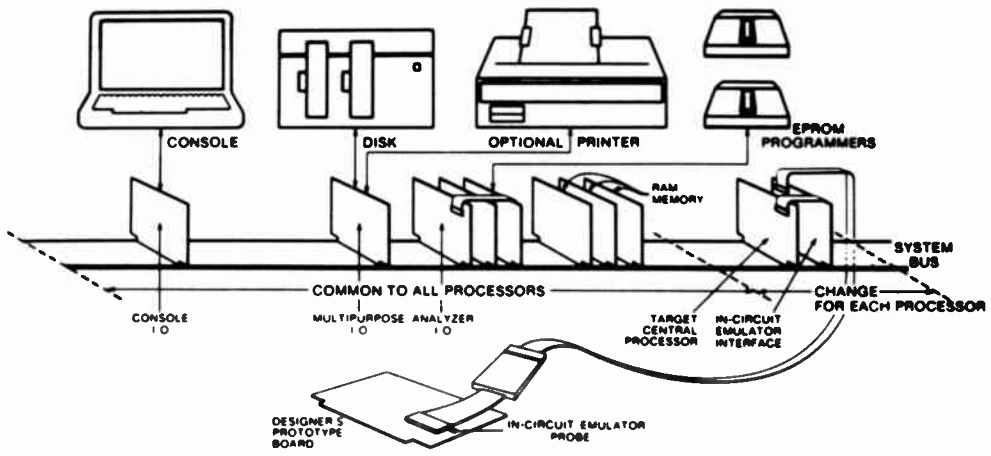

Fig. 1. Schematic diagram of the GenRad/Futuredata Advanced Microprocessor Development System.

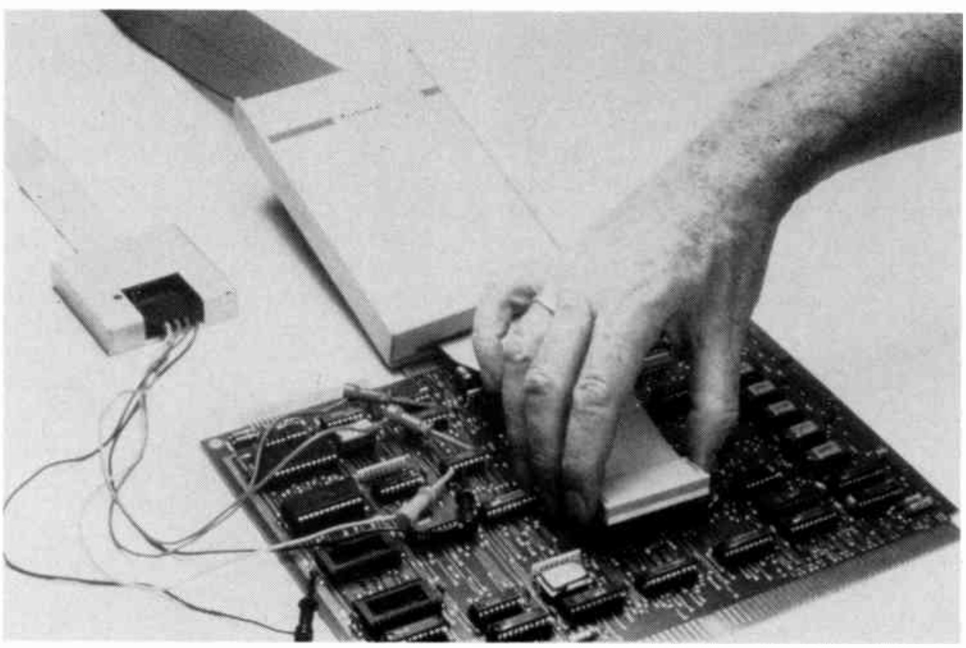

Fig. 2. The AMDS probe in use in development of an l.s.i. system board.

Software Generation

The development system can aid the process of software generation in two areas: text-editing and program translation. Taking the last point first, program translation is the process of taking a program which is written in a symbolic, human readable form, and translating it into a form which the microprocessor can understand: machine code. This translation is performed automatically by the development system on request, with the development system using a translator program called either an assembler or a compiler.

An assembler requires as its input a 'source program' written in a symbolic language which closely reflects the internal structure or architecture of the microprocessor being programmed. Writing programs in such an 'assembler language' can at times be quite time consuming.

A compiler, on the other hand, accepts a source program written in a 'high-level' language, which is unrelated to the microprocessor architecture. Instead it uses a grammar and vocabulary of commands which is designed to be easy to learn and use for a particular class of programming tasks. This leaves the microprocessor engineer free to forget about the details of the microprocessor's internal structure, and instead concentrate on the overall logic of his program. Unfortunately, using a compiler results in an inevitable loss of program execution speed and increase in program memory size requirements, as a compiler can never be as efficient as a skilled programmer writing directly in assembly languages. Therefore the choice of a high-level language versus assembly language must be made on a case by case basis.

When evaluating assemblers, attention should be paid to the various features offered; good assemblers provide facilities over and beyond simple code translation, which under certain circumstances can have a substantial impact on the time required to code a program. Such facilities include the ability to invoke a long, user-defined sequence of instructions via a single command (macro-processing), the ability to evaluate complicated mathematical and logical expressions, easy generation of data tables, constants and text strings, and the ability to generate relocatable or modular output code. Even though some of the features offered in an assembler may seem excessively exotic to the uninitiated, it will pay to investigate them closely and consider what constraints a poorer assembler will impose as one gains experience. Certain assembler features can even have an impact on the basic design of a program, and may also make it practicable to write code in such a form that it can be re-used on later projects. One example of this is macros: a well-designed set of macros, oriented towards a particular class of programming task, can come close to being classified a special-purpose high-level language.

Another point to consider with assemblers, especially if one is contemplating writing large programs, is the speed of the assembler. When it comes to the time to debug a program, many re-assemblies are generally required to correct bugs. If the time taken for each assembly is excessive, a lot of time can be wasted just waiting for the assembler. Typical assembly speeds in floppy-disk based development systems range from 200 to 2000 bytes per minute, or 4 to 40 minutes for an 8K program. Multiply that by maybe ten, twenty or even more re-assemblies, and the cost difference becomes significant.

Compilers are even more difficult than assemblers to evaluate. Factors to consider are which language is used (is it a standard, well-known language or a particular manufacturer's proprietary language?), how efficient is the compiler in terms of output program size and execution speed, does it provide for manual optimization of critical areas and for linking with assembly language programs, and does it indeed provide facilities suitable for a particular project?

Another development system program which is needed where the assembler or compiler generate relocatable code, is the linker. Using relocatable code, a program can be written in a modular form, with each module being assembled or compiled separately but making reference to other modules via symbolically-named labels. At the time of assembly or compilation absolute memory addresses need not be determined; it is the function of the linker to link the various modules together and assign actual address values to the various program instructions and symbolic labels.

Before a program can be assembled or compiled, it must somehow or other be entered into the development system. As it would be humanly impossible to type in, say, a 2000-line program completely without errors, all development systems provide a program called a text editor. The text editor, or simply editor, allows the microprocessor engineer to type in his source program, and to correct any mistakes as he goes along. Corrections and alterations are made via a series of keyboard commands, and the final program can be stored in some permanent, machine-reader medium, such as floppy-disk, for subsequent recall. In this manner, the bulk of typing need only be done once, and any corrections required when errors are detected during debugging can be done by recalling the source program from disk, correcting it and recording it back onto disk. It should be noted that the text editor is merely a program for manipulating text in a general sense. Except for some special-purpose editors such as the GenRad/Futuredata Pascal editor, the editor is totally unaware of whether it is being used to prepare a source program or a magazine article. In fact, the manuscript for this paper was drafted entirely on a standard development system text editor.

The earliest editors were designed to operate in computer systems which used a teletypewriter as the operator terminal, and most development systems today still use this type of editor, normally referred to as serial editor. With a serial editor, the speed of the terminal makes it impractically slow for the editor to type out more than a single line of the user's text at time, unless specifically instructed to type more. Also, when the user is editing or modifying a line, the editor can type out the modified line only after the user has committed himself to a group of modify commands, so the user needs a great deal of mental dexterity to keep track of what the likely effect of his commands will be. Another characteristic of serial editors is that each line of text is numbered for identification, and should any lines be inserted or deleted, all subsequent lines will be renumbered, making it difficult to locate a required line. All in all, while serial editors are capable of getting the job done, they leave a lot to be desired in terms of user convenience and speed of use.

More recently, development systems have emerged which incorporate an integral c.r.t. terminal. In some of these, the terminal is merely a logically separate serial v.d.u. packaged in a common enclosure with the development system electronics, but in a couple of instances the c.r.t. display is directly refreshed from the main memory of the development system, and can be updated at up to 200,000 characters per second as compared to 960 char/s for the fastest serial terminal. This radical departure from the traditional hardware design allows a completely new approach to the design of text editors. In the GenRad/Futuredata editor, for example, 21 contiguous lines of the user's text are displayed on the c.r.t. at once, so any particular line can be quickly identified by context rather than by cumbersome line numbers. When a line needs to be altered, a flashing cursor on the screen indicates where in the line any changes will occur, and the editor instantly updates the display in place to reflect the results of individual keystrokes. The result is that any user mistakes are instantly detectable.

A well-designed 'screen-oriented' editor of this kind, operating in conjunction with a genuine direct-memory refreshed c.r.t. display, can conservatively reduce editing time by a factor of three to one as compared to the old style serial editor. As up to 30% or even 50% of 'hands on' time with a development system may be spent text editing, the potential time and cost savings are considerable.

Debugging and Integration

In a well-designed microprocessor development system, the three processes of software debugging, hardware debugging and hardware/software integration tend to merge together into one combined operation. During this combined 'integrated debugging' phase, several resources of the development system, both hardware and software, are brought into play. The main software function provided by the development system is the debugger, and the main hardware function is the in-circuit emulator.

In-circuit Emulators

The in-circuit emulator, or simply emulator, is a hardware device built into the development system, which allows the development system to be connected to the microprocessor engineer's hardware prototype, whilst placing no constraints, or at least very few, on the electrical and mechanical design of the prototype. This constrasts strongly with, say low-cost development systems which virtually force the microprocessor engineer to base his design on the bus structure, physical dimensions etc. of the low-cost development system (for better or for worse).

The emulator achieves this design freedom by 'looking like' a microprocessor chip, even to the extent of connecting to the prototype via a dual-in-line plug which has the same pin assignments as the microprocessor. When this plug is inserted into the microprocessor socket in the prototype, the prototype can be made to perform exactly as if it had an actual microprocessor installed.

There is, however, one very important difference between an emulator and a real microprocessor: with a microprocessor chip installed in his prototype, the microprocessor engineer has virtually no way of controlling his prototype, nor of monitoring its internal behaviour, except via whatever input and output devices (e.g. switches, l.e.d.s) he may have incorporated in his design. With the emulator, on the other hand, he can achieve very close control over his prototype, because the development system, via the emulator, has taken over the function of the component which normally controls the prototype.

The emulator also allows certain resources within the development system to substitute for parts of the prototype. For example, memory within the development system can be used in lieu of prototype r.a.m. or p.r.o.m., and similarly the development system's clock may be used if the prototype does not yet have a clock circuit. In general, the emulator does, or at least should, allow work to continue as far as possible, even if the prototype is not yet fully designed or constructed.

Debugger Program

The debugger serves two main purposes:

(a) To allow the microprocessor engineer to execute his program under controlled conditions.

(b) To provide a means for the microprocessor engineer to control the emulation process.

In actual practice, these two functions are so closely interwoven that they are practically indistinguishable from each other.

Debugging with Emulation

Using an emulator, debugging of hardware and software can be carried out in a very systematic, step by step manner. A basic axiom in any form of debugging is that the process be broken down into the smallest possible steps.

Using the emulator, basic hardware testing can usually be performed very easily. For example, a simple keyboard command on the development system can send a byte of data out through the emulator probe, addressed to an output port, and activate whatever indicators (l.e.d.s, relays etc.) are connected to the port. Similarly, input ports can be addressed and monitored from the development system. For more complex circuits or, if problems are encountered, a simple program which addresses the output or input repeatedly, will act as a convenient source of a signal for display on an oscilloscope.

Once the prototype hardware has been checked, debugging of the software can start, with the tested hardware available to the software as and when needed. At this stage the true power, or lack of power, of the debugger becomes evident.

Although much microprocessor software is time dependent, i.e. will function correctly only if executed at the full speed of the microprocessor, initial debugging should be performed at a more leisurely rate. Two basic techniques exist for initial testing of program: single stepping and software tracing. With single stepping, the program is executed one single instruction at a time, and the contents of memory, registers etc. are inspected by the user to check that the results are those expected. Single stepping can be time consuming if the development system requires separate commands after each step to display the required information and preferably the next instruction (or more) in a human-readable format. However, in systems like the GenRad/Futuredata AMDS, which automatically display such information as processor register contents, memory contents and the next several instructions after each step, single stepping is an extremely powerful method of preliminary testing, in particular because bugs can be discovered before they cause possibly major damage to the program or data. Also, it is very easy, especially with a dynamically updated display, to alter register and memory data while stepping through the same segment of code repeatedly, and hence test the code for operation under varying conditions. This interactive mode of program check-out also encourages the microprocessor engineer to be constantly anticipating what his program will do, and in effect be reviewing his program design for mistakes. A single-step facility with automatic display of the results, is only practical in development systems which use a direct-memory-refreshed display, because of the large amounts of data which must be written on the display after each step.

The second technique for basic program testing, software tracing, is better suited to systems which use a slower, serial terminal. In software trace, the debugger single steps the program continuously, printing out the processor register contents on the terminal after each step. Some debuggers also print the instruction in disassembled form. The software trace does not, however, normally print out any memory data, so any changes in memory contents must be worked out by the user by inference. The software trace continues automatically until halted manually or otherwise. The result of software tracing is a screen full of data, or, when a printing terminal is used, a length of paper, which traces the flow of the program. The user must analyse this data to discover where any bugs occurred. Software tracing does not lend itself very well to allowing intervention by the microprocessor engineer for such things as altering registers and memory data, and there is also the potential danger of a program destroying itself or its data before the trace is terminated.

When individual sections of a program have been checked out using single stepping or tracing, they can be tested in larger units by the use of breakpoints. A breakpoint is a trap set in a program, which allows the program to be executed at full speed or in a trace mode up to where the breakpoint has been set. When the breakpoint is encountered, execution is halted and the development system reverts to debugger command mode. Thus by correct use of breakpoints, selected sections of a program can be executed at will, and the microprocessor engineer can then investigate the results. While breakpoints are usually set to be triggered when a specified intruction is executed, some development systems also allow breakpoints on reads or writes to a nominated memory address. Even more complex breakpoints will be described later when considering logic analysers.

Setting breakpoints implies that the user can locate the correct memory address for the breakpoint. With some debuggers, the user must know and specify the absolute, hexadecimal address value. More advanced debuggers, however, allow addresses to be referred to by a symbolic name, defined by the user in his original symbolic source program. This feature, which can save considerable amounts of time printing a new hard copy assembly listing each time a program is edited and re-assembled, is called symbolic debugging.

Note that all the time the program is being checked, the emulator can give it access to the hardware prototype, so the microprocessor engineer has the ability at all times to monitor program outputs and generate realistic inputs. Even at an early stage system integration has begun, so there is less risk of nasty surprises when the system is brought up to full speed.

Just as single stepping, tracing and breakpoints permit a gradual phasing-in of more and more of the program, a well-designed emulator will assist in phasing-in more and more of the hardware. All well-designed emulators allow for a number of different degrees of emulation, such as using development system memory in lieu of prototype memory and individual enabling of prototype clocks, d.m.a. lines, interrupts etc. Also, it is a useful feature of some systems that the development system r.a.m. memory can be selectively write-protected, to allow a realistic simulation of the p.r.o.m. which will eventually contain the program.

Debugging in Real Time

Where a microprocessor design is critically dependent on operating in real time, be it because the program uses software timing loops or because the capabilities of the processor are being stretched to the limit, single-stepping and software tracing go only part of way towards providing complete debugging facilities. To cope with the problems of real-time debugging, many development system manufacturers offer logic analyser or real-time trace options for their systems. These devices, which are integrated into the development system, are closely related to general-purpose logic analysers. However, they differ from the general-purpose units in three major respects:

(a) They are not as fast, and for the most part lack the ability to detect subtle hardware timing problems.

(b) They are permanently connected to the microprocessor bus, with only a small number of uncommitted chanels.
(c) They are very much easier to use for debugging problems relating to hardware/software interactions, because they have been optimized for that application and the development system software can aid the user by helping to interpret the data captured by the analyser.

Functionally a development system logic analyser consists of a fast memory, up to 64 bits wide by 256 deep, which can capture data off the microprocessor bus in real time during execution. They also include up to three complex breakpoint circuits, usually with as many bits as the width of the trace memory, plus delay counters, timers and circuits to enable storage of only selected items of bus data.

As important as the hardware is the support software, which helps the user control the analyser and formats and displays the data from the trace memory. The support software is included in the debugger, providing a smooth transition from the early debugging phases to the real time testing.

In operation, the analyser allows full speed execution of the user's program, using the complex breakpoints to halt execution when a nominated set of bus conditions occurs. During execution bus data are stored in the trace memory, and as the memory overflows the oldest data are discarded. When the breakpoints stop execution, the analyser software formats and displays the trace data. Usually the data display consists of hexadecimal and disassembled representations, though the GenRad/Futuredata AMDS also has a second display format which interprets the trace data as logic waveforms.

Because the analyser must capture data off the bus in real time, the trace data cannot include the contents of internal microprocessor registers or of memory. Nevertheless, the added complex breakpoints and real-time operation make it a worthwhile addition to a development system, especially in speed critical applications.

The 'Circle of Design'

Debugging a design, be it microprocessor-based or not, is essentially an iterative process. In a conventional electronic development project, the prototype is tested until a bug is discovered. When the cause of the bug is identified, a fix is found by patching the circuit. The wise designer then 'goes back to the drawing board' and amends his design documentation. The prototype is then re-wired to reflect the design change, linked up to other modules, power supplies etc., and finally debugging can be resumed.

In microprocessor designs, this same iterative process takes place with the hardware, but a similar analogous process also applies to the software: When a software bug is found, the microprocessor engineer works out a fix. He then calls the editor, modifies his source code, re-assembles or compiles it, links it to other software modules and then returns to debug mode.

This repetitive procedure is referred to as the Circle of Design. Evaluating a microprocessor development system in terms of its day-to-day performance can be reduced to studying how well it eases the microprocessor engineer around the circle of design. Using a typical 2K assembly language program as an example, an inefficient development system can consume as much as three to four hours to get around the circle of design, not including manual editing and debugging time. With a modern, disk-based system, the figure is closer to 15 minutes, allowing for a print-out of the assembly listing. If however, the system provides symbolic addressing during debugging, the print-out can usually be eliminated, and the time reduced to as little as 2 minutes. This figure assumes the use of a command or batch file, which allows all fixed system commands to be pre-programmed and then be invoked by one single, high level command, e.g. 'CIRCLE'.

Clearly, then, different development systems differ substantially in their ability to cope with the time consuming task of repeatedly going around the circle of design. Direct time and cost savings apart, a microprocessor engineer who is working with an efficient system in terms of the circle of design will produce a more reliable, well-tested program than his counterpart who is forced to take short cuts such as making hexadecimal patches to his program using the debugger. Also, being able to go back and update the source code quickly and easily will ensure that when the program is completed, the source code, which represents the major program documentation, will be fully up to date.

Conclusion

The microprocessor is a new kind of electronic component which combines l.s.i. technology with computer science in order to make the advantages of l.s.i. technology available at a reasonable cost. Designing with microprocessors differs markedly from both traditional electronic design and computing. The process is dominated by the critical interaction between hardware and software. Tools which have traditionally been used as design aids in the two separate fields of electronics and computing can be applied to microprocessor designs, but usually result in the design process being excessively difficult and expensive. The microprocessor development system is designed specifically to combine hardware and software design tools into one integrated system, and provides all the facilities needed for cost-effective microprocessor product design.

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High data rate transmissions over h.f. links

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SUMMARY

A review is presented of the problems inherent in transmitting data over h.f. links. The propagation medium imposes characteristics of time and frequency dispersion, fading and delay distortion upon the transmitted signal, particularly when wide bandwidths are used. The magnitude and variability of these features are quantified and a simplified expression for the received signal is derived. Techniques that have been used to transmit high data rates over h.f. links are summarized and their relative merits compared. It is concluded that the ionosphere continues to be a limiting factor in the design of an efficient modem, but that recent developments in microelectronics provide the potential to make a significant improvement in the performance of future communication systems.

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1 Introduction

The high frequency (2–30 MHz) portion of the spectrum has long been recognized as a useful and economic medium for achieving wide distribution of energy over large distances. Although satellite communication systems are becoming more widely available, h.f. will continue to be extensively used by many nations for point-to-point transfer of information and for commercial shipping and aircraft communications; military forces rely heavily upon h.f. for land, sea and air operations. The major constraint for a satellite link is to maintain an adequate signal-to-noise ratio for the high data rates that are required. In contrast, constraints on h.f. links centre around the dispersive characteristics of the transmission medium and in the high levels of interference that may be encountered.

The design of h.f. systems depends upon accurate predictions and new technology to improve circuit reliability. System planners should know what frequency ranges must be covered, what transmitter powers are necessary to overcome the background noise at the receiver and what antenna configurations are most suited to the applications required.

The evaluation of h.f. link reliability has been detailed in a previous paper;[1] an air-to-ground link was chosen as an example to illustrate the concepts involved and the problems with which the communications system designer must cope. The resultant effects caused by time and frequency dispersion were not specifically addressed, however, and the conclusions reached assumed that such effects are not major. The present paper considers these dispersion effects in detail, and analyses the limitations they impose upon high data rate transmissions of an h.f. signal.

Section 2 summarizes the operational constraints of using h.f. data transmissions for point-to-point and mobile applications. The properties of the propagation medium are analysed in Section 3; each major characteristic is discussed in turn, its physical cause identified and the magnitude of its resultant effect quantified. Section 4 considers some techniques that have been used to transmit data at high rates over 3 kHz voice bandwidth channels and compares their relative merits. Sections 5 and 6 extend the study to consider the use of wider bandwidths, the problems that may arise and some techniques that might be employed. Finally, in Section 7, some future trends are briefly examined and their possible impact upon communications systems are considered.

2 Operational Constraints

2.1 Point-to-point Links

The h.f. spectrum is used extensively for long-range point-to-point communications and broadcasting; the characteristics of such links have therefore been widely studied. Commercial services are available[2,3] for predicting the optimum working frequencies and quality of communications at those frequencies. Most point-to-point land fixed h.f. communication circuits use high-gain rhombic or log periodic antennas, whilst arrays of horizontal dipoles, also with significant directivity, are popular for broadcasting using the sky wave.

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Many circuits employing data transmissions have a large frequency complement. This allocation can be used to advantage to choose frequencies close to the maximum usable frequency (m.u.f.) and thus ensure that differential delays between propagation modes are small enough to provide frequency flat fading over a 3 kHz channel. Post-detection diversity combining can be employed to combat such fading by using spaced receiving antennas and multiple transmission frequencies. The digital errors that remain are then caused predominantly by either wideband impulsive noise or man-made interference; the time varying dispersive effects of the channel are of secondary importance. In principle, therefore, the performance of these point-to-point links may be optimized by good engineering design and practice in respect of the equipment and antenna systems, whilst high transmitter power is often available.

2.2 Mobile Applications

Much more difficult problems are presented by h.f. communication to mobiles. Communication is often required at ranges from a few kilometres to hundreds or even thousands of kilometres over a wide variety of terrain, and this implies different modes of propagation according to range. Physical constraints are placed upon antennas that are used for manpack or vehicle application so that efficiencies may be seriously degraded; radiation patterns are obtained that may not be suited to the propagation mode, whilst transmitter power is often severely limited.

When transmitting data to and from these mobiles, it is neither easy nor always possible to use frequencies close to the m.u.f. as in the case of point-to-point links with large frequency complements; time-varying channel dispersive effects can then become of primary importance. At the frequencies available to the mobiles, the resulting differential delays between propagation modes may be sufficient to produce narrowband frequency selective fading within a 3 kHz channel. To achieve satisfactory results over an h.f. link of this kind, careful consideration must be given to the h.f. channel characteristics, the terminal radio equipment (including modulation techniques and error coding), the planning of operational links and the management of the frequencies to be used over those links.

2.3 High Data Rate Requirements

Further complications arise when high data rate transmissions are required. For example, digital voice requirements imply data rate transmissions of 2·4 kbit s^{-1}. Higher data rates would give better quality from the speech synthesis aspect, but channel bandwidth considerations show that approximately 2·4 kbit s^{-1} is the highest rate that can be tolerated in a 3 kHz channel. Military radio links may need to incorporate a high degree of immunity to electronic counter measures; complex modulation schemes involving frequency hopping and spread spectrum must therefore be adopted. This, in turn, necessitates a detailed study of the propagation medium to determine whether various forms of wide bandwidth modulation techniques can be transmitted with fidelity. The problems inherent in the design of modems to achieve satisfactory transmissions at 2·4 kbit s^{-1} over h.f. channels have not yet been adequately solved; it has been the ionosphere which has proved to be a limiting factor in the design of an efficient modem.

Table 1

General h.f. channel characteristics

Propagation mechanism	Channel characteristics	Relevant parameters
Ground wave	attenuation delay	soil conductivity terrain type range wave polarization wave frequency
Single mode sky wave	attenuation delay fading delay distortion Doppler shift Doppler spread	time of day sunspot activity season of year range wave polarization wave frequency
Multimode sky wave	time dispersion interference fading	different modes different hops high/low angle rays magnetoionic splitting relative attenuation relative delay

3 Characteristics of the Propagation Medium

Good network and frequency management are vital, particularly for the successful performance of a mobile radio system. The m.u.f. increases with range and, if a choice of receiving stations is available, it may be advantageous[4] to work to the more remote station so that higher working frequencies can be used and thus better antenna efficiencies achieved. The requirement for good frequency management of h.f. links is implicit throughout this paper.

Groundwave communication is more straightforward than skywave; it can be assumed that the groundwave is merely an attenuated, delayed but otherwise undistorted version of the transmitted signal. Ionospheric skywave returns, however, in addition to experiencing a much greater variability of attenuation and delay, also suffer from fading, frequency or Doppler shifting and spreading, time dispersion and delay distortion. These features are summarized in Table 1 and will be discussed in detail.

3.1 The Received Signal

Consider a complex transmitted baseband signal, $E(t)$, traversing a single propagation path through the ionosphere. Let it experience a delay τ. The medium is dispersive and thus the signal is subject to delay distortion, caused by the fact that the delay is a function of frequency. This distorted waveform is denoted by $\hat{E}(t)$. In addition, the signal experiences attenuation and random fading. This can be represented by multiplying the delayed, distorted signal by a random gain $G(A, \nu, \sigma, t)$ where A characterizes the attenuation $(0 \leqslant |A| \leqslant 1)$ and ν, σ represent the fading in terms of a

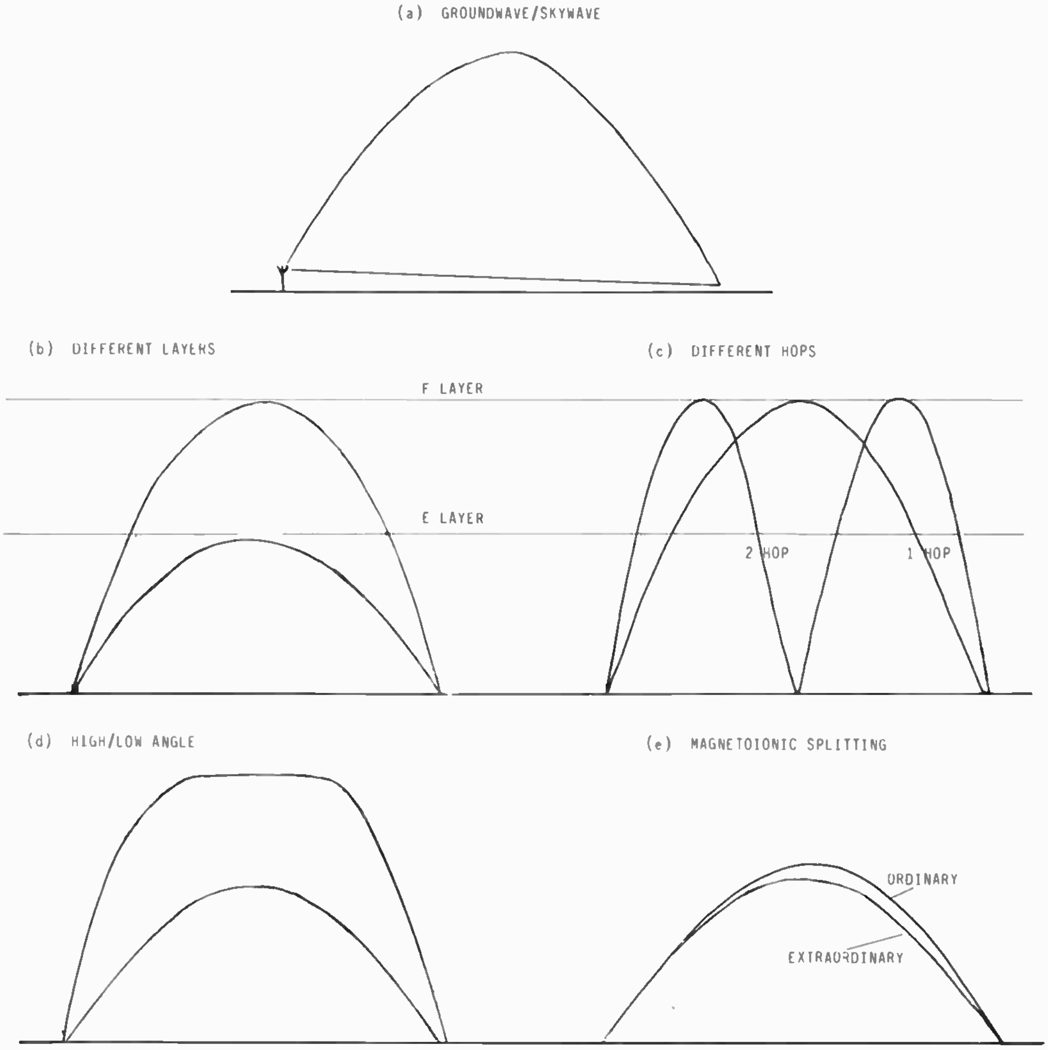

Fig. 1. Causes of multipath propagation.

frequency shift and spread respectively. The received signal $E_R(t)$ thus becomes

$$E_R(t) = G(A, v, \sigma, t)\,\hat{E}(t-\tau). \quad (1)$$

Components of this signal may be returned from both the E region and F regions of the ionosphere (the latter may include both high and low angle ray paths). There are skywave returns for the ordinary and extraordinary magneto-ionic components and for multiple hop paths (see Fig. 1). Although many propagation modes are possible, all but a few experience a large attenuation; the number of 'effective' modes is generally small.

Each mode has a different value of the characteristics of equation (1). For the jth mode, the received signal is

$$E_{Rj}(t) = G_j(A_j, v_j, \sigma_j, t)\,\hat{E}_j(t-\tau_j) \quad (2)$$

Consider now the groundwave. This can be assumed to experience a delay τ_g, and a non-random gain, but no distortion. Thus, $\hat{E}(t-\tau)$ becomes $E(t-\tau_g)$ and G becomes A_g $(0 \leqslant |A_g| \leqslant 1)$. The total received signal is then

$$E_R(t) = A_g E(t-\tau_g) + \sum_{j=1}^{N} G_j(A_j, v_j, \sigma_j, t)\,\hat{E}_j(t-\tau_j) \quad (3)$$

where N represents the number of 'effective' skywave modes. Expressions for these terms are derived in the Appendix. It is not necessary, however, to delve into the detailed mathematics to consider the effects imposed upon the received signal by the characteristics of the propagation medium. The relevant phenomena are summarized in Table 2. Each is now discussed in more detail in terms of its cause, magnitude, variability and resultant effect.

3.2 Multipath Propagation and Time Dispersion

Multipath characteristics can be described by the dispersion produced in the unit impulse response of the medium. Time dispersion can result from one or more of the following (see Fig. 1):

(a) Groundwave and skywave paths,
(b) Skywave returns from different ionospheric layers,
(c) Skywave returns involving different numbers of 'hops',
(d) High and low angle skywave paths,
(e) Splitting of the magneto-ionic components, ordinary and extraordinary, resulting from the effects of the Earth's magnetic field.

Table 2

Causes of distortion on an h.f. channel
(Parameters referenced are those used in equation (3))

Effect	Cause: Within a single mode	Cause: Between different modes
Time dispersion	spread of τ_j, due to slightly different constituent raypaths	τ_j different for each propagation mode
Fading	G_j a function of time — movement in ionosphere — polarization variations — absorption changes	different time dependence of each G_j
Frequency dispersion	ν_j, σ_j are non-zero — phase path is time dependent	relative phases between modes changes with time
Delay distortion	τ_j a function of frequency and/or time	τ_j may have a different frequency/time dependence for each mode

Each propagation path or mode has its own characteristic group delay τ_j. The time dispersion of the medium is caused by the difference in group delays between the different modes; it can give rise to intersymbol interference when the signalling rate becomes comparable with the relative multipath delays. The maximum serial data transmission rate is thus limited to the reciprocal of the range of multipath propagation times. This is itself a function of frequency, path length, geographical location, local time, season and sunspot activity. The data rate can be maximized[5] by working close to the m.u.f., although this is extremely difficult to achieve in practice for mobile applications. As the operating frequency is decreased from the m.u.f., a frequency is reached at which the spread is a maximum. For a 2500 km path, the maximum time dispersion has been shown[5] to be about 3 ms; for 1000 km it increases to 5 ms and for 200 km it is about 8 ms.

Under some conditions, the transmission rate could be increased by a factor of 100 over the normal values[5] by judicious choice of operating frequency. In practice, however, the upper limit is approximately 200 bit s^{-1} when conventional detection equipment is used. Even within a single mode of propagation, there remains an approximately 100 μs spread due to the slightly different constituent ray trajectories caused by roughness of the ionospheric layers and non-zero antenna beamwidths. Under anomalous conditions, such as spread F, when the ionosphere contains many irregularities, the time dispersion can be much greater.

There are several important effects which multipath imposes upon a given communications technique and its associated equipment when transmitting high speed digital h.f. data:

(a) The equipment is more complex, with special modems, diversity combining etc. For example, in phase shift keyed (p.s.k.) systems, abrupt phase changes occur as successive modes reach the

Table 3

Summary of fading characteristics

Type	Cause	Fading period	Correlation bandwidth	Remarks
Flutter	small scale irregularities in F region	10–100 ms	1 kHz	associated with spread F
Diffraction	movement of irregularities in ionosphere	10–20 s	50 kHz	follows a Rayleigh distribution
Polarization	rotation of axes of polarization ellipse	10–100 s	25 kHz (night) 400 kHz (day)	only effective when both magnetoionic components present in approx. equal proportions
Skip	time variation of m.u.f.	generally non-periodic		avoided by working well below m.u.f.
Focusing	curvature of reflecting layer	15–30 mins		
Absorption	time variation of ionospheric absorption	1 hour		greatest at sunset and sunrise
Groundwave—skywave	comparable strengths of different propagation modes	2–10 s	300 Hz–3 kHz	generally more severe than for skywaves alone
Skywave modes	comparable strengths of different propagation modes	1–5 s	300 Hz–3 kHz	
High and low angle rays	comparable strengths of different propagation modes	½–2 s	300 Hz–3 kHz	
Magnetoionic splitting	comparable strengths of different propagation modes	10–40 s	300 Hz–3 kHz	

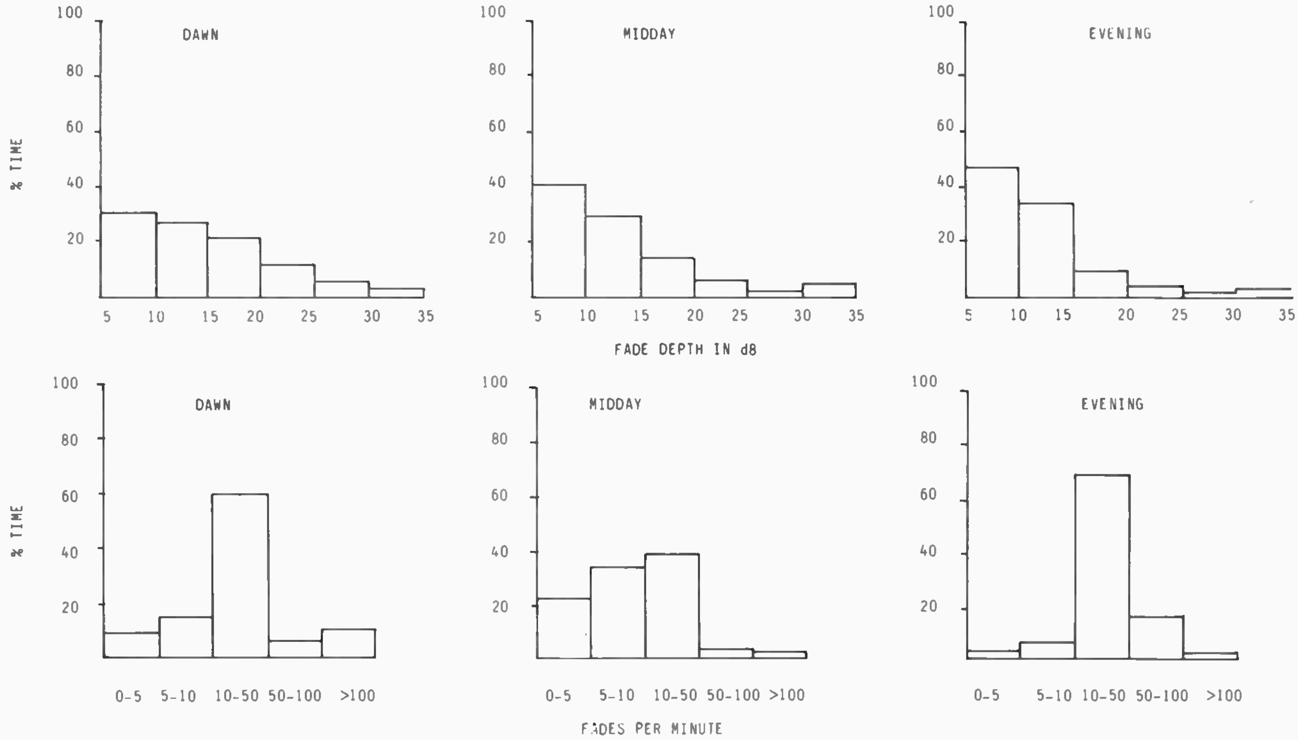

Fig. 2. Typical fade rates and depths received by a monopole.

receiver, necessitating the provision of a guard interval at the end of each signalling period. In bandlimited systems using multitone signalling, this reduces the number of tones available, since greater frequency separation is required.

(b) The error rate is degraded, as a result of intersymbol interference, and high error rates may occur even at high signal-to-noise ratios.

(c) The choice of operating frequency is limited to a small frequency band below the m.u.f. Working at frequencies too far below the m.u.f. increases the likelihood of encountering larger multipath delays.

3.3 Fading

Skywave signals characteristically fluctuate in amplitude and phase. No matter how irregular the ionosphere, the amplitude of the signal at a fixed receiver would remain steady if it were a static medium. The width of the received power spectrum (i.e. the fading rate) is then related to changes in the ionosphere.

There are a number of different kinds of fading, defined according to their origin; the main causes are movements and changes of curvature of the ionospheric reflector, rotation of the axes of the received polarization ellipse, time variations of absorption and changes in electron density. In addition to these effects which may be produced independently for each mode, more significant fading may be caused by interference between two or more modes, particularly when they are roughly of equal amplitude. The different types of fading, with their typical fading rates are summarized in Table 3.

Figure 2 presents some average fading rates for a typical h.f. channel at mid-latitudes.[6] It is clear that, particularly for the dawn and evening periods, the 10–50 fades per minute grouping is by far the most common. This is caused by interference between different skywave modes. For midday, the results are spread rather more evenly from 0 to 50 fades per minute, but again higher rates of fading are infrequent. Also shown in Fig. 2 is fade depth; fades of less than 10 dB occur most frequently.

For a two-path channel with relative delay d seconds, troughs in the amplitude-frequency response are separated by $1/d$ Hz and give rise to frequency selective fading; signals with bandwidths greater than $1/d$ Hz are thus required for in band frequency diversity. The $1/d$ Hz bandwidth is known as the correlation bandwidth and is given for different types of fading in Table 3. As the distance between two closely spaced receivers is increased, the correlation coefficient between their respective received signals decreases. The distance at which the coefficient drops to 1/e is called the correlation distance; it is of the order of a few wavelengths for skywave reception (i.e. $\gtrsim$ 100 m at h.f.).

3.4 Frequency Dispersion

For any given single propagation path, a shift v_j in frequency can be caused by time variation of

(a) height of the reflecting layer

(b) electron density (and hence refractive index) along the path.

Thus, if ψ is the phase angle of a ray path at time t, then

$$v_j = -\frac{f}{c}\frac{d\psi}{dt} \qquad (4)$$

for a fixed transmitter and receiver.

The frequency (or Doppler) shifts experienced at night are small compared to daytime effects,[7] whilst relatively large positive values occur at sunrise and large negative values at sunset. On 'quiet' days, values range[8] from 0·01–1 Hz. Shifts tend to be considerably less for E modes than for F modes, and slightly less for oblique than vertical incidence.

Evidence from over-the-horizon radar[9] shows that 'quiet' conditions usually prevail, since resolution down to 0·1 Hz is often possible. When the ionosphere is disturbed, however, such as occurs during conditions giving rise to spread F, there is typically a continuum of shifts of sometimes 5–10 Hz. During strong solar flares, deviations of up to 50 Hz have been measured[7] but these are only caused for a matter of minutes and are most unusual. Typical shifts caused by flares are 1–2 Hz.

Now since each mode of propagation is composed of a number of rays which traverse slightly different ray trajectories, each ray path has a slightly different frequency shift. This results in a spread of received frequencies, characterized by $2\sigma_j$ (see Appendix). Measurements[10] have not, unfortunately, been concerned with the shift and spread of individual modes; they have recorded composite Doppler values involving many modes. It has been estimated[8] that, under quiet conditions, spreads of 0·02 Hz would be applicable to E modes and 0·15 Hz to F modes.

Continuous Doppler spread spuriously modulates each transmitted pulse and therefore contributes to the fading of the received pulses. The fading period has been found,[11] however, to be much greater than typical pulse durations.

3.5 Delay Distortion

Delay distortion occurs because the group delay is a function of frequency and is consequently not constant across a signal bandwidth. For a given ionospheric path, the oblique ionogram gives the frequency-time dispersion characteristics. Two examples are shown in Fig. 3. The dispersion caused by the E layer is very small; it has been estimated[12] that the rate of change of group delay with frequency is typically 5×10^{-6} µs Hz^{-1}. The F layer, particularly near its m.u.f. can give much more rapid changes of group delay with frequency, as evident from Fig. 3.

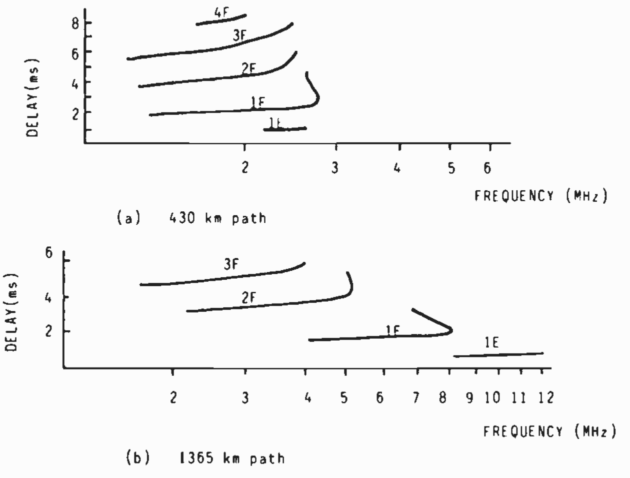

Fig. 3. Ionograms showing dispersion characteristics.

The importance of delay distortion for data transmission is concerned with the rate of change of delay with frequency and time. Ionospheric channels are non-stationary in both frequency and time, but if consideration is restricted to band-limited channels (say 10 kHz) and sufficiently short times (say 10 minutes) most channels are nearly stationary and can be adequately represented by a stationary model.[8] This means that, since propagation is limited to a discrete number of modes, the channel can be modelled by a delay line with a discrete number of taps, each of which are modulated in phase and amplitude by a time varying quantity.

Correlation measurements[13] over an h.f. link have shown that:

(a) the probability distribution of in-phase and quadrature components of the transmitted envelope followed a Rayleigh distribution with good fit,

(b) approximately 1·1 seconds is necessary for the time correlation coefficient to reach 0·5.

4 Techniques for 3 kHz Bandwidth Applications

4.1 Non-adaptive Systems

The signalling rate must be kept well below the reciprocal of the multipath delay to avoid the effects of intersymbol interference. A higher data rate can be effected by multiplexing the data stream with a number of different tone frequencies.

The effect of narrowband interference upon a multitone signal is to produce a high error rate primarily on tones adjacent to the interfering signal. Under multipath conditions, different modes may interfere with each other, reducing the overall signal power and disrupting phase relationships between tones. Differential detection is therefore preferable to absolute phase modulation; a more up-to-date comparison can be obtained if it is made between adjacent tones. This is the basis of non-adaptive d.p.s.k. systems.

Kineplex[14] is a four-phase multitone time d.p.s.k. system in which the information is contained in the relative phase difference between sequential bits transmitted on the same tone. The phase of the received bit is stored, and compared with the phase of the next bit and so on. Variations in the channel response which are slow compared with the bit duration give similar distortion to bits adjacent in time, so that the relative phase difference is approximately unchanged. One Kineplex version uses 20 tones, with each tone composed of two independent sub-channels. Transmission occurs with 75 baud per sub-channel, providing a capacity of 3000 bit s^{-1}. A tone spacing of 100 Hz gives a bandwidth occupancy of 2 kHz for the transmission system.

In frequency d.p.s.k. systems, the information is coded as the phase difference between two tones transmitted simultaneously on different frequencies. Differential comparison is thus performed under multipath conditions which are closely correlated. A better performance might be expected than is achieved for time d.p.s.k. systems at the expense of additional equipment complexity.

Andeft[27] is a four-phase frequency d.p.s.k. system which uses 40 Hz tone separation, with 66 tones transmitted simultaneously, two of them being used for synchronization and as starting reference frequencies. Each tone is compared with the adjacent tone to detect the relative phase. Whole frames are detected simultaneously using 64 sets of correlators, modulators and phase detectors.

4.2 Adaptive Systems

Adaptive systems involve cascading the channel with some form of correlator at the receiver in order to 'equalize' effects produced by the channel. The transfer function can be described in terms of either:

(a) an impulse response in the time domain, or

(b) a frequency response in the frequency domain.

There are two essentially different strategies for (a). One approach attempts to combine all multipath components, whilst the other cross-correlates a single mode in an effort to reject all others.

The approach for (b) uses a filter which produces a flat frequency response and a linear phase response (i.e. a filter with a frequency transfer function which is the reciprocal complex conjugate of the channel).

For either (a) or (b), the equalization networks gradually become aged because of the time-varying nature of the channel. Thus, any adaptive system operating over an h.f. channel must be able to:

(i) measure the channel parameters (which may involve transmitting a probe signal known to the receiver),

(ii) set matched filter elements at the receiver according to the measured parameters,

(iii) repeat (i) and (ii) sufficiently often to follow variations of the channel.

The Adapticom system[15] applies time domain adaptation to the reception of a 2660 baud serial transmission for which the bit duration (about 0·4 ms) is considerably less than the multipath time spread; the spectrum of each bit occupies the whole voice bandwidth. The matched filter operates on the baseband and its response is determined by tap amplifier gains.

An isolated probe pulse transmitted is received as a sequence of multipath signals. Instantaneous values of the composite received signal are sampled at the delay line and stored as tap amplifier gains. The matched filter equalizes the delays, squares all amplitudes of multipath spectral components and adds them coherently, thus compressing each signal into a duration comparable to that of the transmitted signal. The matched filter characteristics in the receiver must be updated frequently to follow changes in the channel transfer function.

The Kathryn system[16] applies frequency domain adaptation to the reception of a p.s.k. multitone signal. An overall data rate of 2550 bit s^{-1} is achieved using 34 orthogonal tones transmitted in 75 baud frames, each frame carrying information and probe signals in phase quadrature. A 1 ms guard time is used to attempt to maintain orthogonality between tones under multipath conditions. The receiving terminal uses two receivers for diversity operation with optimum combining. A pseudo-random probe sequence, identical to that at the transmitter, is generated in synchronism at the receiver. The measurement section of the receiver examines each received tone and determines the amplitude and phase distortion of the probe component. The latter is then removed from each tone and the remaining information component corrected in phase and modified in amplitude by the weighting section. The measurement and information weighting sections of the receiver form the adaptive matched filter. Continuous updating is provided using the probe sequence. However, the system possesses some inertia so that the receiver phase reference can never precisely compensate for the current state of the channel.

4.3 Comparison of Adaptive and Non-adaptive Systems

A detailed comparison of adaptive and d.p.s.k. systems for high data rate transmissions was presented[17] some

Table 4

Summary of system characteristics

System Name	Processing domain	Data rate (bits/sec)	Modulation	Adaptive processing	Guard time	Learning time
Adapticom	time	2660	d.p.s.k.	matched filter		20 ms
Kathryn	frequency	2550 (75 baud frames)	p.s.k. (34 orthogonal tones)	diversity—local reference correlation	1·14 ms	26 ms– 54 ms
Kineplex	time	3000	d.p.s.k. 4 phase (20 tones)	relative phase comparison on same tone	4·24 ms	20 ms
Andeft	frequency	4800	d.p.s.k. 4 phase (66 tones)	relative phase between two frequencies	1·67 ms	33 ms
Codem	time	2400 (3750 coded)	d.p.s.k. 4 phase (25 tones)	coding for channel	2·67 ms	10 ms

years ago. It has been shown that serial data transmission with pulses narrow enough to resolve multipath can achieve[18], with optimum equalization, an irreducible bit error rate (b.e.r.) that is a number of orders of magnitude less than the irreducible b.e.r. of parallel data transmission using multitone systems.

The applicability of adaptive matched filter techniques relies on the channel multipath impulse response remaining constant for significantly longer than the duration of the echo train from a single sample. Thus, the product X of the multipath spread and Doppler spread must be appreciably less than unity for adaptive systems to be useful. It has been shown[18] that the transmission limit of communication for parallel data modems occurs for $X \simeq 1/2000$, whilst for serial data and adaptive equalization, it occurs for $X \simeq 1/200$. In practice, however, the performance of an adaptive system is worse than the performance of non-adaptive multitone systems. The major problem is undoubtedly caused by the rapid variability of the channel, which makes the greatest demands on equalizer performance when the signal is at its poorest. Of attempts such as Kathryn, Andeft, Adapticom and Kineplex,[15] only Kineplex has entered service on point-to-point circuits. The characteristics of these systems are summarized in Table 4.

4.4 Error Detection and Correction Techniques

Interference often occurs in bursts in the h.f. band and this can result in the loss of significant parts of a digital voice transmission. The advent of microelectronics has provided a means to develop systems that have 'built-in' error detection and correction (e.d.c.) which, until recently, would not have proved cost effective. Sophisticated e.d.c. techniques employ powerful codes and interleaving to reduce error rates to acceptable levels; the effective data rate is thereby decreased. For digital voice applications, however, there may be an unacceptable delay caused by error correction processing algorithms. A compromise must therefore be maintained between coding complexity, level of interleaving and tolerable processing delay.

Codem[19] is a relatively recent, and somewhat unconventional approach. It uses a design of modulation and coding combined in such a way as to enhance the effectiveness of the overall communication system. The codem technique uses a form of channel measurement in the decoding process to enable an assessment to be made of the required coding complexity. The method of modulation is chosen to suit the code. The reliability of each bit is measured by the amplitude of the received tone, and an analogue measure of the phase transition between successive bits. The reliability results are then used to make the decoding more effective.

A significant performance improvement can be achieved without introducing an overall system delay beyond one frame. The effects of frequency selective fading can be reduced by the use of the error correcting code across the frequency band, since the error rate is essentially determined by the tones of lowest amplitude.

5 Wide Bandwidths

5.1 General Limitations

Systems employing data transmissions in the h.f. band have generally been designed for operation with voice channel equipment, and signal bandwidths have so far not exceeded a few kilohertz. At frequencies reasonably close to the optimum working frequency (o.w.f.), such bandwidths have provided useful protection against selective fading. When considering wideband modulation methods for h.f. skywave transmission, it is relevant to examine the bandwidth limitations of the channel. The absolute maximum channel bandwidth, based purely upon signal-to-noise ratio, ranges from the lowest usable frequency (l.u.f.) to the m.u.f.

The l.u.f. is determined by the minimum acceptable signal-to-noise ratio. Frequencies below the l.u.f. provide ratios that are too poor for useful communication. The

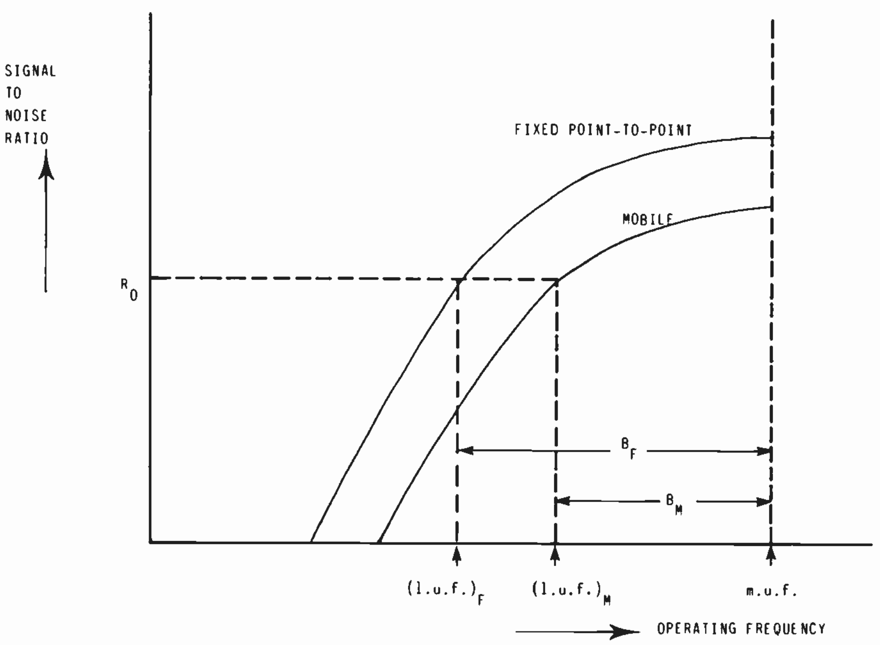

Fig. 4. Maximum operating bandwidth.

l.u.f. depends upon the radio equipment characteristics such as transmitter power and antenna gain and upon external noise and interference levels.

The m.u.f., however, is purely a characteristic of the ionosphere, propagation path and time of day; it is independent of radio equipment and noise level. The maximum bandwidth therefore depends upon the maximum acceptable error rate determined from the just tolerable signal-to-noise ratio, R_0. This bandwidth, B_F, for a fixed ground station might range from a few megahertz during favourable daytime conditions to less than 1 MHz at night. B_F is shown schematically in Fig. 4. An h.f. mobile would, by contrast, have a higher l.u.f. and consequently a smaller available bandwidth, B_M, because of a much smaller effective radiated power as a result of reduced antenna efficiency and nominal transmitter power.

This maximum bandwidth, the difference between the m.u.f. and the l.u.f., is an overestimate; in practice the bandwidth is limited by channel dispersion and interference.

5.2 Channel Dispersion Effects

The most convenient way of determining the echo structure of signals transmitted obliquely is by the ionosonde technique,[5] but with the transmitter and receiver at different ends of the path. These oblique incidence sounders, employing pulses of 10 µs to 100 µs duration, have provided direct information on multipath characteristics of ionospheric paths required for the design of wideband communication systems. Two examples are shown in Fig. 3. Evidence from h.f. over the horizon radar shows that range resolution requires a wide signal bandwidth, but that it is seldom the ionosphere can effectively support an instantaneous bandwidth greater than about 100 kHz. The problems that arise from delay distortion differ according to the type of wideband signal in use. For a true spread spectrum signal, the problem of acquiring and maintaining synchronization to a fraction of the spreading sequence period is extremely difficult, even in the absence of multipath. For spread bandwidths of 500 kHz or greater, an accuracy of synchronization significantly less than 1 µs would be required, which implies an improvement of several orders over existing h.f. modems. The synchronization problem becomes more acute if the dominant propagation mode changes across the signal bandwidth; this feature can act as a significant bandwidth limitation. A frequency hopping system, however, may only require bit synchronization at the data keying rate, although care must again be taken if the hop crosses to another propagation mode.

5.3 Interference Effects

Experimental work[20] has shown that interference is an important cause of errors in h.f. data transmission. Indeed, a dominant cause for degradation to h.f. communications[21] in the aeromobile band has been narrowband interference from other legitimate users of the allocated frequencies.

The ability of a data system to operate in the presence of interference depends upon the correlation between the required signal and the interference, and the ratio of the required signal power to the interference power. Since a signal pulse of bandwidth F and duration T has $2FT$ independent values, the designer of wideband systems has freedom to realize low correlation. The total interference power accepted into the receiver, however, may give poor system performance.

Experimental results have tended to show that spreading the signal spectrum over a few kilohertz at h.f. generally gives poorer performance than when narrowband signals are used. Interference at h.f. has a very irregular power spectral density; the chance of finding, at random, a clear range of frequencies for a narrowband signal is therefore greater than the chance of finding a relatively uncluttered wider bandwidth.

6 Techniques for Wide Bandwidth Applications

6.1 Matched Filter Systems with Wideband Correlation

Some systems use a wideband signal that is detected by a matched filter. As an example consider chirp[22] which

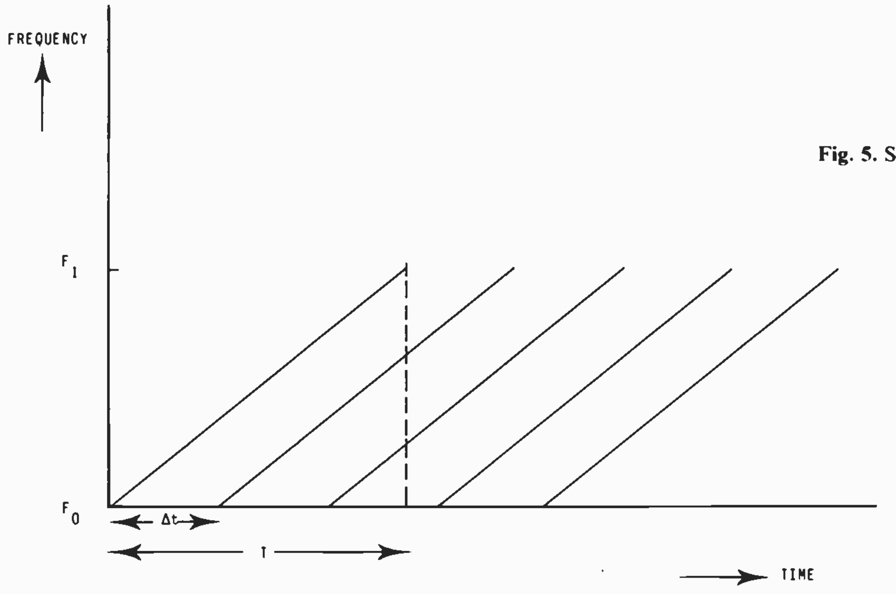

Fig. 5. Sequence of linearly swept overlapping signals.

consists of a swept frequency signal traversing a frequency band from f_0 to f_1 in time T. (f_1-f_0 is not necessarily restricted to the signal bandwidth and T is not necessarily the same as the input data interval.) The signal is detected at the receiver by a matched filter which has a frequency–group delay characteristic complementary to that of the transmitted signal. A compressed pulse appears at the output of the filter. This pulse has a width equal to the inverse of the frequency spread and an amplitude $[(f_1-f_0)\,T]^{\frac{1}{2}}$ times the amplitude of the transmitted signal. The key to achieving high data rates with a chirp system lies in the action of the matched filter and the time compression that it produces.

If a filter is matched to a linear frequency sweep, the output pulse envelope is of the form $(\sin x)/x$. Shaping of the transmitted signal envelope, and/or the use of a non-linear frequency sweep can also be used to suppress the pulse sidelobes and to concentrate the signal energy into the main pulse. If a sequence of swept signals (see Fig. 5) is transmitted, each of duration T s at intervals $\Delta t = 1/(f_1-f_0)$ s apart, it is therefore possible to produce a sequence of non-overlapping compressed pulses at the output of the matched filter in the receiver. The behaviour over an h.f. channel is then as follows:

(a) Under moderate multipath conditions, the chirp system performs better than conventional multitone d.p.s.k. systems because the differential phase comparison is effectively made between signal components separated by the signal interval Δt, rather than the longer signalling interval T appropriate to multitone systems. Thus, slow changes in the multipath conditions can be more effectively followed.

(b) Under extreme multipath conditions, there is a severe problem of intersymbol interference because the signalling rate is comparable with the multipath delays.

6.2 Matched Filter Systems with Signal Gating

Consider a pseudo-random noise (p.r.n.) system with overall symbol duration T, signalling rate D and individual chip width t_w (see Fig. 6); each symbol is composed of a p.r.n. sequence. The matched filter must, in this instance, pass all of the frequency components of each chip. The system bandwidth which is open to interference is therefore the reciprocal of the chip duration rather than the input signal bandwidth. There

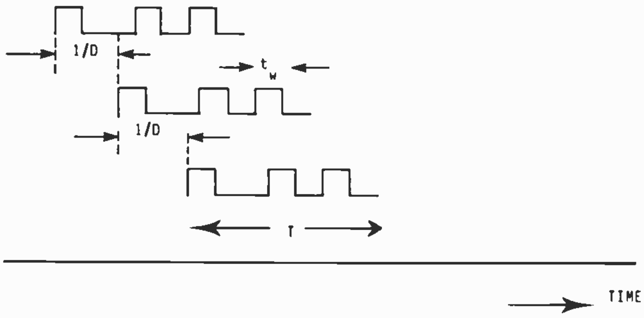

Fig. 6. Sequence of pseudo-random noise signals.

is consequently a higher probability of encountering an interfering signal and, in principle, any gain should be cancelled out on the average. In practice, however, interference is not uniformly distributed; the effect is to reduce the peaks and to fill in the troughs of the performance curve. The performance now depends upon the mean interfering power over the whole band. It is less affected by its statistical spread and thus a more constant level of performance can be attained.

It is possible to select only a single mode and to discriminate against the others by time gating. There are two major implications:

(a) The output pulse width of the matched filter must be much shorter than the typical delay time between modes (i.e. the signal bandwidth must be relatively great). With typical delays of 1 ms, the pulse width should ideally be less than 300 μs, which implies a bandwidth of at least 3 kHz.

(b) Time synchronization of the detector gate must be accurate, otherwise the delayed signals may degrade the decision threshold. The gate must consequently remain closed until all multipath components have been received, otherwise there is the danger of a late signal from a previous bit being confused with the signal from a new bit.

6.3 Direct Sequence Spread Spectrum

The modulation of the message signal by a fast rate pseudo-random sequence can be used to produce a spread spectrum signal.[23] This provides an alternative, but mathematically equivalent, approach to the matched filter pulse compression type of system.

At the receiver, a local replica of the pseudo-random sequence is generated in synchronism with the incoming signal and is used to despread it, thus recovering the message. During the despreading process, any interfering signal is itself spread and, on the average, its level is reduced by the ratio of the signal bandwidth to the spread bandwidth. The system processing gain is therefore the ratio of the code chip period to the data period, the same result as derived previously. The system bandwidth which is susceptible to interference is again increased, as for the matched filter pulse compression system, and the same comments apply.

The chip length must again be much shorter than the delay time between modes. Under these conditions, code synchronization permits the selection of an individual propagation mode. Discrimination against other modes operates with the same processing gain as for interference. Moreover, because of the spreading action of the code, the other modes become randomized and noiselike; they do not produce the same degree of intersymbol interference. However, the spread spectrum system is less efficient in this respect than the matched filter technique, for which precise gating can completely suppress all multipath interference.

7 The Future

The impact of very large scale integration (v.l.s.i.) technology has been recently analysed[24] for airborne communication systems. It is clear, however, that v.l.s.i.

will be evident in all types of future communications systems. It provides the ability to reduce size, weight and power consumption of existing equipment and to increase the overall system reliability. It also leads to the introduction of more complex systems by introducing other techniques and applications which have not previously been possible due to the lack of necessary technology. The following comments are intended to provide a brief insight into such trends as are relevant to h.f. applications.

7.1 Modulation and Coding

It has already been emphasized that previous attempts at adaptive equalization have proved to be too slow to follow changes in the propagation characteristics of the h.f. medium. Recent approaches,[19] described in Section 4.4, using coding as well as complex modulation schemes, rely on advanced technology for their successful implementation. A different approach could use information received about the propagation medium in the data stream itself. The application of Kalman filtering techniques[25] should enable the receiver to compensate the incoming data stream for the effects produced by the medium. Although it is becoming increasingly common when applied to navigation systems,[24] the problem is much more extreme for an h.f. data communication system and considerable further work is necessary to produce a viable system.

There will be increasing emphasis on the need to protect information whether it be from unauthorized users or from unwanted interference. This can be achieved by the use of advanced modulation techniques and encryption. The latter is most easily effected for voice signals if the speech waveforms are digitized, while the use of spread spectrum techniques to overcome unwanted interference is also readily implemented through the use of digital waveforms. Sophisticated spectrum spreading may involve encoding, data symbol interleaving and modulo-two addition of a pseudo-random noise data sequence. Powerful codes, such as Reed–Soloman, are now capable of correcting a high percentage of errors. V.l.s.i. techniques enable high levels of data interleaving to be used in order to distribute any bursts of errors into a random sequence when the data stream is de-interleaved at the receiver.

7.2 Digital Speech

Voice encoding techniques have been available for a number of years. The principle is to remove the redundant information from the speech signal and convert the result into a narrow digital bandwidth. One of the disadvantages, however, is that the resultant reconstituted speech is not always very clear.

Less sophisticated techniques using limited vocabulary voice recognition[26] combined with speech synthesis systems have been more successful. The baseband voice information to be passed over the medium is reduced to a minimum by pre-processing speech signals before transmission; this enables merely the appropriate address of each word in memory store to be transmitted. Various integrated circuits are now available on the market which are capable of generating highly realistic speech outputs. Recent trends have tried to improve the accuracy of translation rather than extend the size of vocabularies used. It is now possible to achieve,[28,29] with a 'trained' speaker, a 100-word vocabulary with 99% accuracy; the corresponding figure for 'untrained' speakers, however, falls far short of this value.

7.3 Adaptive Antennas

The improvement in circuit reliability achieved by using fixed or rotatable directional antennas[6] at h.f. is well known. In the h.f. band, antennas for mobile applications will continue to cause problems of efficiency; the fundamental limitations are caused by the small physical size compared to a wavelength. For ground based systems, however, the use of antenna arrays will become more common. V.s.l.i. techniques provide the processing power necessary to perform efficient wavefront analysis. Such V.l.s.i. ;edure can determine the constituent parameters of a multicomponent wavefield from measurements of complex amplitudes of signals received in the elements of an antenna array.[30] The dynamic nature of the h.f. medium necessitates the use of a fast processing capability to optimise the system performance.

Natural and man-made interference arriving from a different azimuthal direction to that of the wanted signal can be considerably reduced in amplitude by suitable phasing of the array to produce nulls in the radiation pattern of the receiving antenna. A similar principle can be applied in the elevation plane. Multimode propagation may produce two signals of comparable amplitude arriving at different elevation angles resulting in deep fades. A null in the antenna radiation pattern directed towards one of these components will considerably reduce the signal fluctuations. It is unlikely that such a technique will be effective in reducing within-mode fading, owing to the small angular separation between the components of each mode. Nevertheless, adaptive arrays should be effective in attenuating unwanted transmissions and weaker ionospheric modes which arrive from directions well separated in the angular domain from the main signal.

7.4 Digital Filters

Applications which rely upon fast adaptive processing through equalization and voice analysis techniques demand the use of filters providing high stability and performance. This can be achieved through the use of v.l.s.i. technology in the implementation of digital filters.

7.5 Future Systems

Although future systems will undoubtedly be considerably more complex than those at present on the market, v.l.s.i. technology will allow the new equipment to occupy the same volume for somewhat similar weight and power consumption requirements as current communications transceivers. This principle is an underlying factor in the trend towards the realization of multiband, multimode radio communication systems.

Multifunction systems are also becoming more sophisticated. These rely upon the use of a common data link not only for all communication needs but for those of navigation and surveillance as well.

8 Conclusions

A review has been presented of the problems inherent in transmitting high data rates over h.f. channels. Groundwave communication is more straightforward than skywave; it can be assumed that the groundwave is merely an attenuated, delayed but otherwise undistorted version of the transmitted signal. Ionospheric skywave returns, however, in addition to experiencing a much greater variability of attenuation and delay, also suffer from fading, time dispersion, delay distortion, frequency shifting and spreading. Typical magnitudes and variabilities of these quantities have been determined and their effect upon the received signal described.

The primary limitation imposed by multipath propagation is that the signalling rate must be kept well below the reciprocal of the multipath delay to avoid the effects of intersymbol interference. Mobile applications present serious problems with the limited available transmitter power, inefficient antennas and the wide range of distances (and hence frequencies) to be covered.

Multitone systems enable the data rate to be increased at the expense of increased bandwidth. However, circuits for mobile applications which are unable to employ post-detection diversity combining and to operate at frequencies close to the m.u.f. suffer from narrowband frequency selective fading within the 3 kHz channel.

Adaptive systems have been developed to attempt to equalize the dispersive effects of the channel. In practice such systems are unable to respond sufficiently rapidly to the variations of the channel characteristics. Error rates can be decreased by the use of powerful e.d.c. techniques associated with interleaving to avoid the effects of burst errors. Such techniques, however, may involve operationally unacceptable processing delays for digital voice applications.

Current systems have tended to be limited to operation with conventional voice channel equipment. Wideband techniques using matched filters associated with either wideband correlation or signal gating show promise, but the fundamental problem of signalling rate remains. Similar comments apply to direct sequence spread spectrum systems. The bandwidth limitations imposed by the channel centre around the dispersive characteristics and the interference. Large spread bandwidths imply significant synchronisation problems which become more acute if the dominant propagation mode changes across the signal bandwidth.

It is clear that the problems inherent in the design of modems to achieve satisfactory transmissions at 2·4 kbit s^{-1} over h.f. channels have not yet been adequately solved for the mobile user. With the rapidly advancing state of microelectronics, and techniques of v.l.s.i., it is likely that there is considerable mileage to be gained from using sophisticated signal processing and adaptive techniques employing Kalman filtering and speech recognition for digital voice applications.

9 Acknowledgments

The author would like to thank Mr. D. R. Sloggett of Racal Milgo and Dr. J. P. Sudworth of the Royal Aircraft Establishment for helpful discussions and suggestions.

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11 Appendix: A simplified expression for the received signal

The complex transmitted baseband signal, $E(t)$, can be represented by a Fourier integral in terms of its Fourier transform, $F(f)$:

$$E(t) = \int_{-\infty}^{\infty} F(f) \exp\{2\pi j f t\}\, df \qquad (5)$$

The exact form of $F(f)$ is unimportant. For a single mode of propagation, the distorted baseband signal can, to a first approximation, be expressed as

$$E_R(t) = g(t) \int_{-\infty}^{\infty} F(f) \exp\{2\pi j(ft - \phi)\}\, df \qquad (6)$$

where $g(t)$ is a gain factor ($g \leqslant 1$) and ϕ is a phase modification, a function of frequency, imposed by the propagation medium. The group velocity or delay τ, is determined by that value of t which makes the phase $2\pi j(ft - \phi(f))$ stationary with respect to frequency. Hence

$$\tau(f) = d\phi/df = \phi'(f) \qquad (7)$$

If f_1 denotes the carrier frequency, $\phi(f)$ can be expanded in a Taylor Series about $f = f_1$, thus:

$$\phi(f) = \phi(f_1) + (f - f_1)\phi'(f_1) + \tfrac{1}{2}(f - f_1)^2\phi''(f_1) + \ldots \qquad (8)$$

This can be simplified to:

$$\phi(f) = \phi(f_1) + (f - f_1)\tau(f) + P(f, \tau) \qquad (9)$$

where P is a function of first and higher derivatives of the group delay with respect to frequency. If $\phi(f_1)$ is denoted by ϕ_1 and $\tau(f_1)$ by τ_1, then (6) becomes:

$$E_R(t) = g(t) \exp\{2\pi j(f_1\tau_1 - \phi_1)\} \int_{-\infty}^{\infty} F(f) \exp\{2\pi j f(t - \tau_1)\} \exp(-2\pi j P)\, df \qquad (10)$$

Let

$$\hat{E}(t) = \int_{-\infty}^{\infty} F(f) \exp(-2\pi j P) \exp(2\pi j f t)\, df \qquad (11)$$

and

$$G(t) = g(t) \exp\{2\pi j(f_1\tau_1 - \phi_1)\} \qquad (12)$$

where G is a complex gain. Then for the jth mode, the received signal (10) becomes

$$E_{Rj}(t) = G_j(t)\, \hat{E}_j(t - \tau_j) \qquad (13)$$

In the Rayleigh fading model, $G(t)$ is a complex, zero mean, Gaussian process with identically distributed real and imaginary parts. Random gains associated with different modes are assumed to be independent.

Consider the power spectral density $P_{Gj}(f)$ for the jth mode to have a Gaussian shape. If v_j is the Doppler shift, A_j the r.m.s. gain ($0 \leqslant |A_j| \leqslant 1$) and $2\sigma_j$ the Doppler spread, the power spectral density is

$$P_{Gj}(f) = A_j^2 (2\pi\sigma_j^2)^{-1} \exp\{-(f - v_j)^2/2\sigma_j^2\}. \qquad (14)$$

Now $P_{Gj}(f)$ is the Fourier transform of the autocorrelation function $\rho_j(\tau)$ where

$$\rho_j(\tau) = \langle G_j^*(t)\, G_j(t + \tau) \rangle \qquad (15)$$

and $\langle\ \rangle$ denotes the expected or mean value and the asterisk denotes a complex conjugate.

Then

$$\left.\begin{aligned} \rho_j(\tau) &= \int_{-\infty}^{\infty} P_{Gj}(f) \exp(2\pi j f \tau)\, df \\ &= A_j^2 \exp(-2\pi^2\sigma_j^2\tau^2 + 2\pi j v_j \tau) \end{aligned}\right\} \qquad (16)$$

Hence the random gain $G(f)$ is also a function of A_j, σ_j and v_j. Thus

$$E_{Rj}(t) = G_j(A_j, \sigma_j, v_j, t)\, \hat{E}_j(t - \tau_j) \qquad (17)$$

as given in equation (2) of Section 3.

For the groundwave, the delay τ_g is independent of frequency. Thus $P = 0$ and $\hat{E}(t) = E(t)$. Also $v_j = \sigma_j = 0$. Hence (17) becomes

$$E_{Rg}(t) = A_g E(t - \tau_g) \qquad (18)$$

as given in equation (3).

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Industrial re-training programmes for technicians and craftsmen

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Based on a paper read at the IERE Conference on Retraining in the Electronics Industry for the Microprocessor Age held in London in July 1980

SUMMARY

This paper follows the introduction of a typical microprocessor-based product through a medium-sized company and specifically identifies the training needs of the technicians.

The technician job functions are identified, where they are in the company, and the tasks they will be expected to perform.

A microprocessor-based test system is described, and the specific product differences from its predecessors used to identify the re-training requirements.

Suggestions are made for training modules for various skill grades and jobs.

This detail is then consolidated into a company training programme covering a three-year period aimed at ensuring that the technicians are taught what they should know when they need to know it.

It is concluded that successful training must be specific to the application, with tight links between the teachers and the industrial environment.

Editorial note: For convenience, the title 'Technician' is used throughout the paper although some of the job descriptions are clearly appropriate to the 'Technician Engineer'.

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1 The Electronics Company

Many technology-based industries cannot achieve increased prosperity or growth by simply increased output, better production methods, or more aggressive sales policies.

The cost/performance ratios of new designs, coupled with the market-place enthusiasm for new technology products makes new product development a very rewarding exercise, providing high growth, profits and employment prospects.

This realization has led to the inevitable shortage of design engineers, particularly those with microprocessor or software experience. As the new products pass through the company then new skills and methods are required in other departments and very soon the whole company is changing. The ability to manage change is the management skill of the microprocessor age.

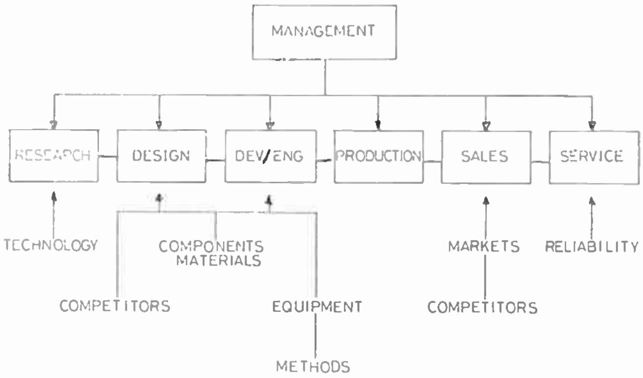

Fig. 1. Company functions.

Figure 1 shows the company functions where technically qualified staff are employed. Many small electronics companies are organized like this, with ideas originating in Research, being designed and developed, engineered for Production, manufactured, sold and then serviced. As the new product progresses through the company, more and more information is generated. This information is generally broken down into functional detail so that less and less user skills are required. By the time production and sales are reached the technical details usually have little significance.

If we look at the impetus for change inside the company we see that during the design and development phase there are external pressures to use new technology, new components, materials and equipment. In the Sales Department there is often great awareness of competition and outside opportunities. However, the production inputs are almost completely internal. The manufacturing and testing methods are passed on from Engineering, the volumes are passed back from Sales, and cost control from above. This introspection, together with the low operator skill, leads to very short term operating policies, with very little awareness or consideration for external factors. The consequence is that technicians and craftsmen in Production have little opportunity for self development, or to use different skills, unless they change jobs or deal with new products. The situation must be far worse in industries which are not expanding.

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2 The Technician's Role

Table 1 shows the technical spectrum of ability in the company. Of those with technical qualifications the technicians and craftsmen represent the highest numbers, and the percentages on the diagram are typical of a medium-sized electronics company (250–1000 employees).

Table 1

Company technical spectrum

Grade	Researchers	Designers	Engineers	Technicians	Craftsmen	Skilled Operators
Qualifications	Ph.D.	M.Sc.	C.Eng. B.Sc.	HNC	ONC 'O'	CSE —
Numbers	2%		10%		20%	
Future needs	?	increasing		?	decreasing	

It must be accepted that for many reasons the need for graduates and qualified engineers will grow. The knowledge, versatility and low wage differential of a qualified engineer make him the best buy in periods of change.

Similarly, as automation proceeds the low skill operator is displaced, and without dramatic growth the employment drops. The role and potential of the technician is not so obvious.

Table 2 shows a list of the typical technician job descriptions, and their functional distribution within the electronics company.

From their job descriptions one quickly realizes that the technician is primarily in a technical support role, i.e. assisting R & D staff and documenting detail, testing production output and ensuring its technical quality, handling technical enquiries in the Sales Department, servicing the products in the field etc. We rely on his brain.

The craftsmen grades are able to interpret drawings and other engineering information, but they use their manual dexterity. It is through them that the feasibility of a manual task is established and its method finalized.

3 The New Product

The programme shown in Fig. 2 represents a typical new product, and the milestones reached as the project progresses from concept through to production and sales.

This gives an indication of the timescales, which are considered to be typical of a medium-sized project (Engineering investment £250k). Obviously small projects and variants of existing products could be produced faster.

The technician training programme must present the required material at the appropriate time in the product development programme, so that it relates directly to the day-to-day role.

Furthermore re-training should concentrate on differences between the new micro-based product and its predecessors, together with changes in job function and production methods. Those doing the training must therefore have some knowledge of the product, its production and intended applications.

The block diagram (Fig. 3) and photographs (Fig. 4) show a new micro-based a.t.e. system which exemplifies this class of product. Key differences from its previous

Table 2

Distribution of technicians through company

Description	Research	Design	Engineering	Production	Sales	Service
Technicians						
Junior Design Engineer		×				
Lab. Technician	×	×				
Draughtsman		×	×			
Production Engineer			×	×		
Test Engineer				×		
Methods Engineer			×			
Q.C. Engineer				×		
Test Technician				×		
Buyer				×		
Application Engineer					×	
Internal Sales Engineer					×	
Service Engineer						×
Maintenance Engineer						×
Craftsmen						
Instrument Maker		×	×	×		
Tool Maker			×	×		
Model Maker		×	×			
Prototype Wireman	×	×	×			
Chief Inspector				×		

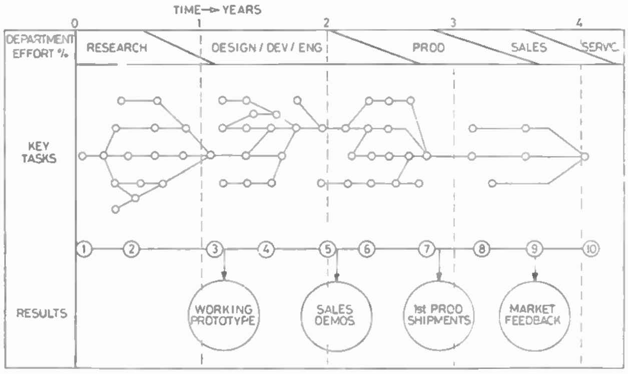

Fig. 2. The new product programme.

generation are as follows:

(1) It is a completely micro-based system using the latest l.s.i. devices. The i.c.s are complex and the p.c.b. interconnection density is high. P.c.b.s are standard Eurocard sizes.

(2) The bus-structured architecture allows a p.c.b. to be mounted anywhere along a multi-layer back plane. There is no wiring in the system. Sub-station interconnections are via IDC connectors and ribbon cable, not wiring looms.

(3) P.r.o.m.-based firmware controls all machine functions which are time shared and therefore there are very few static states, either analogue or digital.

(4) The machine gives the operator plain language instructions through a front panel alpha-numeric display. All test programs are entered via simple guided instructions on a v.d.u. There are no instrument controls and all operating software is 'transparent'.

(5) A wide range of customer options, both hardware and software requires fundamental re-appraisal of the testing and commissioning functions.

(6) The product has become mechanically very simple, using a standard racking system and modular assembly methods.

In short, the mechanics have become easy, the hardware has become firmware and the software has become hard!

If we look at the consequences of these product differences, then the basic requirements of the necessary training emerge.

4 The Training Requirements

Table 3 lists suggested training modules directly related to the technical requirements of this product.

Those listed in A are easy and recommended for introduction and general awareness amongst company staff. Those listed in B are practical things which most technician grades should know. The courses listed in C will be specially selected for those test engineers and production engineers who will fault find and test the final product.

The detailed content of the courses cannot be dictated, as they will relate closely to the type of products being manufactured. An electro-mechanical industry dealing with its first micro-product will need to take more care than say a computer peripherals manufacturer.

These training modules can be grouped and matched against the job functions of the appropriate technicians. (Table 4).

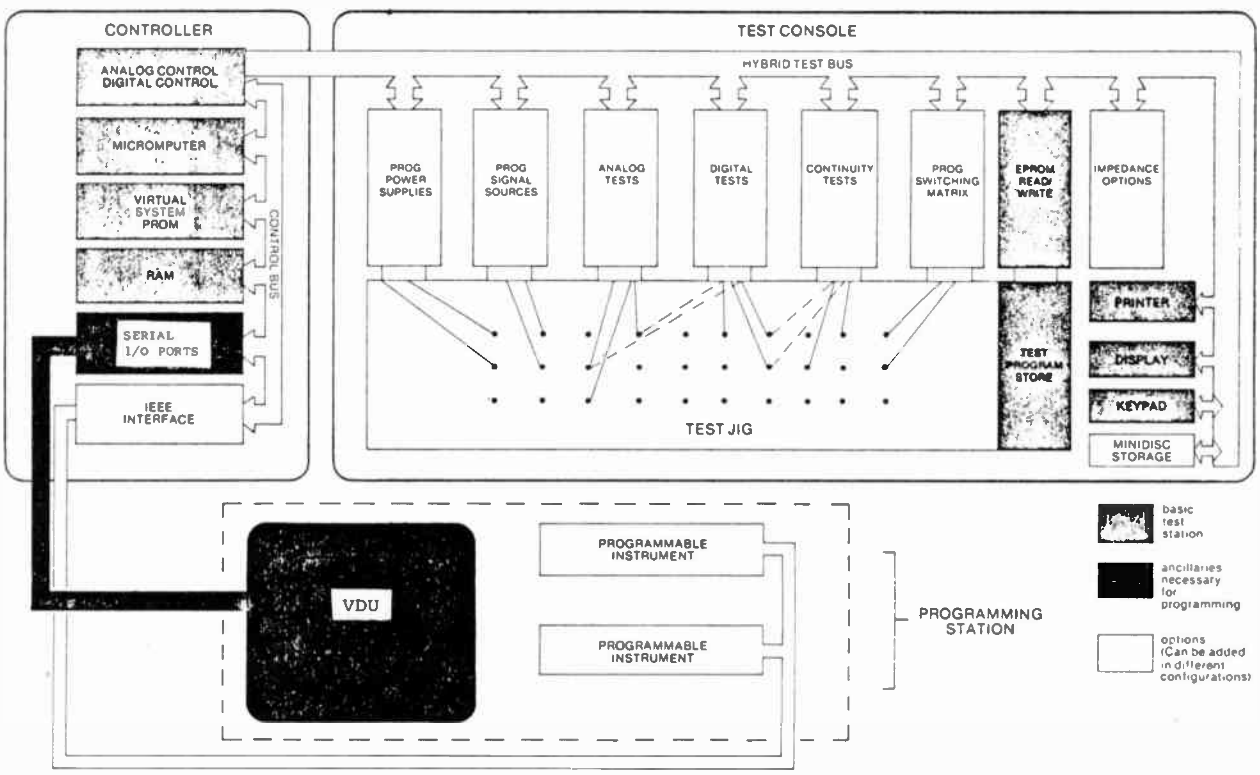

Fig. 3. Block diagram of a.t.e. system.

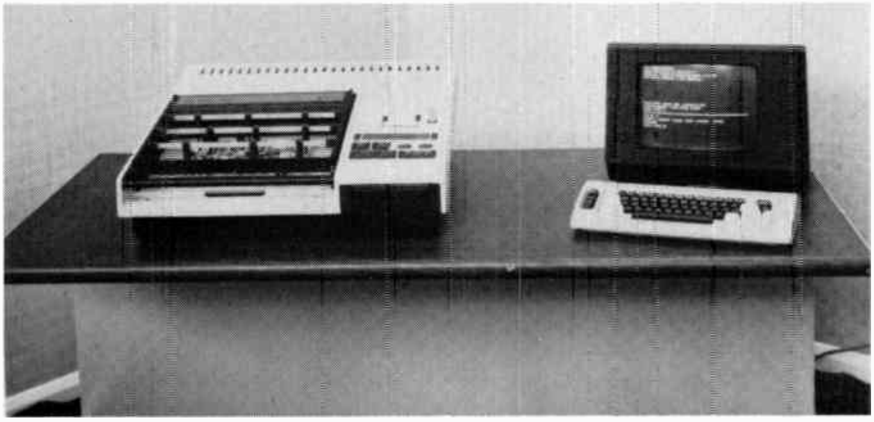

Fig. 4. (a) The A8000 a.t.e. system.

Table 3

Suggested Training Modules

A. 1. TEACHER'S TRAINING PROGRAMME
Agreement on course structure and content.

2. DIGITAL & MICROPROCESSOR BASICS
Digital basics, computer elements, time sharing, bus structures, the program.

3. DESCRIPTIONS OF NEW PRODUCTS
Block schematics, descriptions, key sales features, and technical specifications.

4. NEW ELECTRONIC COMPONENTS
Introduction and general description.

5. NEW PRODUCTION ASSEMBLY, TEST & PACKAGING METHODS
Automatic insertion, flow soldering, interconnection techniques, use of tooling etc.

6. NEW PRODUCT MARKET PROFILE
Volumes and anticipated cost structure.

B. 1(a) FULL TECHNICAL DESCRIPTION OF NEW PRODUCT

1(b) FULL TECHNICAL DETAILS OF ALL NEW ELECTRONIC COMPONENTS
Suppliers, specification, etc.

2. HYBRID CIRCUITS
Manufacturing basics, assembly, test and re-work ground rules.

3. HIGH DENSITY P.C.B.s
Assembly methods, shorts and opens testing, re-work and i.c. removal, multi-layers.

4. FAULT FINDING L.S.I. DEVICES
System partitioning, substitution, logic and current problems, introduction to a.t.e.

5. PROGRAMMING BASICS
Elementary programming techniques, use of high-level languages and the specific instrument language or instruction set.

6. USE OF PERIPHERALS
V.d.u.s, printers, p.r.o.m. programmers, standard interfaces, RS232, IEEE, etc.

7. USE OF DIGITAL TEST EQUIPMENT
Description and operation, logic analysers, signature analysers, storage oscilloscopes and custom test equipment.

C. 1. USE OF A.T.E.
Supplier training courses and in-house programming requirements.

2. DIAGNOSTIC SOFTWARE AND FIELD TEST ROUTINES
Self test programs, use of field test equipment, portable a.t.e. and detailed trouble shooting methods.

3. DIGITAL 'DISEASES'
Crosstalk, noise, r.f.i., timing problems, priorities timing faults, software, loops, lockouts etc.

5 Training Programme

The final programme should match the new product technology with the job specifications at the appropriate times, as shown in Fig. 5.

These modules are quite tightly coupled to the job requirements, and yet they consolidate nicely into introductory courses every six months, with the more difficult courses yearly.

Much of the material for the courses will be of direct relevance to the local technical college and polytechnic.

Table 4

Typical technicians' jobs on a micro-based project

DESIGN:

Junior Design Engineer/Lab. Technician: breadboard experimental circuits, check data sheets, check p.c.b. layouts and parts lists, enter code and program p.r.o.m.s, progress supplies, assist test with prototypes, check test schedules etc.

Draughtsmen: detail piece parts, layout p.c.b.s, liaise with model makers, produce production documentation, check parts lists, assemblies etc.

Instrument/Tool/Model Maker: build space models, fabricate and assemble prototypes, prove first drawings, produce experimental/prototype tooling, establish feasibility of production methods.

Wiremen: assemble prototype p.c.b.s from circuit drawings, check p.c.b. assemblies against drawings, cable routing and wiring as required.

ENGINEERING/PRODUCTION

Production Engineer: prove all production drawings, p.c.b.s and assembly information, specify assembly/reflow soldering jigs and fixtures, finalize assembly methods, manufacture test fixtures.

Test Engineer: supervise first production batches, verify test methods and test schedules, specify and assist design of a.t.e. fixtures, write a.t.e. programs for production p.c.b.s trouble shoot faulty p.c.b.s, final testing and adjustment to products, repair test equipment.

Q.C. Engineer: assure reliability of purchased components and p.c.b.s, routine checks on assembly, spot checks on test, maintenance of fault documentation, customer check on final products.

SALES

Applications/Internal Sales: technical telephone enquiries, precise definition of customer requirements, application notes, technical data sheets, supervision of demonstration stock, liaison with Service Department.

Service/Maintenance: Customer faults and field failures, software maintenance and retro-modifications, repair of test equipment.

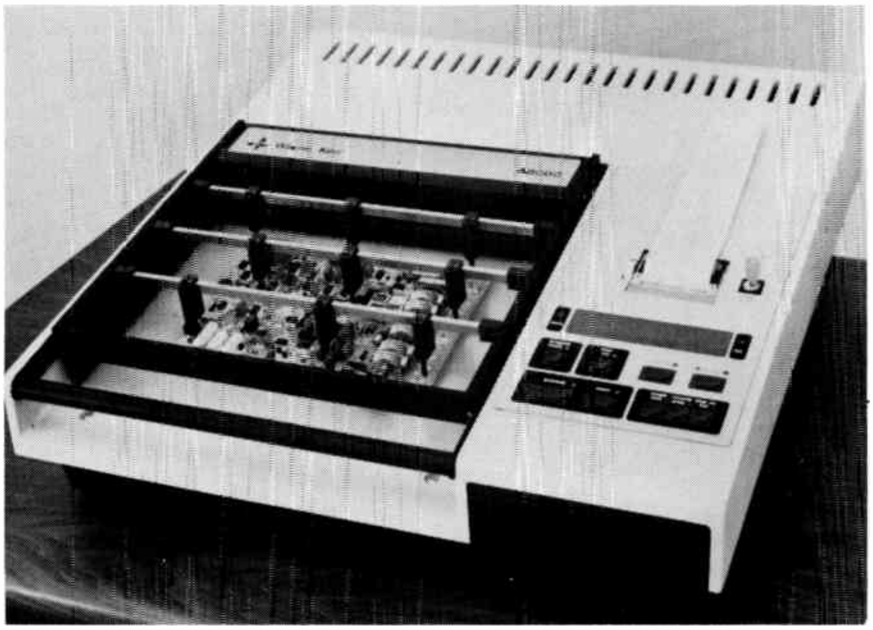

Fig. 4. (b) Close-up view of the test console and controller.

With sufficient forethought the material can be presented during evening courses at college, in-house or by private training companies depending on its scope and complexity.

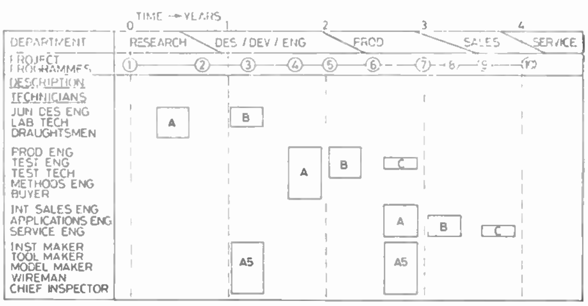

Fig. 5. The technician training programme.

The technician training programme at Brighton Technical College gave the technician staff at Wayne Kerr the skills to make the transition from electromechanical products to microprocessor-based products smoothly and successfully. The technicians were very keen and willing to accept training and consequently morale and attendance increased markedly.

Productivity/manufacturing of the new products was several times higher than that of their predecessors leading to attractive company benefits and much credit must be due to the Technical College for their practical approach to the training carried out.

6 Conclusions

(1) If the company considers the training and manpower planning requirements as the new designs proceed, then there is ample time to do the training properly without 'hire-and-fire' policies.

(2) The relationships between the technical college, or other training body and the company must be much closer than has been in the past.

(3) The teachers will have to be in close contact with new technology, and will need a very practical environment in which to develop their training material.

(4) The total sum of technical knowledge in today's new products is enormous. This must be sorted carefully and its presentation timed properly. The biggest danger is that middle-aged technicians will reject general-purpose courses as academic or not relevant. Sorting the wheat from the chaff is not a trivial exercise.

(5) Re-training is not a luxury overhead item, it is directly related to the company's strategic plans and can be integrated with them.

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Principles of independent receivers for use with co-operative radar transmitters

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SUMMARY

The paper describes the radar configurations known as bistatic and multistatic, in which one or more receivers are situated remotely from a radar transmitter, but operate in co-ordination with the transmitter to provide range and bearing information for targets illuminated by the transmitter beam. The advantages of such passive, remote receiver installations are discussed.

The main part of the paper is devoted to two topics: a description of ways in which the necessary synchronization reference signals may be provided to the receiver without the need for any fixed telecommunication link between transmitter and receiver; a description of the way in which target range and bearing information in bistatic systems may be obtained by fast, real-time, numerical solution of the bistatic geometrical relationships. An experimental, totally-independent, bistatic receiver using the transmissions from a u.h.f. air traffic control radar is then described and its performance discussed.

The paper concludes with mention of future work with such a receiver, to include the provision of moving target information and a multiple-beam phased-array receiving antenna.

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1 Introduction

The primary function of the conventional pulse radar is to determine the range and bearing of an object, usually referred to as a target. This is achieved by transmitting pulses of r.f. energy sequentially in different azimuthal directions and measuring the time taken for pulse echoes to return to a receiver co-located with the transmitter. Such radars, for simplicity and economy, generally make use of a common antenna for transmit and receive functions, the necessary isolation being achieved by a duplexing device and r.f. power limiter in front of the receiver; the common antenna, the rotation rate of which is insignificant by comparison with the pulse repetition rate of the r.f. pulses, ensures commonality of azimuthal direction between transmitted pulses and received echoes; the co-location of transmitter and receiver ensures ease of access by the receiver to timing signals associated with the emission of the r.f. pulses and their exact frequency. The provision, at the receiver, of an r.f. reference frequency coherent with that of the transmitted r.f. carrier to better than a few hertz over the pulse repetition interval is especially important when the small Doppler frequency shifts associated with moving objects are to be identified. Provision of such moving target information (m.t.i.) considerably aids the discrimination of wanted, but rather weak, target returns from larger, unwanted, echoes (clutter) due to sea waves, ground reflections, or known fixed objects.

The conventional radar, with co-located transmitter and receiver, is also rather susceptible to man-made interference sources. The transmitter cannot help advertising its position as a result of the r.f. pulse emissions and this allows interfering signals to be directed at the receiver by a jammer, thereby preventing the receiver from detecting targets in the direction of the jamming beam. If the jamming is sufficiently strong, it can enter the receiver not only through the main beam response of the antenna, but also through the sidelobes and cause target detection over a very wide range of azimuthal angles to be prevented. Sidelobe cancelling and adaptive nulling techniques are being widely investigated so that jamming signals entering through the sidelobes may be very strongly reduced and the detection performance in the main beam direction restored. However, cancellation techniques cannot be used to restore detection of targets which are in the same direction as the jammer. This is a serious problem since it is highly likely in the military context that targets of interest to the radar will be accompanied or covered by jamming sources.

Interest has thus increased in so-called bistatic radars in which the receiver is located some distance away from the transmitter site. If the separation is such that a typical jamming beam directed at the transmitter will not encompass the receiver site, considerable advantage will be obtained. Though the receiver may still experience a weak jamming signal from the jammer sidelobes, this will have a less serious effect; additionally, though targets and jammer are co-directional viewed from the transmitter site, an angular separation may exist when viewed from the receiver site. Cancellation techniques would then further reduce the receiver isolation to

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jamming, particularly if the receiver possessed high angular resolution associated with a large horizontal antenna aperture. Bistatic radar thus has the main advantage of a relatively simple, possibly mobile, receiver which is passive, not easily located and therefore less vulnerable. The need to have separate transmit and receive antennas can be turned to advantage; the receive antenna can be designed to give high angular resolution and can be much more flexible, in terms of advanced signal processing to form multiple beams or adaptive nulls, than would be possible with a conventional common transmit/receive radar antenna.

This paper describes work directed towards overcoming the two principle disadvantages of bistatic radar receivers. First, as a result of the separation of transmitter and receiver, it is not a simple matter to provide a coherent r.f. reference, r.f. pulse repetition timing and transmitter pointing information at the receiver. Second, the normal plan-position-indicator (p.p.i.) display may not be used directly at the receiver, since the position of a target is no longer directly proportional to time delay between r.f. pulse emission and echo reception, but is a function of this delay, the transmitter pointing angle and the separation of transmitter and receiver; some computations must therefore be performed on the received echo signals if they are to be displayed to give a geometrically undistorted p.p.i. display.

2 Review of Previous Bistatic Radars

Some of the earliest radars, approximately 40 years ago, were of the bistatic type; these used c.w. transmissions, the presence of a target being detected by the interference between the direct transmitter-to-receiver signal and the reflected echo signal. However, the advent of the high power pulse microwave valve and efficient duplexers encouraged the development of monostatic radars, leaving the bistatic configuration for more specialized applications. Only very recently has significant interest been reawakened as a result of the benefits in situations of high interference.

One long-standing application of bistatic radar has been to use interferometric techniques between monostatic and bistatic receivers, using a single transmitter, to obtain improved target position accuracy and resolution as compared to that obtainable from monostatic radar alone;[1,2] this has been used in particular to track satellites and re-entry vehicles.

The bistatic system can, of course, be readily extended to use multiple receiving sites operating with a common transmitter and an early example (1960) of this multistatic technique for tracking satellites was the SPASUR system.[3]

The current interest in bistatic and multistatic radar has involved a number of studies[4–6] and an extensive research program, given the name Sanctuary.[7,8] The Sanctuary system is envisaged to use airborne transmitters, for better performance against low-flying targets and avoidance of terrain obscuration; the received echoes could then be detected and processed either by airborne or ground-based receivers. Most of the systems currently under investigation in Europe, including the UK, involve ground-based bistatic radar and are generally devoted at present towards gaining a better understanding of the properties of the bistatic configuration.

3 Geometric Configuration of Bistatic Radar

In the usually envisaged form of bistatic radar, shown in Fig. 1, the transmitter and receiver are separated by a distance, $2d$, which is a significant fraction of the maximum monostatic range of the radar r_m. A target is shown at distance r_t from the transmitter and r_r from the receiver, these distances often being referred to as slant ranges. The transmitter is taken to be of the conventional monostatic type with an antenna that rotates mechanically to give azimuthal surveillance by means of a fan or pencil beam of r.f. pulses. At the transmitter site, information is available on the transmit beam azimuth angle θ_t (and elevation angle ϕ_t in the case of a pencil beam), together with the r.f. carrier reference frequency and the timing of the r.f. pulses.

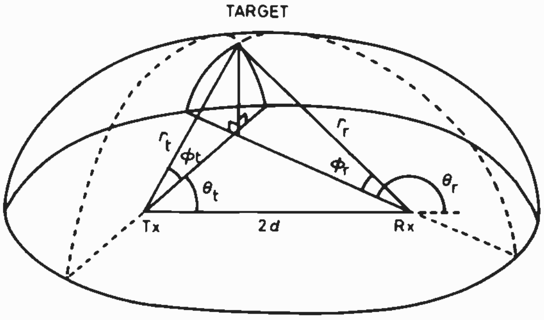

Fig. 1. Bistatic radar geometry.

The antenna at the bistatic receiving site cannot be of the same, mechanically-rotated, type as at the transmitter in this normal radar surveillance application; the angle of arrival of target echoes at the receiving site will change more rapidly with time, as successive targets at different ranges from the transmitter are illuminated, than the receiving antenna could follow. This difficulty can be solved, although with loss of antenna gain, by using an omni-directional antenna; however, the only intrinsically available input signals at the receiver then consist of scattered echo pulses from a target, or targets, with no directional information and the pulses that reach the receiver by the direct path from the transmitter. These direct path signals will vary greatly in magnitude, following the azimuthal radiation pattern of the transmitting antenna, but in principle they provide reference timing marks. The time delay, t, between receipt of the direct pulse and the scattered target echo pulse is given simply by:

$$t = (r_t + r_r - 2d)/c \qquad (1)$$

where c is the e.m. wave propagation velocity. A given value of t locates the target as lying on an ellipsoidal contour, the foci of which are the transmitter and receiver sites. If the radar video signals derived from these direct and echo pulses at a bistatic receiving site are fed into a conventional p.p.i. display and the display sweep rate synchronized with the transmitting antenna rotation rate, a radar display will be obtained, since the target position is defined by the intersection of the transmitting beam with the ellipsoidal surface. The display will, however, be a distorted display since the presentation format assumes that $t = 2r_t/c$ and therefore the displayed range R is given by

$$R = \frac{r_t + r_r}{2} - d \tag{2}$$

Targets at any position along the line joining transmitter and receiver are represented as having zero displayed range and cannot be resolved. The display distortion is that given by compressing the geometry so that transmit and receive sites merge to a single point, as shown in Fig. 2.

Since the transmitting antenna beam pointing direction, θ_t, must be known at the receiving site in order to achieve this display, this information may also be used to correct the distortion. For the case where target altitude is considered negligible compared to the ranges involved, a vertical fan beam transmitter being used, consideration of the bistatic geometry yields:

$$r_t = \frac{ct(ct+4d)}{2ct+4d(1-\cos\theta_t)} \tag{3}$$

Measurement of t and θ_t, for known d, followed by the above transformation then yields the target range from the transmitter, and provides an undistorted p.p.i. display centred on the transmitter; targets on the direct path between transmitter and receiver can still not be resolved, but the receiver site is shown in the correct geographical position on the display. This display correction can be performed by tailoring the display scan waveforms in analogue manner[9] according to equation (3), or numerically after digitization of the radar video signals;[10] the latter method is more flexible and better suited to other needs of radar signal processing.

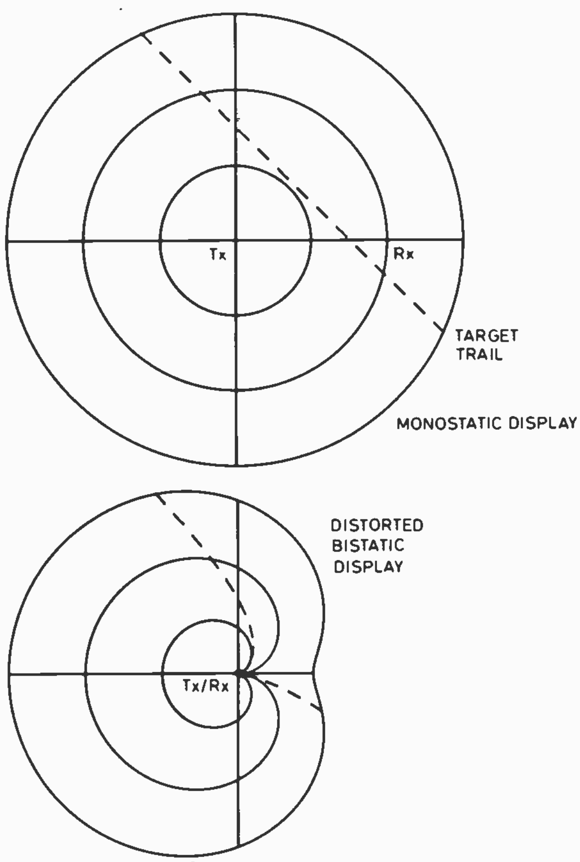

Fig. 2. Bistatic display distortion.

In order to obtain three-dimensional information about target position, it is necessary to measure three parameters out of the set θ_t, θ_r, ϕ_t, ϕ_r, t. If the bistatic receiver can be provided with an electronically-steerable or multi-beam one-dimensional array antenna, one angle of arrival (θ_r or ϕ_r) of echo signals may be measured which, with θ_t and t, satisfies the requirements. A planar, fully steerable, receiving array antenna could be used to derive the parameter set θ_r, ϕ_r and t. The various transformation equations between the parameter sets are given by Skolnik.[11] Such array antennas, moreover, provide receiving antenna gain and give protection against unwanted signals arriving from other angles, such as interference or target echoes from the transmitting antenna sidelobe radiation.

4 Provision of Reference Signals at Independent Receivers

Attention will now be directed towards methods of providing the various reference signals required at the receiving site.

4.1 Transmitter Pointing Angle

This is very low data rate information obtained at the transmitting site from the antenna driving gear, often through an optical shaft encoder. The information is in very suitable form for direct transmission over a low bandwidth link, such as a telephone line, between transmitter and receiver. It may be desirable nevertheless to avoid such a link, perhaps because the receiver is mobile, and there may exist also reasons why a radio propagation link cannot be established; in these circumstances, transmitter pointing angle may still be obtained to a fair degree of accuracy provided the receiver can detect the sweeping of the transmitter beam over the receiver site or its scattered signal from a fixed target at a known location.

In the case when the main beam may be seen directly, if the interval between successive passes of the main beam is measured using a digital clock, the beam direction relative to the transmitter–receiver baseline may always be inferred by measuring the fraction of the interval that has elapsed since the last pass. The method relies on the transmitting antenna rotation rate being constant, at least over a period of several complete rotations. Indications are, for conventional radar antennas, that the rotation rate stability is very good even under adverse weather conditions; cumulative timing errors may be avoided by resetting the digital clock on each pass. In total, with very simple digital circuitry for detecting the main beam maximum and providing the timing function, a transmit beam pointing direction indication to an accuracy of approximately 1° may be obtained.

If the transmitter has no consistent scan pattern or the direct main beam is not uniquely distinguishable in some way from other signals at the receiver site, there is no option but to use a telecommunications link.

4.2 Transmitted Pulse Train Timing Reference

The usual transmitter waveform consists of a repetitive train of short pulses or staggered groups of pulses, between 50 ns and a few microseconds wide, the width τ used being dependent on the required range resolution cell dimension $c\tau/2$. The transmitter duty cycle is usually in the region of 1%, but must also satisfy the requirement for the interpulse period, T, to allow sufficient time for pulse echoes to return from the maximum required range $r_m = cT/2$. In order to achieve useful range measurements, it is clear that timing measurement accuracy on transmitted and echo pulses must be a fraction of the pulse width.

In the conventional monostatic radar no difficulty exists since the transmitted pulse reference timing and the received echo pulse timing are made at the same location; timing accuracy is dependent on the bandwidth of the electronic circuits used and may easily be within a few nanoseconds. The obvious course with a remote receiver is to provide a telecommunications link between transmitter and receiver to carry the pulse repetition frequency reference; the link bandwidth would be directly related to the timing accuracy required and for short pulses a bandwidth of some tens of megahertz would be required. Once again, such a link may be avoided in many circumstances. As commented earlier, the signal obtained at the receiver consists of target echoes and usually some direct signal from the transmitter which fluctuates with the rotation of the transmitting antenna. If this direct signal is sufficiently strong, it may be used as the timing reference. The strength of this direct signal may be considerably enhanced by receiving it in a separate high gain antenna pointed directly at the transmitting site. However, deep nulls do occur in the transmitting antenna radiation pattern and the direct signal at the receiver may for short intervals of a few interpulse periods be below the detectable level; with low direct signal levels, multipath effects may also cause additional constructive and destructive interference, not only contributing signal nulls, but also timing errors.

These difficulties may be overcome if the transmitter pulse waveform characteristics (pulse length, interpulse period, stagger) are known and reasonably constant. The waveform is synthesized independently at the receiver using relatively simple digital circuitry. All that remains is to maintain synchronism between the two waveforms by applying minor timing corrections at the receiver when suitably strong direct signals from the transmitter are received. Since the waveform at the transmitter is usually derived from a temperature-controlled crystal oscillator, a simple voltage-controlled crystal oscillator (v.c.x.o.) at the receiver will generally provide sufficient stability between opportunities for resynchronization. In the worst case of resynchronization only once in an antenna rotation period of 10 seconds, a timing accuracy of 1 μs would result with an oscillator stability of 1 part in 10^7, typical for a v.c.x.o.; a radar using pulses shorter than a few microseconds would either require a higher stability oscillator or more frequent resynchronization.

For radars with random pulse trains it appears, nevertheless, that a telecommunications link would be necessary.

4.3 Transmitter R.F. Carrier Reference

Unless moving target information is required, the receiver only requires knowledge of the transmitter frequency to an accuracy smaller than the receiver i.f. bandwidth; this accuracy may easily be achieved independently of the transmitter, even without a crystal reference, from a commercial microwave source used as the receiver local oscillator. Random frequency agility in the transmitter would give rise to difficulties, but is not a very severe constraint since techniques for very fast frequency measurement now exist.

When m.t.i. is required, however, considerable complications arise in bistatic systems. One method of obtaining m.t.i. in monostatic radars with magnetron transmitters, where r.f. output is not coherent from pulse to pulse, is as follows: during the short time of the transmitted pulse, the phase of a stable c.w. oscillator in the receiver is synchronized to the transmitted pulse; after the end of the transmitted pulse, this oscillator maintains sufficient phase coherence required for down-conversion of echo signals and their separation into moving or stationary target categories. The oscillator stability must be such that any frequency drift over the interpulse period must be small with respect to the Doppler frequency associated with the required target velocity resolution. Generally, rather poor target velocity resolution is obtained with such a system since it is difficult to provide high free-running oscillator stability and yet maintain phase-synchronization performance. There is no reason why an identical scheme with comparable m.t.i. performance should not be used in a bistatic receiver, provided that direct pulses from the transmitter may be received and used as the phase synchronization reference. The constraints are much more severe than on the use of the direct pulses for obtaining the p.r.f. reference since the receiver local oscillator has to be phase-synchronized on every transmitter pulse. Unless a telecommunications link is provided, therefore, m.t.i. performance will be lost on all occasions when the direct pulses from transmitter to receiver fall below the receiver detection threshold.

The more common method of obtaining good m.t.i. performance in monostatic radars requires the use of a fully coherent transmitter in which one or more stable c.w. oscillators provide the r.f. carrier, which is then pulse modulated and amplified in a klystron or travelling wave tube. Given the previously discussed conditions of good direct pulse reception, there is no reason why a bistatic receiver operating with such a coherent transmitter should not obtain at least the reduced m.t.i. performance associated with the scheme of a reference oscillator synchronized to the direct pulses. To obtain bistatically the full m.t.i. performance of the monostatic radar would require a microwave frequency telecommunications link carrying the coherent signal or, perhaps more conveniently, highly accurate frequency references (atomic clocks) at both transmitter and receiver, periodically synchronized through a low bandwidth telecommunications link.

5 A Totally Independent Experimental Bistatic Receiver

5.1 System Description

A totally independent bistatic receiver has been constructed at UCL using the techniques outlined above to obtain the transmitter pointing angle and p.r.f. signals by local synthesis. The transmitter used is a civil air traffic control radar located at London Heathrow airport, some 25 km from the receiver site, operating in the u.h.f. band (600 MHz).

At present, the receiver uses a single omni-directional antenna; after downconversion and amplification video signals at 30 MHz suitable for both receiver synchronization and display are obtained. Receiver synchronization is performed during the main beam dwell period when the transmitter sweeps past the receiver. During this period, about 25 direct path pulses are obtained, from which the time when the centre of the main beam points at the receiver may be estimated. The number of direct path pulses are counted digitally during each main beam dwell period, the centre of the main beam being declared to occur when the number of pulses counted during each current main beam is equal to half the number obtained on the previous one. As each main beam centre signal is declared, a digital azimuth scan counter is reset, providing a zero reference for the transmitter pointing angle θ_t of Fig. 1. The azimuth scan counter is then incremented at a constant rate until the next main beam centre is declared, when the counter state is noted before being reset to zero. A total of 2048 discrete azimuth positions within the 360° horizontal rotation are provided by automatically increasing or decreasing the increment rate of the azimuth scan counter if the noted state at each zero reset is in error. In this manner, fluctuations of the nominal transmitter rotation rate are accommodated in the receiver, providing accurate transmitter pointing angle data (to $\pm 0{\cdot}2°$). It is assumed that the transmitter antenna rotates at a uniform rate, which leads to degradation in accuracy if the within-scan rotation rate fluctuates. For the antenna under consideration, a maximum error of $\pm 0{\cdot}8°$ in a steady wind speed of 30 ms^{-1} (70 miles/h) is incurred. In addition, errors in determination of the centre of main beam signal and in alignment of the transmitter-receiver baseline degrade the overall azimuth accuracy to about $\pm 1{\cdot}6°$. This figure is, however, within the transmitter antenna 3 dB beamwidth of 2·1°, and is deemed to be adequate for most purposes.

Receiver p.r.f. synchronization is also performed during the transmitter main beam dwell period. The receiver p.r.f. generator is controlled by a 10 MHz voltage-controlled crystal oscillator. The known transmitter p.r.f. and stagger pattern are generated by digitally counting the v.c.x.o. output signals to provide p.r.f. pulses at the appropriate times. Initial synchronization is performed during each main beam dwell period to align the transmitter and receiver p.r.f. signals. Just before this initial synchronization occurs, the relative timing of the two p.r.f. signals are compared, in order that the v.c.x.o. frequency may be altered to compensate for frequency drifts due to temperature variations in either the transmitter or receiver. This is necessary, since even a small frequency difference of just 5 Hz between transmitter and receiver p.r.f. oscillators introduces a timing error of the order of one r.f. pulse length over a single transmitter rotation. This p.r.f. 'flywheel' generator provides a p.r.f. signal accurate to better than ± 1 µs over the complete 6 second rotation period, which for present purposes is deemed to be adequate compared to the radar pulse length of 4 µs.

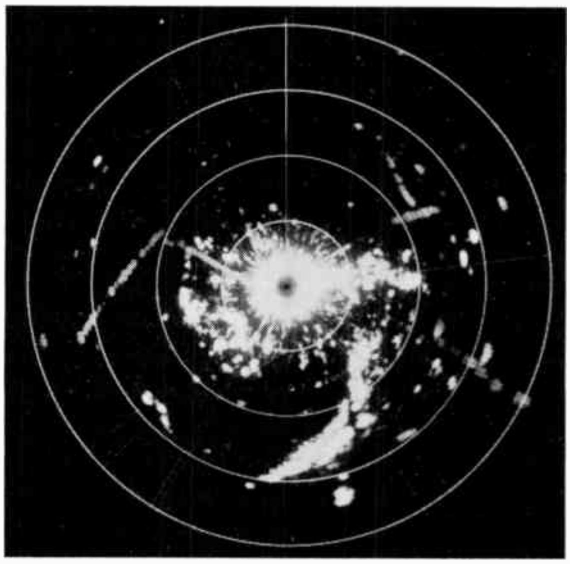

Fig. 3. Typical display record (distorted).

The azimuth rotation signal and the p.r.f. reference signal are used to drive a p.p.i. display, the display video signal simply being the downconverted, amplified and detected signals from the antenna. A typical display record is shown in Fig. 3. This display has not been corrected for the bistatic distortion described earlier, the transmitter and receiver baseline thus being collapsed to a point at the display centre as in Fig. 2. The displayed range for this typical display is R of equation (2).

5.2 Display Correction

Display correction is performed numerically by solution of equation (3) for every detected target. 'Target', here, refers not only to wanted targets such as aircraft, but also to clutter and stationary point targets such as buildings. As seen from the typical display of Fig. 3, there is a considerable amount of detected clutter in the bistatic radar coverage. Without any means of distinguishing between such clutter and any wanted targets, every detected echo signal must be distortion-corrected by assigning range (ct) and angle (θ_t) data to it and applying equation (3).

The rate at which all target 'hits' are declared is obviously a prime consideration here, since the speed at which any correction processor must operate is a direct function of the target hit data rate. The mean target hit data rate of the typical display of Fig. 3 is about 2000 hits per second, implying that the complete correction process must be performed in a maximum of 500 µs if real-time correction is to be realized. In the UCL system, a fast general-purpose micro-computer (Data General Micronova MP200) is used to implement the correction process, a single solution of equation (3) requiring 33 µs to execute using Assembly language, and 1210 µs using Fortran. Although it would have been preferable to use Fortran as the computer language for ease of transfer to other processors, it was immediately clear that Assembly language would have to be used for those parts of the process that required very fast operations. The resulting program is therefore a combination of Fortran modules for operator interface or parameter initialization and Assembler modules for fast real-time calculation of corrected data. To further increase efficiency and speed of operation, the term cos θ_t of equation (3) is obtained from a hardware look-up-table (read-only memory).

The correction processor is able to operate in real time on up to about 30 000 target hits per second, and is thus clearly able to correct the typical display of Fig. 3. At particular times, however, the instantaneous data rate may be very high, for example, at the start of each interpulse period where solid clutter produces continuous hits over a short range interval. For this reason, asynchronous buffer stores are provided on both the processor input and output to interface the highly variable incoming video and display data rates to the essentially constant data conversion rate of the processor.

A typical corrected display using this processor is shown in Fig. 4. The display is centred on the transmitter site, since the correction method used calculates the transmitter-to-target range, r_t. The radial spoke on this display indicates the direction of the receiver relative to the transmitter; the blank ellipse around this baseline is produced by ignoring all received echoes for a few microseconds after each direct path pulse. The transmitter and receiver sites form the two foci of this ellipse. This blanking corresponds to the small circular blanked zone at the origin of the conventional monostatic display or distorted bistatic display.

The use of a numerical process to correct for bistatic display distortion is extremely versatile. In the present system, the display range setting and the transmitter-receiver baseline length are under software control, and with only a little extra complexity, such functions as nominal p.r.f. and rotation rate might be brought under computer control. In addition, display formats other than the p.p.i. may be realized by calculation and solution of alternate correction equations. For instance, if a bright, daylight-viewable display is required, a standard raster-scanned television monitor might be envisaged. In the past, conversion from the polar coordinate p.p.i. to the cartesian coordinate television has often been performed by electrostatic storage tubes or closed-circuit television techniques. If, however, as in a bistatic radar receiver, some form of coordinate correction is in any case required, then it is a relatively simple matter to convert from distorted polar coordinates to either corrected polar coordinates or corrected cartesian coordinates by simple software alteration. However, if a television-type display is to be used, some form of television frame store will in general be necessary; with modern memory prices, such stores may be provided both simply and inexpensively.

Using the mid-point of the transmitter-receiver baseline as the cartesian coordinate system origin, and the receiver direction as the positive x-axis, the equations to be solved to yield cartesian coordinates (assuming the corrected range r_t of equation (3) has already been calculated) are:

$$\left.\begin{aligned} x &= r_t \cos\theta_t - d \\ y &= r_t \sin\theta_t \end{aligned}\right\} \qquad (4)$$

Solution of these equations requires only an additional

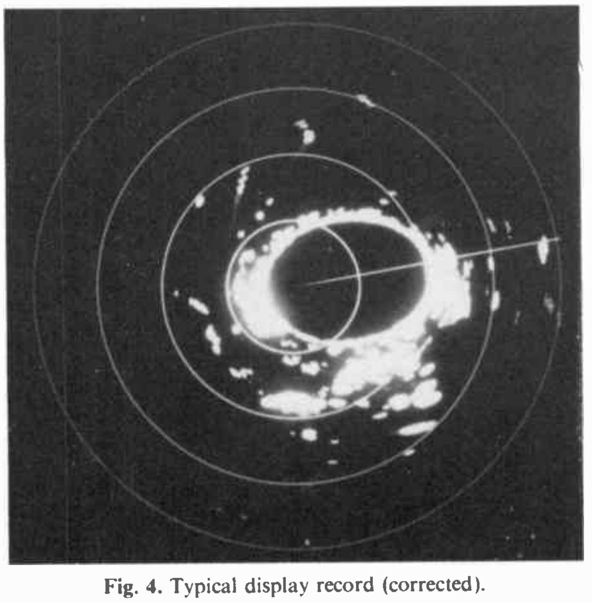

Fig. 4. Typical display record (corrected).

Fig. 5. Computer and receiver.

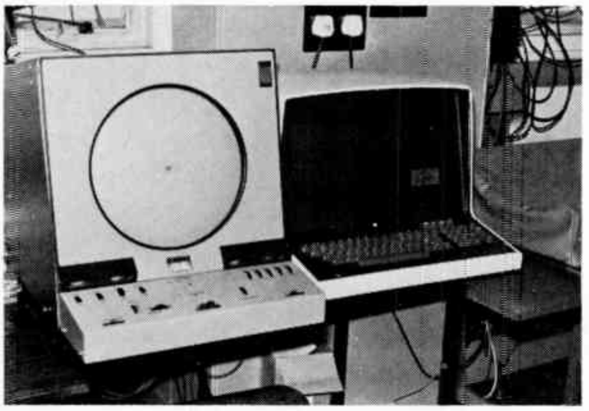

Fig. 6. P.p.i. and v.d.u. displays.

17 µs of processing time if both $\cos \theta_t$ and $\sin \theta_t$ are provided by the hardware look-up table, resulting in a maximum data processing rate of about 20 000 hits per second. A frame store for use with the UCL receiver is presently under construction to demonstrate the ease with which a bright display may be accommodated in the above manner.

The computer system and the p.p.i. display are illustrated in Fig. 5 and Fig. 6.

5.3 Range Performance

The comparative range performance of monostatic and bistatic radars is best illustrated by the use of the radar range equation. For a monostatic radar, a simple form of this equation is:[11]

$$P_r = \frac{P_t G_t^2 \lambda^2 \sigma_m}{(4\pi)^3 r_t^4 L_s} \tag{5}$$

where

P_r = received power (W)
P_t = transmitted power (W)
G_t = transmitting (and receiving) antenna gain
λ = r.f. signal wavelength (m)
σ_m = monostatic target cross section (m^2)
r_t = target range (m)
L_s = system losses

A bistatic radar will, in general, have different transmit and receive antenna gains, G_t and G_r, and the ranges of the target from both the transmitter and receiver will, in general, be different. In addition, the target cross-section will not, in general, be the same for a target viewed bistatically. The corresponding bistatic radar equation is therefore:

$$P_r = \frac{P_t G_t G_r \lambda^2 \sigma_b}{(4\pi)^3 r_t^2 r_r^2 L_s} \tag{6}$$

The range performance of the UCL bistatic radar system is in good agreement with that predicted theoretically, bearing in mind the significant decrease in the $G_t G_r$ product compared to the G_t^2 term of the monostatic radar equation (about 30 dB). Reliable detection for aircraft targets (of about 10 m^2 to 20 m^2 cross section is obtained up to about 40 nautical miles range, or about 75 km, targets occasionally being tracked out to ranges in excess of 70 nautical miles, or 130 km. Range here is defined as $(r_t r_r)^{\frac{1}{2}}$.

5.4 Resolution

The range, altitude and azimuth resolutions obtained with a bistatic radar depend largely on the correction system used and the choice of display origin. For example, if only the transmitter azimuth angle and range sum are measured, the azimuth resolution is given by the transmitter beamwidth if a transmitter-site origin is assumed; resolution will be a function of beamwidth, azimuth angle, baseline length, pulse length and range if a receiver-site based origin is assumed. Range resolution in either case is a complex function of range, azimuth pointing angle, baseline length, pulse length and additionally in the receiver-site origin case, transmitter beamwidth. For the transmitter-site origin case, the range resolution is never better than that obtained monostatically, $c\tau/_2$, where τ is the r.f. pulse length.

In particular instances, range resolution better than that obtained monostatically may be obtained by surveillance over appropriate areas.[1] If, for example, both the transmitter and receiver azimuth pointing angles are measured, the range resolution obtained is no longer a function of pulse length, but solely the transmitter and receiver beamwidths. With small beamwidths ($\lesssim 1°$) very small values of range resolution may be obtained at short ranges, though at long ranges, the resolution deteriorates very rapidly (since θ_t and θ_r become similar).

Altitude resolution similarly depends on the correction system used and the various parameters that are measured, as well as the value of the altitude itself. Unlike a monostatic radar, where the altitude resolution deteriorates as altitude increases, the bistatic radar measuring transmitter and receiver azimuth pointing angles and range sum realizes an improvement in resolution as target altitude increases. Better altitude resolution than that obtained with a monostatic radar may easily be obtained by decreasing the r.f. pulse length.

Present work at UCL involves the construction of a multiple-beam receiver to measure the angle θ_r. In addition to providing the receiver with some sidelobe protection, this will enable some altitude information to be obtained, though only at short range, due to the relatively large beam widths involved.

5.5 Accuracy and Resolution of the UCL Receiver

The overall accuracy of location of target position is a function of the accuracy of measurement of the range sum $r_t + r_r$, the baseline length $2d$ and the transmitter pointing angle θ_t. In addition to the basic synchronization accuracies mentioned earlier are quantization errors in both range and azimuth incurred through the use of the digital correction processor. The overall measurement errors in the quantities t, $2d$ and θ_t of equation (3) are $\pm 2{\cdot}7$ µs, ± 108 m, and $\pm 1{\cdot}7°$ respectively. For values of t in excess of 50 µs (values of r_t and r_r for targets more than about 4 nautical miles from the baseline), the maximum range errors introduced are always under

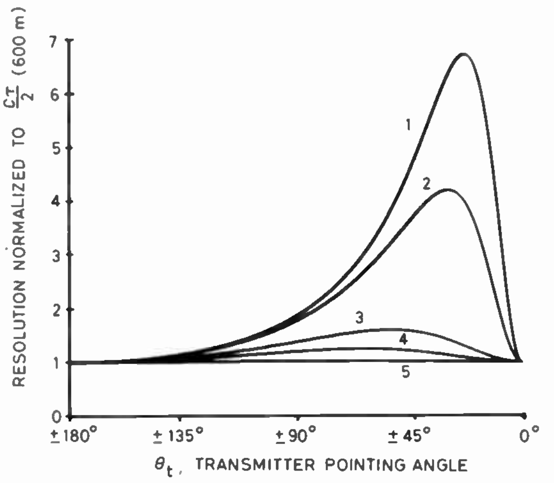

Fig. 7. Range resolution.

Baseline length, $2d$ = 13·2 nmi. Pulse length τ = 4 µs.

Curve	t (µs).	Range sum $r_t + r_r$ (n mi).
1	5	14
2	10	14·8
3	50	21·2
4	100	29·2
5	500	93·2

about 0·6 nautical miles (about 1 km), the maximum value reducing to about 0·4 nautical miles for longer range targets. The correction processor introduces quantization errors of a maximum of $\frac{1}{16}$ nautical mile (about 100 m) for all ranges.

The resolution of the UCL system in azimuth is that of the transmitter, namely 2·1°. The variation of range resolution with transmitter pointing angle for various values of t is illustrated in Fig. 7. Altitude is not measured in the present system, so no accuracy or resolution figures are given.

6 Correction for Target Altitude in Bistatic Systems

As indicated earlier, three-dimensional target location information may be provided if one or more of the additional parameters ϕ_t, ϕ_r and θ_r is measured.

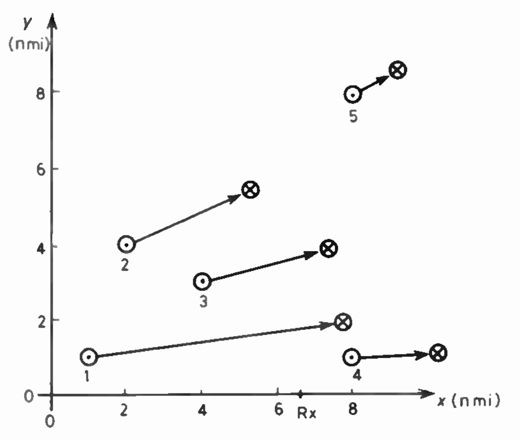

Fig. 8. Altitude errors.
⊙ correct plan positions ⊗ calculated positions.
Targets at 30 000 feet. Baseline length = 13·2 nmi.

Measurement of ϕ_r or θ_r naturally requires the additional feature of directive receiving antennas. The correction equations that might be used are already known,[11] though it is worth noting the simplicity of these equations for the case where both the transmitter and receiver azimuth pointing angles are known, and the bistatic range sum $s = r_t + r_r$ is measured. For correction in cartesian coordinates:

$$\left.\begin{aligned} x &= \frac{d \sin(\theta_r + \theta_t)}{\sin(\theta_r - \theta_t)} \\ y &= \frac{2d \sin\theta_r \sin\theta_t}{\sin(\theta_r - \theta_t)} \\ z &= \left(\frac{(s^2 - 4d^2)(s^2 - 4x^2)}{4s^2} - y^2\right)^{\frac{1}{2}} \end{aligned}\right\} \quad (7)$$

And for correction in polar coordinates.

$$\left.\begin{aligned} r_t' &= \frac{2d \sin\theta_r}{\sin(\theta_r - \theta_t)} \\ r_r' &= \frac{2d \sin\theta_t}{\sin(\theta_r - \theta_t)} \end{aligned}\right\} \quad (8)$$

r_t' and r_r' are the ground projections of the transmitter-to-target and the receiver-to-target ranges respectively. Both r_t' and r_r' are given since the display origin might be taken as either site. Target altitude, z, is most easily obtained from equations (7). It is clear from the above equations that if θ_r and θ_t are similar in magnitude, the calculated coordinates are highly sensitive to changes in either θ_r or θ_t. Thus, small errors in measurement of θ_r and θ_t may lead to large errors in calculation of x, y, z, r_t' and r_r'. It is clear that such a measurement system should only be used over surveillance areas where θ_r and θ_t are reasonably dissimilar, i.e. in sectors perpendicular to the baseline, and not at long range.

In monostatic radar, target altitude only introduces very significant range errors when the target is close to the transmitter, the measured slant range being significantly greater than the horizontal projected range. In a bistatic radar, target altitude becomes important when the transmitter-receiver baseline is approached. The form of the errors introduced, if altitude is neglected, vary depending on the correction system used: if, for example, only the transmitter pointing angle, θ_t, and the range sum $r_t + r_r$ are measured, errors due to target altitude will be apparent in range only relative to the transmitter, but in both range and azimuth relative to the receiver. The magnitude of the errors at short range may be quite severe, though at ranges greater than the baseline length, the errors approach those obtained with a monostatic radar measuring slant range. This is illustrated in Fig. 8, which shows the true and calculated positions of several targets at various locations for a target altitude of 5 nmi (30 000 ft or 9144 m).

7 Conclusions

An experimental bistatic radar system has been demonstrated. Ways of overcoming the need for a synchronization information link between transmitter and receiver have been suggested and shown to be practically viable. This permits the realization of a totally independent, passive, radar receiver which could, essentially in portable form on the ground, sea or in the air, provide target information in regions illuminated by any radar transmitter.

The advantage of passive radar receivers in the military context, as opposed to complete monostatic radars, lies in their reduced vulnerability to jamming and attack. However, from a wider viewpoint, a bistatic or multistatic system offers great advantages in spectrum conservation over multiple monostatic radars, and allows radar information to be provided to individual users for only the cost of a receiver. Possible applications might therefore be envisaged for small boats in coastal waters and for collision avoidance or collision warning in aircraft.

The separation of transmitting and receiving antennas allows greatly increased flexibility in radar systems and in radar signal waveforms. Continuous-wave signals, generally limited in radar application because of direct leakage between transmitter and receiver or strong clutter echoes, may achieve new importance; such a waveform is ideally suited to microwave solid-state generators and enables a similar mean power to that of conventional pulse radars to be achieved, but without the detectability and some technological difficulties associated with high peak power. A separate receiving antenna may also be of very different configuration from the transmitting antenna, and is amenable to greater complexity since it only handles low-power signals. Array receiving antennas could therefore provide multiple parallel receiving beams, fast electronic scanning of beams and adaptive beam pattern control. All or any of these features could be used to enhance the performance obtainable from the conventional radar transmitter.

The subject of bistatic and multistatic radar is at an early stage of what promises to be an exciting future development.

8 Acknowledgments

Very useful discussions during the course of this work have taken place with Professor D. E. N. Davies, Professor K. Milne, Mr P. Bradsell, Dr C. Pell, Mr D. Eastaugh and Mr C. Latham.

Grateful acknowledgment of support is also extended to Plessey Electronic Systems, Plessey Radar, the Science Research Council (Microwave Research Unit support and CASE award), and the Ministry of Defence Procurement Executive (Royal Signals and Radar Establishment).

Further thanks are also extended to Col. E. Arkoumaneas and Dr N. Mavrokoukoulakis of the Hellenic Air Force Technology Research Centre (KETA), Athens, for useful discussions; a collaborative bistatic radar research programme between UCL and KETA is now under way, supported by NATO (AGARD), and this assistance is gratefully acknowledged.

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Contributors to this Issue

Keith Clarke joined the then Post Office Engineering Department in 1959 and commenced a two-year period of training in telecommunications and general engineering. In 1961 he started a 'sandwich' course for the B. Tech. degree in electrical engineering at the University of Bradford, his industrial training periods being spent with the Post Office Engineering Department and with the General Electric Company at Coventry. On completion of the course he was seconded to the Technical Support Unit of the Ministry of Technology where he was concerned with tender adjudication and acceptance tests on computers purchased by the Government.

In 1967 Mr Clarke was granted a further leave of absence to attend a postgraduate course in Computing Science at Imperial College, University of London, and was awarded the D.I.C. for a dissertation on 'Data Structures for Computer Aided Design'. On return to the Technical Support Unit his task was to examine the opportunities and problems presented by the arrival of the computer time-sharing bureau industry in the UK and he was responsible for setting-up the TSU time-sharing centre.

In 1970 his period of secondment to the TSU ended and he joined the Post Office Research Laboratories at Dollis Hill. Here he was involved in the introduction of computer-aided design facilities in the laboratories including the installation of, and programming for, the first computer graphics systems. He assisted Sam Fedida with his initial report on the viewdata system and as this project grew gradually devoted more of his time to it. By 1975 he led a section concerned entirely with viewdata and in 1979 he became head of the newly formed Viewdata Division. He is at present in charge of all R & D (including software development) for the UK Prestel service.

Mr. Clarke has some 15 major professional publications to his credit in the fields of computer time-sharing, computer aided design and viewdata, more recently on international standards, and he has lectured a number of University and Polytechnic courses in these subjects. In 1976 he received the degree of M.Phil. from the University of London for a thesis on 'The Cost Effective Application of Computer Graphics in a Research Environment'.

Nicholas Maslin (Member 1978) graduated in physics from Cambridge University in 1973. After two years of research at the Cavendish Laboratory, he was awarded the Hamilton Prize and was elected a Bye-Fellow of Downing College, Cambridge, gaining his Ph.D. degree the following year for his studies of ionospheric cross-modulation. In 1976 he joined Radio and Navigation Department of the Royal Aircraft Establishment to work in the field of radio communication to aircraft; three years later he became a consultant with Software Sciences, adopting particular responsibility for projects with application to radio communication and navigation. Dr Maslin has published a number of papers on the subject of radio propagation, for one of which he received an Institution Premium for 1978.

Derek Bond graduated from the University of Leeds with B.Sc.(Hons.) in physics in 1965. He has held positions with CETA, Poole, and with Plessey Group Research Laboratories and he was Development Manager at Wayne Kerr before joining the Electronics and Instrument Division of Bell & Howell as Engineering Director in December 1979.

John Forrest read natural sciences and electrical sciences at Cambridge University. He then carried out research in plasma physics under UKAEA sponsorship at Oxford University and obtained the D.Phil. degree in 1967. The next three years were spent as a Research Associate and Lecturer at Stanford University, California, in the Institute for Plasma Research, working on microwave interactions and instabilities in plasmas. In 1970 Dr Forrest returned to the UK to take up an appointment at University College London, where he is currently a Reader. His research interests cover microwave semiconductors, optical signal processing and antenna theory, all with particular application to radar and communications. He is currently Chairman of the IEE Professional Group E15, dealing with Radar, Sonar, Navigation and Avionics.

Jim Schoenenberger studied for the B.Sc.(Eng.) degree at University College London, graduating with first-class honours in 1977. He then carried out research in bistatic radar systems at UCL and obtained the Ph.D. degree in April 1981. He is currently employed at UCL as a Research Associate working on bistatic radar. Dr Schoenenberger's current interests are concerned with digital electronics and digital beamforming techniques for use in radar systems.


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N. M. MASLIN


D. F. BOND


J. R. FORREST


J. G. SCHOENENBERGER

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.

FEBRUARY

***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)

***Electro-Optics and Lasers** *23rd to 25th March*
International conference on Electro-optics and Lasers organized by Kiver Communications will be held in Brighton. Information: Kiver Communications, Millbank House, 171-185 Ewell Road, Surbiton, Surrey.

***Electronic Components** *29th to 31st March*
International conference on new applications of Passive Electronic Components, organized by the Société des Electriciens, Electroniciens et des Radioélectriciens in association with the Electronics Industries Group will be held in Paris. Information: SEER, 48 Rue de la Procession, 75015 Paris.

***Reliability** *29th March to 2nd April*
One week international CBO-seminar on Reliability Engineering—Advanced Technology and Industrial Applications will be held in Rotterdam. Information: CBO Management and Technology Systems Centre, P.O. Box 30042, 3001 DA Rotterdam, Netherlands. (Tel. (010) 13 90 20)

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** *20th to 22nd 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. 01-240 1871).

***On-Line Control** *5th to 8th April*
International Conference on Trends in On-line Computer Control Systems, organized by the Institution of Electrical Engineers, to be held at the University of Warwick, Coventry. Information: Conference Department, IEE, Savoy Place, London WC2 0BL (Tel. 01-240 1871, ext. 222).

*● **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)*

* **Antennas and Propagation** *24th to 28th May*
International Symposium on Antennas and Propagation organized by the IEEE in association with URSI, to be held in Albuquerque, New Mexico. Information: IEEE, Conference Coordination, 345 East 47th Street, New York, NY 10017.

***Measurements** *24th to 28th May*
Ninth Congress on Technological and Methodological Advances in Measurement organized by IMEKO to be held in Berlin. Information: IMEKO, Secretariat, P.O. Box 457, H-1371 Budapest.

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)

***Microwaves** *15th to 17th June*
International Microwave Symposium organized by the IEEE will be held in Dallas, Texas. Information: IEEE, Conference Coordination, 345 East 47th Street, New York, NY 10017.

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, 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)

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. 01-240 1871).

AUGUST

*★ **Software** *25th to 27th August*
Residential Symposium on Software for Real-Time Systems organized by the IERE Scottish Section will be held in Edinburgh. Information: Mr J. W. Henderson, YARD Ltd, Charing Cross Tower, Glasgow.

***Satellite Communication** *23rd to 27th August*
A Summer School on Satellite Communication Antenna Technology organized by the Eindhoven University in association with IEEE Benelux and the University of Illinois will be held at Eindhoven University. Information: Dr E. J. Maanders, Department of Electrical Engineering, University of Technology, Postbox 513, 5600 MB Einahoven, Netherlands. (Tel. (040) 47 91 11).

SEPTEMBER

***Microwaves** *6th to 10th September*
Twelfth European Microwave Conference organized by the IEEE in association with URSI to be held in Helsinki. Information: IEEE, Conference Co-ordination, 345 East 47th Street, New York, NY 10017.

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 '82** *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. 01-240 1871).

★ **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)

***Telecommunications and Fibre Optics** *21st to 24th September*
Eighth European conference on Telecommunication and Fibre Optics organized by the Electronics Industries Group (GIEL), to be held in Cannes. Information: GIEL 11 rue Hamelin, 75783 Paris Cedex 16

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-Gesellschaft, 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. 01-240 1871).
(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)*

***Manufacturing Technology** *26th to 28th October*
Fourth IFAC/IFIP Symposium on Information Control Problems in Manufacturing Technology organized by the National Bureau of Standards, US Department of Commerce, in association with IFAC/IFIP will be held in Gaithersburg, Maryland. Information: Mr J. L. Nevins, Vice Chairman, National Organizing Committee, 4th IFAC/IFIP Symposium Charles Stark Draper Labs, Inc. 555 Technology Square Cambridge, MA 02139 USA. (Tel. (617) 258 1347.