

Founded 1925

Incorporated
by Royal Charter 1961

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

Volume 49 No. 2

February 1979

The Radio and Electronic Engineer

The Journal of the Institution of Electronic and Radio Engineers

Balanced education for the chartered engineer

Elsewhere in this issue of *The Radio and Electronic Engineer* we publish as a policy statement a summary of the Institution's views on a number of education and training issues now being debated in the general context of the future size and shape of the engineering profession and with particular reference to the work of the Finniston Inquiry. All those issues are quite understandably concerned with the science and technology content of the engineer's education. But if we are to avoid unbalanced debate there is one further facet of the topic which must be given some attention. It is the standard of competence in English to be expected of Chartered Engineers.

The CEI which, through the ERB, now sets the education, training and experience standards for all Chartered Engineers registered in the United Kingdom does not specify any standard of education or level of achievement in English beyond stating in its Training Requirements Statement No. 11 that 'Since trainees must be in a position, when qualified, to discharge the responsibilities of a Chartered Engineer in the United Kingdom, they should be made aware of the importance of competence in the English language'. No attempt is made to define an appropriate standard of competence or to suggest how or when compliance with any particular standard should be tested. And does it not seem somewhat illogical—even unfair—to allow any potential Chartered Engineer to complete his academic qualifications and embark on his professional training before making him aware of the importance of competence in our language?

That it is indeed important that 'engineers can communicate' was made clear at the IERE colloquium held under that title in London early last year. In his opening keynote speech, Sir Ieuan Maddock (Past President), formerly Chief Scientist, Department of Industry and now Secretary of the British Association for the Advancement of Science, stressed the importance of communication skills in the work of the engineer. He emphasized the need for better communication between people in science and engineering at all levels, between experts in the separate disciplines, between the expert and the layman and also between experts and the opinion leaders who influenced decisions in public life. This authoritative view was echoed by other speakers and was never challenged in the follow-up discussion. And how could it be: for who can doubt the need for the engineers, whether they be doing or managing, to be able to communicate their ideas, solutions, reports and proposals both to their engineering colleagues at whatever level and to those non-engineers with whom they work and the general public whose understanding and support they need in so much of their innovative endeavour.

Perhaps, therefore, the time has come (if it is not long past) when the profession should face up to this communication problem and not only formulate and publish its agreed basic standard of competence in the English language for the professional engineer, but also devise and establish procedures for testing and proving that level of competence early enough in the education and training sequence. Early enough, that is, to ensure that scarce scientific and technological education and training effort is not wasted on those who are likely to be denied formal qualification at the end of the road for lack of communication talent and skill. And perhaps, again, the very first step in this process is not too difficult to see. Might it not be to specify at least 'O' level English Language in addition to Mathematics and an acceptable Science subject at 'A' level as the absolutely basic standard for acceptance to any science or technology course or examination intended to lead to qualification as a Chartered Engineer?

S.M.D.

IERE News and Commentary

Register of Consultants

Many of the technical enquiries made to the Institution can be dealt with by the Chartered Engineers on the permanent staff backed up by the resources of the Library. A fair proportion however, call for both specialized knowledge and time to investigate the problems raised and in such cases enquirers are normally put in direct touch with members known to have relevant experience. But the ever-widening extent of electronics means that it is not always easy to identify the 'right man' and to meet this problem it has been decided to prepare a 'Register of Consultants'.

It is intended that the Register should include both Chartered Engineers and Technician Engineers who (1) are already self-employed consultants or are permitted by their employers to undertake *independent* consultancy work and (2) have specialized knowledge in one or more areas of electronic and radio engineering.

The compilation of the Register will be on an informal basis and members who consider they meet the above criteria are invited to write to the Secretary briefly but informatively, giving details of their specializations and availability.

Vacuum Processes for the Electronics Industry

Following the success of its 1977 seminar on 'High-vacuum technology: systems and applications', Sira Institute is organising a seminar on 'Vacuum processes for the electronics industry'. The seminar will be held on 2nd-4th April 1979 at the University of Sussex, Brighton. It will be of interest to all who need to know more about the part played by vacuum technology in the manufacture of electronic components and to those in the electronics industry who value the opportunity to hear, and take part in, authoritative discussion of the newer techniques in this field.

Sessions will cover the chemistry, physics, and applications of plasma processes, methods of gas analysis and pressure measurement, and the major applications of vacuum beam processes. The speakers are being drawn from British and overseas industrial research laboratories, from universities, and from the Post Office Research Centre.

Further information may be obtained from Mrs R. G. Keiller, Sira Institute Ltd, South Hill, Chislehurst, Kent BR7 5EH.

Fellowship of Engineering Distinction Lecture

The Fellowship's first Distinction Lecture, in Guildhall, London, was delivered by H. E. Sheikh Ahmed Zaki Yamani, Minister of Petroleum and Mineral Resources for the Kingdom of Saudi Arabia, on 16th October last. Entitled 'Great Britain, OPEC and Saudi Arabia', it was listened to by an audience of over six hundred people, and a lively and interesting discussion followed.

Limited supplies of the Lecture are available from The Publication Department (SYL), Fellowship of Engineering, 2 Little Smith Street, London SW1P 3DL.

Leeds Electronics Exhibition

Mr. Denis Heightman, President of the Institution, is to open Leetronex, the 16th annual Leeds Electronics Exhibition. The Exhibition, from July 3rd to July 5th, 1979 will be held in the Department of Electrical and Electronic Engineering, at the University, Leeds.

Further details about the Exhibition, which will include a Symposium organized by the IERE Yorkshire Section, may be obtained from Mr. C. S. Petch, Director of Leetronex, Department of Electrical and Electronic Engineering, The University of Leeds LS2 9JT (Tel: 31751 ext. 328).

Correction

In the paper 'Survey of design techniques for flat profile microwave antennas and arrays', published in *The Radio and Electronic Engineer* for November 1978, the following amendments should be made: Page 563, Section 10, Reference 16: *should read Palumbo, B., and Cosentino, S., 'Circularly polarised L-band planar array for aeronautical satellite use'*, AGARD Symposium on Antennas for Avionics, Munich, 26th-30th November 1973. AGARD Conference Publication 139, pp. 22-1 to 22-15.

Page 563, Section 10, Reference 18: place of publication *should read AGARD Symposium on Antennas for Avionics, Munich, 26th-30th November 1973. AGARD Conference Publication 139, pp. 42-1 to 42-15.*

Standard Frequency Transmissions

(Communication from the National Physical Laboratory).

Relative Phase Readings in Microseconds
NPL—Station
(Readings at 1500 UTC)

December 1978	MSF 60 kHz	GBR 16 kHz	Droitwich 200 kHz
1	0.7	1.6	41.1
2	0.7	3.6	40.5
3	0.7	2.6	40.0
4	0.7	2.1	39.2
5	1.0	5.1	38.7
6	1.0	3.6	38.0
7	1.3	5.1	37.4
8	1.5	3.6	36.9
9	1.6	6.1	36.3
10	2.2	4.6	35.7
11	2.1	3.6	35.0
12	2.4	5.0	34.4
13	2.8	3.6	33.8
14	2.6	4.6	33.1
15	2.4	3.6	32.4
16	2.1	4.7	31.6
17	2.3	4.0	30.9
18	2.5	5.8	30.2
19	2.6	5.2	29.7
20	2.9	5.1	28.1
21	2.5	5.1	27.6
22	2.3	5.8	27.0
23	2.3	5.9	26.5
24	2.5	5.6	26.0
25	2.4	5.3	25.4
26	2.5	3.6	24.8
27	2.7	6.6	24.1
28	2.6	5.7	23.5
29	2.5	3.6	22.9
30	2.6	4.8	22.1
31	2.7	6.2	21.4

- Notes: (a) Relative to UTC scale ($UTC_{NPL-Station}$) = +10 at 1500 UTC, 1st January 1977.
(b) The convention followed is that a decrease in phase reading represents an increase in frequency.
(c) Phase differences may be converted to frequency differences by using the fact that $1\mu s$ represents a frequency change of part 1 in 10^{11} per day.

Forthcoming Institution Meetings

London

Tuesday, 6th March

COMMUNICATIONS GROUP

Colloquium on DIGITALLY CODED
TELEVISION SIGNALS

Royal Institution, Albemarle Street, London
W1. 10.00 a.m.*

Wednesday, 28th March

JOINT IERE MEASUREMENTS AND INSTRUMENTS
GROUP/IEE

Colloquium on MEASUREMENTS AND
HIGH VOLTAGE

Royal Institution, Albemarle Street, London
W1, 10.00 a.m.*

Tuesday, 10th April

AEROSPACE, MARITIME AND MILITARY SYS-
TEMS GROUP

Colloquium on PORTABLE
COMMUNICATION SYSTEMS

Royal Institution, Albemarle Street,
London W1, 10.00 a.m.*

Friday, 11th May

JOINT IEE/IERE MEDICAL AND BIOLOGICAL
ELECTRONICS GROUP

Colloquium on MINIATURE
TRANSDUCERS FOR MULTI-
PARAMETER CLINICAL
DIAGNOSTICS

IEE, Savoy Place, London WC2, from
where further information may be obtained.

Tuesday, 15th May

JOINT IERE/IEE MEDICAL AND BIOLOGICAL
ELECTRONICS GROUP

Colloquium on STORAGE DEVICES
FOR MEDICAL AND BIOLOGICAL
SIGNAL ANALYSIS AND
RECORDING

Royal Institution, Albemarle Street,
London W1, 10.00 a.m.*

Tuesday, 5th June

COMMUNICATIONS GROUP IERE/RSGB

Colloquium on MICROWAVE
COMMUNICATIONS IN THE
AMATEUR SERVICE

Royal Institution, Albemarle Street,
London W1, 10.00 a.m.

Tuesday, 12th June

COMPONENTS AND CIRCUITS GROUP

Colloquium on PERIPHERAL
COMPONENTS FOR MICRO-
PROCESSORS

Royal Institution, Albemarle Street,
London W1, 10.00 a.m.*

* Advance registration necessary. Further
details from Colloquium Registrar, IERE.

Beds and Herts Section

Thursday, 29th March

Optical fibre communications

By Professor W. A. Gambling (*University
of Southampton*)

Hatfield Polytechnic, 7.45 p.m. (Tea 7.15
p.m.)

Thursday, 26th April

ANNUAL GENERAL MEETING

followed by

Loudspeakers

By J. Akroyd (*Decca Radio and Television*)

Hatfield Polytechnic, 7 p.m. (Tea 6.45 p.m.)

East Midland Section

Tuesday, 3rd April

ANNUAL GENERAL MEETING

Room H.08, Leicester Polytechnic,
7.15 p.m.

Kent Section

Wednesday, 7th March

The Boeing 747 avionics and navigation
system

By Clive Gibson (*British Airways Flight
Instrument and Control Department*)

Marconi Avionics Conference Room,
Rochester, 7.00 p.m.

Thursday, 5th April

ANNUAL GENERAL MEETING

followed by

The Dolby noise reduction system

By J. Iles (*Dolby Laboratories*)

Boxley Country Club, Boxley, Nr.
Maidstone, 7.00 p.m.

Merseyside Section

Wednesday, 7th March

Coal face automation engineering at the
Mining Research and Development Establishment

By D. K. Barham and J. H. Hvidsten
(*M.R.D.E.*)

The Feathers Hotel, 121 Mount Pleasant,
Liverpool 3, 7.00 p.m.

Wednesday, 4th April

ANNUAL GENERAL MEETING

followed by a lecture (details to be
announced)

Feathers Hotel, 121 Mount Pleasant,
Liverpool 3, 7.00 p.m.

North Eastern Section

Tuesday, 13th March

Medical electronics

By Dr S. J. Meldrum (*St. Bartholomew's
Hospital, London*)

Newcastle-upon-Tyne Polytechnic, Ellison
Building, Ellison Place, 6.00 p.m. (Tea
5.30 p.m.)

Tuesday, 10th April

Quadraphonics and other multichannel
sound systems

By Dr. K. Barker (*University of Sheffield*)

Newcastle-upon-Tyne Polytechnic,
Ellison Building, Ellison Place, 6.00 p.m.
(Tea 5.30 p.m.)

Northern Ireland Section

Wednesday, 7th March

Megaw Memorial Prize Lectures

By Final Year Engineering Students of the
Queen's University, Belfast
Ashby Institute, Stranmillis Road, Belfast
6.30 p.m.

Wednesday, 25th April

Electronic development in the automotive
field

By R. Bird (*Lucas Electrical*)

Castlereagh College of Further Education,
7.00 p.m.

North Western Section

Wednesday, 28th March

JOINT MEETING WITH IEE

Electronics for off-shore oil rigs

By J. Couser (*Ferranti Off-shore Systems*)
Lancashire County Cricket Club, Talbot
Road, Old Trafford, 6.15 p.m. (Light
refreshments available before the lecture.)

Thursday, 26th April

Automobile electronics

By a lecturer from Rolls-Royce

Bolton Institute of Technology, Deane
Road, Bolton, Lancs 6.15 p.m. (Light
refreshments available before lecture.)

Scottish Section

Wednesday, 4th April

PUBLIC LECTURE

Human engineering

Prof. J. M. A. Lenihan (*Department of
Clinical Physics, University of Glasgow*)
Boyd Orr Lecture Theatre, Glasgow
University

Thursday, 5th April

PUBLIC LECTURE

Human engineering

Prof. J. M. A. Lenihan
David Hume Building, Edinburgh

Southern Section

Thursday, 1st March

Digital signal processing

By Prof. D. R. Wilson and Dr. D. F. Neale
(Polytechnic of Central London)

Synopsis: The lecture will review the basic elementary principles of Digital Signal Processing and discuss the specification of input/output characteristics. Design aspects of hard-wired digital filters will be considered. Some recent developments using microcomputers as digital filters will be discussed.

Crawley College of Technology, 7.00 p.m.

Wednesday, 14th March

Radio astronomy—fundamental research for the 1980s

By A. Purvis (*University of Cambridge*)

Synopsis: Radio Astronomy, a subject that grew rapidly from the electronics technology of the war, has encountered many unexpected discoveries in its short lifetime. A review of its technological development and the observations that led to, for example, the violent quasars and mysterious pulsars, will be given. This will be used as a background to the new telescopes in use and the research projects being pursued at the Mullard Radio Astronomy Observatory, Cambridge.

University of Guildford, Lecture Theatre 'F', 7.00 p.m.

Wednesday, 21st March

ANNUAL GENERAL MEETING

followed by

Electronics in supertankers

By A. M. Bate (*London and Overseas Freighters*)

Boldrewood Lecture Theatre, Medical School, University of Southampton, 7.00 p.m. (AGM), 7.30 p.m. (Lecture)

Wednesday, 4th April

CEI MEETING

Symposium on The Engineer and the Environment

Southampton University.

Further information from The Director, Southern Science and Technology Forum, Building 25, The University of Southampton Southampton SO9 5NH. (Tel: 558379)

Thursday, 26th April

Microcomputers and their applications

By H. Kornstein (*Intel Corporation*)
Farnborough College of Technology, 7.00 p.m.

South Midland Section

Wednesday, 14th March

Holography and Laser Speckle

By D. A. Gregory (*BAC*)
Abbey Hotel, Malvern, 7.30 p.m.

Tuesday, 24th April

Some thoughts and experiments on a.f. topics

By P. J. Baxendall

followed by the

ANNUAL GENERAL MEETING

Carlton Hotel, Parabola Road, Cheltenham 7.00 p.m.

Wednesday, 2nd May

JOINT MEETING WITH IEE

Digital television studios—when?

By J. Baldwin (*IBA*)

Chemistry Lecture Theatre No. 4, University of Bristol, 6.30 p.m. (Tea 6.00 p.m.)

West Midland Section

Wednesday, 14th March

Robotics

By Dr. Colin Page (*Lanchester Polytechnic*)
Lanchester Polytechnic, Coventry, 6.30 p.m. (Tea 5.45 p.m.)

Synopsis: This lecture deals with the growth in the use of industrial robots and with future developments which will find their way onto the shop floor in the next few years. Representative machines are described, and the ways in which actual industrial robots differ from the classic robots of science fiction are discussed. The problems involved in realizing truly general-purpose robots are outlined and current developments in this area are described briefly.

Wednesday, 25th April

ANNUAL GENERAL MEETING

followed by *Quadraphonics*

By R. I. Collins and C. P. Daubney (*IBA*)
Wolverhampton Polytechnic, 7.00 p.m. (Tea 6.30 p.m.)

Thames Valley Section

Thursday, 3rd May

ANNUAL GENERAL MEETING

followed by

Recent advances in frequency synthesis

By K. Thrower (*Racal Advanced Developments Division*)

Caversham Bridge Hotel, Reading, 7.30 p.m.

Yorkshire Section

Wednesday, 14th March

Microprocessors in land mobile radio

By Dr. O. Downing (*University of Bradford*)
University of Bradford, 7.00 p.m.

Tuesday, 27th March

Prestel: The Post Office Viewdata Service

By K. E. Clarke (*P.O. Research Centre Martlesham*)

University of Leeds, 6.30 p.m.

Tuesday, 24th April

One-day Conference: MICROPROCESSING '79—The Micro in Society

Royal Station Hotel, York.

Thursday, 17th May

ANNUAL GENERAL MEETING

and Ladies Evening

YTV Studios, Leeds, 6.30 p.m.

International Conference on 'Television Measurements'

Organized by THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS with the association of The Institution of Electrical Engineers, The Institute of Electrical and Electronics Engineers, and the Society of Motion Picture and Television Engineers.

Commonwealth Institute, Kensington, London, W8 **21st to 23rd May 1979**

PROGRAMME

(Subject to amendment)

Monday 21st May

Keynote Address—Sir Francis Maclean (*Chairman, BSI Telecommunications Industry Standards Committee*)

SESSION I - DISTRIBUTION SYSTEMS PERFORMANCE

Review speaker—R. C. Hills (*IBA*)

Television measurements through psychophysics to subjective picture quality—J. Allnatt (*Post Office*)

Performance limit philosophies for broadcast television distribution—T. M. Cook and D. C. Savage (*BBC*)

Standards of technical performance for television broadcasting services—D. Bennett and P. K. Kaiser (*Canadian Broadcasting Corp.*)

International network quality control through systematic measurements on insertion test signals—J. N. Douglas (*EBU*)

Establishing a performance specification for a switched television cable system—E. J. Gargini (*Rediffusion Engineering*)

A survey of television blanking width measurement problems—F. Davidoff (*CBS*)

SESSION II - R.F. INSTRUMENTS, MEASUREMENT TECHNIQUES AND RECEIVERS

Review speaker—C. W. Rhodes (*Tektronix*)

A new technique for the generation of television test signals in all bands—Adolf Wendl (*Röhde and Schwarz, Munich*)

Measurements related to the quality of television receiver sound reproduction—P. Hejberg (*Philips, Denmark*)

Tuesday 22nd May

SESSION II - (Continued)

A new synchronous demodulator for performance measurements of television transmitters—C. W. Rhodes (*Tektronix*)

The design and use of high performance u.h.f. transmitters and demodulators for critical television r.f. measurement—Dr. M. Windram (*IBA*)

A programmable digital u.h.f. field strength measuring receiver—J. A. Fox (*BBC*)

The measurement of the external immunity of television broadcast receivers—R. J. Harry and R. J. Hasler (*Home Office*)

SESSION III - VIDEO INSTRUMENTATION AND MEASUREMENT TECHNIQUES

Review speaker—F. Davidoff (*CBS*)

Application of insertion test signals in television studios and new methods for generating insertion test signals—A. Heller and K. Schuster (*Institut für Rundfunktechnik*)

“VISTA”, a vertical interval sweep testing apparatus—H. L. Baker (*Rediffusion Engineering*)

Measurement methods for SECAM signals—J. F. Marquet—(*TeleDiffusion de France*)

The zone plate as an aid to testing television systems—Dr. J. O. Drewry (*BBC*)

Real time measurement of television signal statistics—Dr. J. P. Raina (*Central Electronics Engineering Research Institute, India*)

Comprehensive television test waveform generator—P. Hubbard (*BBC*)

Microprocessor-based video analyser—P. S. Crosby, J. Lewis and D. A. Jordan (*Tektronix*)

Wednesday 23rd May

SESSION IV - COLORIMETRY

Review speaker—C. B. B. Wood

Colour measurement: fundamental considerations—Dr. I. Childs (*BBC*)

Colour measurement: the CIE system and some applications—W. N. Sproson

Colour measurement for television—Dr. R. W. G. Hunt (*Kodak*)

A new automatic measuring method for television pickup devices using an acousto-optic tunable filter—Professor K. Miyaji (*S. I. T., Tokyo*)

SESSION V - DIGITAL SYSTEMS AND TELETEXT

Review speaker—P. L. Mothersole (*VG Electronics*)

The change to digital recording and its effects on instrumentation—M. O. Felix (*Ampex, USA*)

Quality monitoring for a teletext service—P. R. Hutt (*IBA*)

An instrument for the automatic measurement of teletext transmission quality—C. R. Spicer and R. J. Tidey (*BBC*)

Further information from the Conference Secretariat, IERE, 99 Gower Street, London WC1E 6AZ.

Members' Appointments

NEW YEARS HONOURS

The Council has sent its congratulations to the following member whose name appears 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.)

Neville Morley (Fellow 1965, Member 1949) who, until his retirement at the end of 1978, was Deputy Director of Telecommunications, Home Office. Before taking up this appointment in 1964 he was with the Air Ministry at the Headquarters of RAF Signals Command. In 1948 Mr. Morley was awarded the President's Prize for outstanding performance in the Institution's Graduateship Examination.

CORPORATE MEMBERS

Wg Cdr J. M. Brown, RAF (Fellow 1973, Member 1959) is now Station Commander, RAF Staxton Wold. He was previously Signals 59 (Air) at the Ministry of Defence.

Colonel F. R. Spragg, B.Sc. (Fellow 1965, Member 1963) whose final appointment before retiring from the Army last year after 35 years commissioned service with REME was Commandant, School of Electronic Engineering, Arborfield, has joined Mather & Platt Alarms as Technical Operations Manager. Since 1974 Col. Spragg has been a member of the Education and Training Committee and from 1969 to 1972 he served on the Aerospace, Maritime and Military Systems Group Committee.

P. A. Cooke (Member 1973, Graduate 1969) has been appointed Technical Director of Negretti and Zambra; he joined the company in 1972 as a Senior Design Engineer concerned with instrumentation and control equipment after working with Redifon Flight Simulation and Plessey Telecommunications Research as a Design Engineer.

J. Coulson (Member 1970, Graduate 1961) is now Executive Engineer in charge of External School at the Post Office Telecommunications Training College, Stone.

B. Cross (Member 1966), Head of Data Systems Planning in the Post Office Telecommunications HQ since August 1978, will take up the post of Director, South Eastern Telecommunications Region in March 1979. Extending to 13,000 sq km covering the south east of England as far as Portsmouth in the west and Gravesend and Henley in the north, the Region serves a population of nearly 5 million of whom more than 2 million are on the phone. It employs 16,000 people and has 531 local exchanges.

D. E. Grant (Member 1969, Graduate 1963) who has been with Normalair Garrett since 1972, latterly as an Assistant Product Engineer, is now Electronics Manager with Penny & Giles Conductive Plastics, Blackwood, Gwent.

Sqn Ldr R. G. Hatcher, RAF (Member 1973, Graduate 1967) has moved to RAF Coltishall as Officer Commanding Electrical Engineering Squadron, following four years with the Ministry of Defence Procurement Executive, MAP/1 Phantom.

F. F. Kemp (Member 1973, Graduate 1968) has been appointed Assistant Engineer Manager with SGS-ATES, Falkirk; since 1973 he has been with the Allen Clark Research Centre of the Plessey Company, latterly as a Principal Scientist.

H. Lassman (Member 1974, Associate 1972) has been appointed to the position of General Sales Manager, Service Division, Cossor Electronics Limited. Previously he was manager of the Base Service Department from its inception in 1972.

Gp Capt K. G. Lewis, RAF (Member 1968) has taken up an appointment as Commander Regional Signals Support Group at HQ AFCENT, Brumsum, Holland, following a staff appointment at the Ministry of Defence.

H. B. Maughan (Member 1965, Graduate 1961) has joined Negretti and Zambra as Production Director. He previously held production manager positions with System Computers, Sevcon and Elmwood Services. Mr Maughan served for several years on the North Eastern Section Committee.

V. W. Nwebube (Member 1973, Graduate 1966) has returned to Nigeria after studying and working for some 15 years in the UK, at Norwood Technical College and with the BBC and Rediffusion Engineering. He has taken up the appointment of Senior Engineer with the Federal Radio Corporation, Enugu.

L. R. Parker (Member 1968) has been appointed to the Board of RS Components, the major subsidiary of the Electro-components Group. He joined RS as Marketing Manager in 1976 following previous appointments in Research and Development and Commercial Management with Bell and Lee.

J. F. Perkins (Member 1973, Graduate 1968), formerly a Senior Engineer with EASAMS, has joined the Plessey Marine Research Unit as Project Manager.

NON-CORPORATE MEMBERS

Henry J. Kroch, O.B.E., (Companion 1976) has been appointed Chairman of A.B. Electronic Products Group, in addition to being Chief Executive. Mr Kroch has been with the company for 27 years and became Chief Executive in 1964. He is currently Chairman of the European Electronic Component Manufacturers Association and was elected to the Institution's Council in October 1978 (see Journal for September 1978, p. 464 for a fuller biography).

J. N. Davies (Associate Member 1973, Associate 1968) has taken up the post of Chief Engineer (Connectors) with Lee Green Precision Industries. He was previously Development Services Manager with Sealectro for nine years. Mr Davies is active as an industry representative on BSI and CECC technical committees.

T. E. Griffin (Associate Member 1953) has been appointed Materials Controller with McMichael Ltd, Slough.

R. J. Harris (Associate Member 1971) who joined Cable and Wireless in 1956, is now Project Manager, Emirates Microwave Restoration Network based at Abu Dhabi.

I. Haynes (Graduate 1972) has joined Linotype Paul of Cheltenham as a Senior Production Engineer. He was formerly a Technologist with Rank Xerox.

Flt Lt D. R. Hignett, RAF (Graduate 1978) has completed the Advanced Maintenance Engineering Course at RAF College, Cranwell and has been posted to NATO Joint Operation Centre, Maastricht, in the Department of the Chief of Maintenance, Signals Support Group.

C. I. Onwuachu, D.F.H. (Graduate 1972) is now Senior Engineer, Telecommunications Department of the Federal Ministry of Communications, Lagos, Nigeria.

K. J. E. Pinder (Graduate 1969), formerly at the Government Communications Headquarters, has been appointed a Second Engineer Telecommunications with the South Eastern Electricity Board.

P. R. Thrift, Ph.D., M.Sc. (Graduate 1969) has been appointed Head of the Airframe Development Laboratory of Smiths Industries, Basingstoke. Dr Thrift has been at UMIST for the past six years, obtaining his Master's and Doctor's degrees in 1972 and 1975 respectively, since when he has been a Senior Experimental Officer with the Digital Process Research Group at UMIST; he contributed a paper on aspects of this work to the Journal which was published in April 1978 under the title 'Pulse propagation in an unterminated environment'.

Obituary

Colin Frank Hills (Member 1971, Graduate 1964) died on 6th November 1978, after prolonged illness, at the age of 45 years. He leaves a widow and one son.

After leaving school Colin Hills was appointed to a company installing radio, radar and sonar equipment on naval, merchant and private vessels. From 1955 to 1958 he served as an Electrical Fitter in the Royal Air Force and then joined the Ministry of Defence (Navy Department) as an Electrical Draughtsman at Bath. During the next five years he studied for the Higher National Certificate and gained exemption from the Institution's Graduateship examination. In 1966 Mr Hills left the Ministry of Defence to take up an appointment in the Department of Electrical Engineering and Science at the City of Bath Technical College and he was a Lecturer in the Department at the time of his death.

Terence Hutchinson (Member 1970) died on 18th November 1978, aged 47 years, following a long illness. He is survived by a wife and a young daughter.

Born and educated in Ulster, Terence Hutchinson graduated with a B.Sc. degree in applied physics from the Queen's University of Belfast in 1952. Apart from two years' early experience in the Mechanical Test Department of the General Electric Company at Stanmore, Middlesex, he then spent the whole of his professional career with Short Brothers and Harland of Belfast. He joined the Guided Weapons Division in 1954 and rose to be Deputy Head of the Systems Department; he was responsible for the design and development of television and infra-red systems.

Terence Hutchinson was a very dedicated member of the Northern Ireland Section Committee and he was Honorary Secretary for a number of years.

J.T.A.

Derrick Shaw (Fellow 1967) died on 7th October 1978 at the age of 53 years, leaving a widow, two sons and a daughter.

In many respects Derrick Shaw, who was born in Sheffield, could be said to have been one of the fathers of electronics education as we now know it in the area. It was through his persistence and vision that evening courses were established in the early fifties in electronic equipment maintenance by the Department of Physics at Sheffield College of Technology and these became so popular that they were taken over by the then Department of Engineering, thus forming the basis for the present Polytechnic Department of Electronics and Control Engineering.

After service as a submariner (electrical) he obtained in 1950 a B.Sc. degree in physics from Sheffield University and after several positions in Development, became the Head of the Electronic Engineering Laboratories of the B.S.C. Swindon Laboratories in Rotherham. In this capacity, Derrick Shaw was the pioneer of the nucleonic/electronic control of continuous casting machines—a technique now used the world over.

In 1967, on the initiative of the IERE, he was seconded to the United Nations as an Industrial Advisor to Israel and he remained in that country for 6 months.

He returned to B.S.C., where he remained until May, 1971 when he left to become Chief Engineer of Davy Instruments Ltd., until the time of his death.

Derrick was a visionary and an outspoken critic of institutions, including our own, becoming 'too academic' in their approach and advised the Institution on the specialist examination in Industrial Electronics.

A founder member, past chairman and stalwart committee member of the Yorkshire Section, he represented the Institution on the Electrical Engineering Advisory

Committee of Barnsley College of Technology and was also the Representative for many years on the Yorkshire Council for Further Education.

In 1962 he presented, at the Symposium on Industrial Electronics, a paper entitled 'A specification for electronic equipment for use in heavy industry' and this was subsequently published in the Journal.

He was a very active member of the Church and will be sadly missed both as a colleague and a friend.

P.A.B.

Alan Frederick Sollitt (Graduate 1970) died during last summer, aged 40, leaving a widow. After leaving the Royal Air Force in 1963 in the rank of Corporal, having served as a ground radar fitter, Mr Sollitt joined RCA and was employed as a Senior Technician at RAF Fylingdales.

Advice has also been received of the deaths of the following members:

Harry Sayner (Member 1937), of Keighley, Yorkshire during 1978, at the age of 85 years.

Thomas William Edward Towers (Member 1953) of Sidcup, Kent in August 1978, aged 70 years. Before his retirement he was Sales Manager with the Telephone Manufacturing Company, Dulwich.

Joseph Drifill (Member 1949, Associate 1945) of Hull, on 1st November 1978, after a long illness, aged 73 years. At the time of his retirement he was on the teaching staff of Hull Technical College.

Wilfred Snook (Companion 1946, Associate 1961) of Bridport, aged 78 years.

William Marshall Tyson (Fellow 1937, Member 1934) of Grange-over-Sands, Cumbria, in September 1978, age 78 years.

The 1978 MacRobert Award

The MacRobert Award, Britain's major engineering distinction, has been won for 1978 by Pilkington Brothers Ltd for the development of the Ten-Twenty Windscreen by its subsidiary, Triplex Safety Glass Co. Ltd.

The MacRobert Gold Medal was presented on 5th December to Pilkington's Chairman, Sir Alastair Pilkington, by the President of the Council of Engineering Institutions, Lord Hinton of Banksbridge, O.M., at a ceremony in the Great Hall of the Institution of Civil Engineers. Lord Hinton also presented bronze replicas of the medal and cheques totalling £25,000 to the team of five individuals to whom the development is credited. These were: Mr S. E. Kay, B.Sc., F.R.I.C., former Chairman of Triplex; Mr V. J. Osola, B.Sc., C.Eng. F.I.Mech.E., F.Inst.F., Technical Director of Triplex; Dr H. R. S. Jack, Ph.D., B.Sc., C.Eng., F.I.Mech.E., F.Inst.F., lately Chief Engineer, Triplex; Mr J. Pickard, M.A., F.Inst.P., Research and Development Manager, Triplex; and Mr D. C.

Wright, B.Sc., M.Inst.P., Research and Development Manager, Pilkington.

The MacRobert Award is made annually by CEI on behalf of the MacRobert Trust and is presented in recognition of an outstanding innovation or application in the field of engineering or the physical sciences which has enhanced or is deemed likely to enhance the prestige and prosperity of the United Kingdom.

In his Citation, Mr J. C. Duckworth, M.A., C.Eng. Chairman of the MacRobert Award Evaluation Committee said 'Innovations can only be successful when they meet a market need. Knowledge of new technologies can open the way to totally new markets—such was the case with last year's MacRobert Award Winner, the Malvern Correlator. Alternatively, a perceived market need may lead to the innovative development of a new product or process as a

result of a planned programme of research and development work—such is the subject of this year's MacRobert Award, granted to the Triplex Ten-Twenty windscreen'. He continued:

'Many injuries in motor car accidents arise when occupants are thrown forward against, and often through, the front windscreens. Ideally, the windscreens should be strong enough to retain the passenger within the car, but at the same time pliable enough to yield, on head impact, sufficiently to avoid brain damage caused by excessively rapid deceleration. It must fracture in such a way as to cause the minimum number of cuts and abrasions, whilst it must also meet high standards of clear vision, stone impact resistance and production tolerances, and durability at reasonable cost.'

'It was clear that no existing windscreens approximated to these ideal requirements, and Triplex Safety Glass Company Limited, with the support of its parent company Pilkington Brothers Limited, set out to meet them as nearly as possible. An early requirement was a programme of research to establish quantitative criteria by which the merits of different windscreens could be evaluated. The objective technique of laceration measurement developed by this research, (and proved by anthropomorphic dummy testing at Wayne State University, Detroit, and by impact tests at other Laboratories), is becoming accepted worldwide. Having established reliable methods of laboratory testing it was then possible to investigate the optimum specification for the windscreens and the component parts making up the laminate.'

'The final design has markedly different specifications for the outer and inner glass components. The inner one is particularly novel in being highly stressed, whilst its thickness

is less than that of any previous thermally stressed windscreen component. The exacting specification for the glass components set requirements for controlled heating, bending, cooling, and for handling, which were entirely novel in the industry and which necessitated a concentrated programme of research and development leading to highly innovative solutions. Both process and product have wide patent coverage, confirming the novelty of the technology. The final product is very significantly superior to previously existing windscreens in reducing laceration arising from impact with the windscreens, without adversely affecting other desirable windscreen properties.'

The first production application of the Ten-Twenty windscreen was the Rover 3500 car launched in 1976 and all new Rovers produced since that date have incorporated it. The new windscreen was then fitted to the Princess Mk. II, the Triumph Dolomite and the Rolls Royce Camargue; further British cars are to fit the product in the period immediately ahead. The first export order was for the Volvo 262C and negotiations are well advanced for its incorporation as original equipment in a number of other European models. The important characteristics of controlled high strength achievable in Two-Twenty glass, particularly in relation to resistance to impact by objects from outside, has also led to its use in British, French and US-built aircraft such as Concorde, the European Airbus A300B and the Boeing 747.

A highly-automated factory for the manufacture of the Ten-Twenty Windscreens in Birmingham was opened by the Prime Minister in August 1978. A quarter-mile-long production line employs 30 people per shift and is capable of an output of 250,000 units annually.

Applicants for Election and Transfer

THE MEMBERSHIP COMMITTEE at its meeting on 4th January 1978 recommended to the Council the election and transfer of the following candidates. In accordance with Bye-law 23, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communication from Corporate Members concerning the proposed elections must be addressed by letter to the Secretary within twenty-eight days after publication of these details.

January Meeting (Membership Approval List No. 254)

GREAT BRITAIN AND IRELAND

CORPORATE MEMBERS

Direct Election to Fellow
EVANS, William Alun. *Swansea, West Glamorgan.*

Transfer from Graduate to Member

WOODS, Malcolm John. *Hitchin, Hertfordshire*

Direct Election to Member

AMIN, Mohammed Banie. *Swindon, Wiltshire.*
ROBERTSON, Brian. *Histon, Cambridge.*

NON-CORPORATE MEMBERSHIP

Transfer from Student to Graduate

SMITH, Anthony Kim. *Headingley, Leeds.*

Direct Election to Graduate

ADU, Rufus Idowu. *Colchester, Essex.*
HARRISON, Nicholas Paul Dain. *Chelmsford, Essex.*

LAIYEMO, Joshua Adesegun. *London.*
McVITTIE, Allan. *Blundford Camp, Dorset.*
WESTWOOD, Thomas. *Paisley, Renfrewshire.*

Direct Election to Associate Member

HERRING, John Charles. *Somerton, Somerset.*
LEWIS, Barry. *West Wickham, Kent.*
NOSIKE, Dennis Okoye. *London.*

QURESHI, Manzurul Haq. *Sudbury Hill, Middlesex.*
SCOTT, John Phillip. *Peterhead, Aberdeenshire.*
TORRENS, Ronald William. *Kilrea, Coleraine Co. Londonderry.*
WORMALD, Barrie Clement. *Harrogate, North Yorkshire.*

Direct Election to Student

CHIU, Sin Kwok. *Bradford, West Yorkshire.*
FIELDS, Graham John. *Southampton, Hants.*
GREENWOOD, Paul Robert. *King's Lynn, Norfolk.*
MARAMBÉ, Nalin Nanda Kumar. *London.*
PRICE, Andrew. *Torpoint, Cornwall.*
RANDALL, Stephen John. *Surbiton, Surrey.*
WILLIAM, Timothy Stephen. *Sandymount, Dublin.*

NON-CORPORATE MEMBERS

Transfer from Student to Graduate

WAN, Kwing Yuen. *Hong Kong.*

Direct Election to Graduate

HOLMES, Robert Reginald. *Wildenrath, West Germany.*
LAU, Siu Hung. *Hong Kong.*
LEUNG, Hip Sum. *Lubbock, Texas, USA.*

Transfer from Student to Associate Member

FAKYESI, Solomon Oriola. *Akure, Nigeria.*
GALANIS, Creon. *Athens, Greece.*

Direct Election to Associate Member

ONG, Cheong Haut. *Singapore.*

Direct Election to Associate

ROBERTS, John Michael. *Scarborough, Ontario, Canada.*

Direct Election to Student

CHAN, Choon Meng. *Singapore.*
CHAN, Kap Man. *Hong Kong.*
CHUA, Chai Huan. *Singapore.*
CHUA, Geok Kian. *Singapore.*
JAMES, David Antony Arulraj. *Singapore.*
LEE, Huay Eng. *Singapore.*
TEO, Soon Leng Susan. *Singapore.*

OVERSEAS

CORPORATE MEMBERS

Transfer from Graduate to Member

ACHARYA, Ganesh Narayan. *Pilani, India.*

Transfer from Associate Member to Member

ONG, Lam Ching. *Kuala Lumpur, Malaysia.*

Direct Election to Member

SERVETAS, Evangelos. *Patissia, Athens, Greece.*

The Chartered Engineer's Degree: Ordinary, Honours or 'Enhanced'?

Following the publication of the IEE's 'Merriman Report' and the evidence submitted to the Finniston Inquiry by the Chairman and Officers of CEI, this Institution has received so many enquiries about its own intentions in respect of the standard of academic qualifications expected of applicants for Corporate Membership that it seems proper to make a policy statement on the subject.

Honours or Ordinary Degree?

The Institution has not considered it necessary to set up a counterpart of the Merriman Working Party because the issues involved have been studied during the past year by the Working Group on Bye-Law revision, the Working Party on the Finniston Inquiry, the Education Committee, and the Executive Committee. All these bodies have independently concluded and advised Council that they consider that the case for raising the academic standard required for Corporate Membership to that of an Honours Degree has not been fully made out. On the present evidence, therefore, we would oppose any proposal by CEI to make this higher standard of academic qualification mandatory. It is perhaps pertinent to note here that none of the studies undertaken within the Institution during the past year was concerned with academic qualifications in isolation: indeed, the Institution deplores the tendency, evident in many quarters, and no doubt inspired by EEC considerations, to pay more attention to the academic element of an engineer's 'stock in trade' and less to the training and experience elements than it believes to be desirable. Its concept of the designation 'Chartered Engineer' is that it should be indicative of proved engineering aptitude and achievement, and since there is general agreement that all the attempts made so far to establish an invariable connection between levels of academic qualification and ultimate engineering achievement have failed, the Institution wishes, so far as its membership of CEI permits, to continue to judge applicants for Corporate Membership on their achievements 'in the round', rather than in terms of the separate contents of the three watertight compartments into which the component parts of those achievements tend to be arbitrarily divided.

In the context of achievement it should, perhaps, be commented that the recent amendments to those Bye-Laws which define the Institution's 'responsible experience' requirements for Corporate Membership are not indicative of an intention to change the level of achievement expected. They have been made because it seemed to Council that the activities of electronic engineers are now so diverse that the earlier form of these Bye-Laws had become too restrictive and might lead to the exclusion from such membership of persons who had made major contributions to technological development in fringe areas.

Technician Engineer Transition

It is perhaps also appropriate to remind members that it has always been the policy of the Institution, not only to foster good relationships between Technician Engineers and Chartered Engineers, but also to do everything within its power to ensure that there are no insuperable academic obstacles to be overcome by any Technician Engineer who has shown himself capable of the kind of engineering achievement which the Institution expects of its Corporate Members, and is seeking to join their ranks. It has therefore been pleased to note the steady growth in the population of its Technician Engineer class of Associate Member, and in furtherance of

its policy of encouraging the growth of an integrated electronic engineering community has, by its latest Bye-Law amendments, opened membership of its Standing Committees and Specialist Groups, to Associate Members and Graduates.

Those members who have not seen the Merriman Report may perhaps not be aware that, besides recommending an Honours Degree requirement for Chartered Engineers, it advocated a move towards an Ordinary Degree requirement for Technician Engineers, but with the proviso that some revision of Ordinary Degree course structure and syllabus would generally be needed to make it suitable. This recommendation has been made elsewhere also—for example, by Dr. H. L. Haslegrave, the chief architect of the TEC qualifications scheme. The Institution wonders, however, whether those who advocate the change do so with the aim of enhancing standards, or are merely attempting to prevent further erosion of those standards. The HNC in Electrical/Electronic Engineering has lost the battle for survival and entry to it will be discontinued after 1980; although the HND remains, it is evident that the TEC is anxious to kill that also as soon as it can, offering in its place some kind of HTD 'with extras'. It may well be that if present trends cannot be halted, an Ordinary Degree designed on similar lines to the present HND will eventually be needed to provide industry with a supply of Technician Engineers of the calibre it has been accustomed to recruit from holders of Joint Committee awards. The Institution believes, however, that if the course for such a degree was of a widely different structure from that considered appropriate for an Honours Degree, there would be an implication that courses for the latter contain too small a proportion of study time devoted to the practical considerations which distinguish technology from pure science.

Change in Entry Standards

It will be apparent from what has already been said that the Institution's decision not to demand a higher standard of academic qualification from its Corporate Members at the present time is not due to complacency. On the contrary, the overall picture presented by the evolving educational pattern fills its Council, and the Committees directly concerned, with disquiet. The imminent introduction of 'N' and 'F' levels to replace 'A' levels and the proposal to discontinue 'O' levels and CSEs, and replace them by a single award of a standard as yet unknown, have naturally led those concerned with the formulation of degree courses to consider whether the present output standards can be maintained without extending the time spent in studying from three years to four.

As a corollary it was to be expected that some would consider that the present trends might bring about such a degeneration of the standard of academic achievement attained by holders of ordinary degrees that this would cease to be adequate, and they would therefore advocate the raising of the minimum standard required for Chartered Engineer registration to that of an Honours Degree. The Institution believes, and has stated in its submission to the

Finniston Inquiry, that this is the wrong approach. What it believes to be needed is a tightening-up of the requirements for entry to degree courses, which would serve the two-fold purpose of preventing a decline in final standards and eliminating the waste which would result from spending money on the higher education of people whose talents are more suited to practical activities. It believes that there would be no need to introduce ordinary degrees and honours degrees of different structure if the content of all engineering degree courses was regularly reviewed, in order to ensure that they remain suitable and adequate qualifications for those aiming to become Chartered Engineers. It further believes that the HND in Electrical/Electronic Engineering should be retained, and that it should remain under the auspices of the Joint Committee, on which the Institution is represented, and so can continue to be involved in the task of keeping the award in line with the evolving requirements of Technician Engineers of the future.

The CEI Examination

It may not be inappropriate, having referred to the Joint Committee in which the IEE is our senior partner, to mention another recent joint academic activity. A Joint IEE/IERE Working Party has been engaged in the formulation—and discussion with CEI Examiners and Moderators—of proposals for revision of the syllabus of the Electrical/Electronic Engineering papers in Part 2 of the CEI examination, which has remained unchanged since 1974. Amongst the recommendations of the Working Party has been one for the introduction of 'project' type questions, designed to test a candidate's ability to make selective application of his theoretical knowledge to a practical problem, instead of requiring him to regurgitate those parts of that knowledge on which the Examiner has chosen to set the year's questions. Another recommendation made and seriously considered was for the deletion of the study of Maxwell's equations from the syllabus for the 'fundamentals' paper 'Electromagnetic Fields and Networks', on the grounds that few of tomorrow's electronic engineers are likely to need them. The Institution believes that the fact that the latter proposal was not contemptuously rejected as totally heretical confirms its view that electronic technology is in such a state of flux that over-emphasis on, or over-canalization of, the academic studies of the electronics engineer to be, would be ill-advised and untimely. We do not yet know what will be the eventual effect of the impact of the micro-processor: even less can we forecast what new fields will later be opened for exploration by future electronic engineers. But we can be certain that there are no fields in which they will not appreciate the guidance of students of the natural sciences from which all technology derives. It is for this reason that the Institution has revised certain Bye-Laws and engaged in negotiations with CEI aimed at ensuring that Corporate Membership will never be denied to the many holders of degrees in Physics and Applied Physics who are employed in the electronics industry.

International Considerations

In an earlier paragraph, reference was made to the influence of EEC considerations. The Institution believes that there is a real danger that those of our Treaty of Rome partners who claim that the standard of academic qualification demanded of our Chartered Engineers is inadequate, will regard much that is happening in the Engineering Institutions at the present time as evidence that their claim is well founded. We would therefore urge all concerned to think carefully before taking any further action which might imply that a substantial body of opinion in the UK has been persuaded that our Chartered Engineers are under-qualified by comparison with their counterparts elsewhere in Europe. We would go further, and point out that only in the UK is a requirement for demonstration of practical competence part of the criteria for registration. The Institution therefore takes this opportunity of placing on record its belief that the current requirement that a Chartered Engineer should have followed a 5-year programme of further education leading at least to an ordinary degree or equivalent qualification in an appropriate discipline, followed by 2 years of approved practical training and a similar period of specialized experience at a specified level of responsibility before registration can be granted, is both far more demanding than the registration requirements of many EEC critics, and better suited to the nation's needs.

The Enhanced Degree

This is not to deny the possibility that those who claim that some of the ills from which UK industry suffers can be attributed to the fact that many engineers are as naive about management matters as are many managers about new technological developments, may have a point. For the present, however, the Institution wishes to reserve judgement on the value of 'enhanced' degree courses—that is to say, courses in which the duration of study is extended to four years in order to provide time for the student to be initiated into the management and other non-technological problems which he will eventually encounter. The reason for the Institution's wish to take more time to consider the matter is that, while it appreciates that industry may find it inconvenient to release engineers for management or similar studies later in their careers, it wonders whether their initiation into these matters before they have spent some time as engineers at the work face, may create more problems than it solves. It is also thought necessary in this context to establish very much more clearly just what proportion (if any) of the nation's ills is due to the quality of education, training and experience provided for and demanded of its Chartered and Technician Engineers; for until this is established there is a very real danger that the profession will be blamed unfairly either by opportunists anxious to exploit any argument to enhance the status of the professional engineer or, even worse in the nation's long-term interest, by others unwilling to face up to the fact that the fundamental cause of Britain's industrial ills could lie elsewhere in the nation's socio-political structure.

Radio and Electronics in Hong Kong

This is the third of a series of articles dealing with aspects of Radio and Electronics in Hong Kong; the first two, on Telecommunications and on the Electronics Industry, were published in the September issue of the Journal.

Education for Electronic Engineering in Hong Kong

MAN-CHUNG LAU, B.Sc.(Eng.), M.I.E.E., M.H.K.I.E., C.Eng., M.I.E.E., M.I.E.R.E.

The Electronics Industry in Hong Kong

The electronics industry in Hong Kong embodies about 700 factories employing over 70,000 people which is about 10% of the total work force. It is the second largest money-earning industry and exported HK\$4,600 million worth of electronic products in 1977.

With the recent trends of the requirement to manufacture products of increased sophistication and higher quality, and the Government policy to encourage diversification, the planning of technical education and training to provide suitable and sufficient manpower and technology has played an essential role in the expanding economy of Hong Kong.

The Hong Kong Training Council and Manpower Surveys

In 1973, the Government appointed the Hong Kong Training Council to advise on measures necessary to ensure a comprehensive system of training geared to meet the developing needs of Hong Kong's economy. The entire Training Council complex consisting of industry training boards and committees is serviced by the Training Council Division of the Labour Department. The forecast manpower requirements for the electronics industry are shown in Table 1.

Table 1

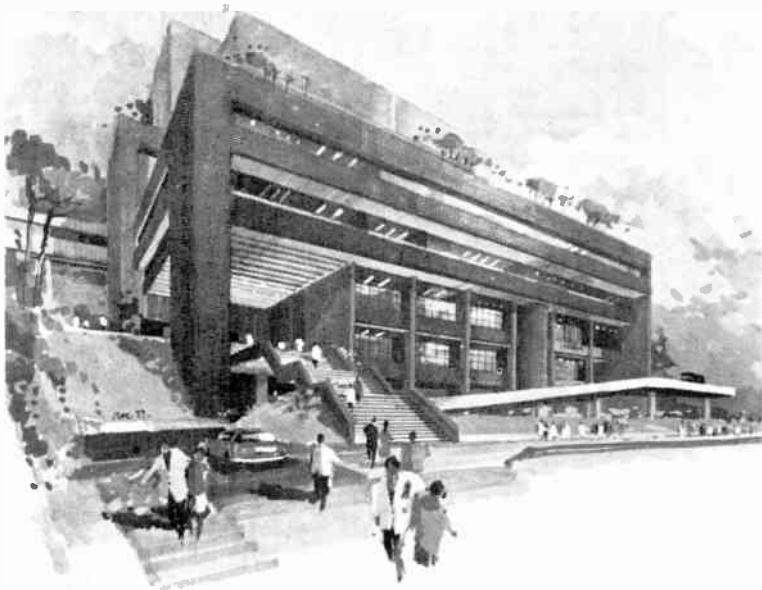
Manpower in Hong Kong electronics industry†

	Forecast Annual Supply Requirement (1977-82)	No. of People Employed (1977)
Engineers/Technologists	87	669
Technicians	409	2875
Craftsmen	475	4908

† From 'Report on Technical Manpower Demand and Supply 1977-82', Government of Hong Kong Publication, August 1977.



Man-chung Lau, (Member 1972, Graduate 1966) is Vice-Principal of the new Lee Wai Lee Technical Institute, Kowloon Tong, which is due to open this year. A graduate of the University of Hong Kong, Mr. Lau held appointments as Lecturer and Senior Lecturer in the Department of Electrical Engineering at Hong Kong Technical College and subsequently was acting Head of the Department of Electrical Engineering at the Morrison Hill Technical Institute from 1972 to 1975. Before taking up his present post he was for two years Head of the Department of Electrical Engineering at the Kwai Chung Technical Institute. Mr. Lau has been a member of the Hong Kong Section Committee since its formation and he was recently elected Honorary Secretary.



(Top)
The new Engineering Building,
University of Hong Kong.
Artist's impression by courtesy
of the University from the
Interflow booklet
'Redevelopment of University
Main Estate'.

(Centre left)
The University Science Centre
of the Chinese University
of Hong Kong.

(Centre right)
The Haking Wong Technical
Institute, one of the five
Government Technical
Institutes.

(Bottom)
The Hong Kong Polytechnic.
The original campus of the
Hong Kong Technical College
is on the right of the
photograph and on the left
are the new Phase I buildings
erected since its expansion
to a Polytechnic.



It should be noted that the numbers in the sub-total may not be taken directly as the manpower available to the industry as graduates from one course may proceed to study another course.

The University of Hong Kong

The Engineering (Civil) Faculty of the Hong Kong University was founded in 1912 while the Department of Electrical Engineering was formed in 1961. The degree courses with specializations in power and machines, electronics, control and computer have enrolment figures in 1978 for B.Sc.(Eng.) I : 73, B.Sc.(Eng.) II : 72, B.Sc.(Eng.) III : 60, M.Phil. : 16, M.Sc. : 10 and Ph.D. : 3.

The B.Sc.(Eng.) degree is recognized by both IEE and IERE for exemption from the CEI Examinations. The current research activities include active network synthesis, power electronics, data communications systems, applications of computers and system stabilities.

The engineering facilities will be greatly improved and expanded with the New Engineering Building under construction. The new Building provides a net area of 11,700 m² with over 50 engineering laboratories and a new training workshop. It is due for completion in 1979.

The Chinese University of Hong Kong

The Department of Electronics in the Chinese University offers a 4-year B.Sc. course and it enrolled 180 undergraduate and 8 postgraduate students in 1977/78. In 1977, there were 30 B.Sc. graduates and 7 M.Phil. graduates. In addition, the Department started a 5-year work-study programme for B.Sc. Electronics in 1975. The programme combines course work with work in industry so as to produce graduates with substantial practical experience to equip them to take up responsible positions in industry. The B.Sc. degree is recognized by the IEE and the IERE for exemption from the CEI Examinations.

The fields of research undertaken by the members of staff include solid-state electronics, liquid crystals and superconductivity; bioelectronics; signal processing; microwave engineering; control and system theory; plasma physics and electromagnetic theory; microprocessor and computer applications. The Department also offers a wide range of extra-mural courses in electronics for the public.

The Hong Kong Polytechnic

The Hong Kong Technical College at Hung Hom, Kowloon, was transformed into the Hong Kong Polytechnic in 1972. New buildings were constructed in the adjacent areas and the Polytechnic has now expanded to house 15 teaching departments and will ultimately provide up to 8000 full-time equivalent student places.

The Department of Electronic Engineering was formed in 1974 separating it from the Department of Electrical Engineering. The curricula cover the areas of electronic circuit design, communication engineering, computer engineering, control engineering and instrumentation. In 1978/79, the Department is expected to provide for a total of 517 full-time students, 274 part-time day release students and 1100 evening

students following a range of courses leading to Associateship, Higher Diploma, Diploma, Higher Certificate and Certificate.

Examples of the projects taken by the Associateship students include a digital servo system, control motors for small milling machines, synchronized clock, pseudo-random noise generator, metal detector, temperature/humidity meter, waveform synthesizer, analogue and digital phase-locked loops, microprocessor for commercial and domestic applications.

The Government Technical Institutes

The Hong Kong Government established Technical Institutes in a number of major industrial areas and they serve like the local technical colleges in the United Kingdom. The first one, Morrison Hill Technical Institute, was established in 1969, while the second and third, Kwai Chung Technical Institute and Kwun Tong Technical Institute respectively, were opened in 1975. The fourth institute, Haking Wong Technical Institute, followed in 1977 and the fifth, Lee Wai Lee Technical Institute at Kowloon Tong, will start to operate in 1979. The sixth Technical Institute is now under planning in Tsun Mun, a new industrial town in the New Territories.

All the Technical Institutes are under the Government Education Department and each will provide about 1300 to 1500 full-time equivalent student places. Although technician courses at the TEC Diploma and Certificate levels are offered, the majority of places are planned for apprentices following part-time day release craft courses.

Furthermore, there is the Hong Kong Technical Teachers' College to provide teachers' training for technical teachers and workshop instructors. There are also 11 pre-vocational schools offering courses at Form 1 to Form 3 levels and feeding their graduates into PTDR craft courses offered by the Technical Institutes.

Conclusion

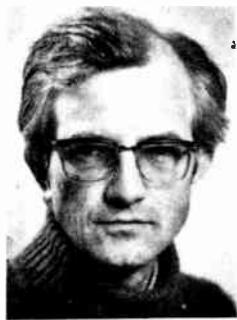
In comparing the output of graduates with the forecast annual supply requirement, the manpower supply from the educational institutions can be considered to be sufficient to meet the requirements. But it can be appreciated that Hong Kong will need more engineers as industry is becoming more sophisticated and more capital intensive with diversification. We do need to develop higher technology in order to continue to export goods and services of the highest quality and at the same time to meet the heavy competition in export markets.

Last but not least, we cannot neglect the increasing pressure of the social demand for the increase of provisions for higher education. This can be easily seen from the figures: there were 103,047 students taking the Hong Kong Certificate of Education Examination in 1978 compared with 86,520 students in 1977.

Acknowledgments

Sources of the information included in this article have been: Professor S. Y. King of the University of Hong Kong, Professor C. F. Chen of the Chinese University of Hong Kong, Dr. J. S. L. Wong of the Hong Kong Polytechnic, and publications of the Hong Kong Training Council.

Contributors to this issue



John Taylor works for the Control and Instrumentation Division of the Atomic Energy Authority's Establishment at Winfrith Heath in Dorset. He joined the Establishment in 1956 and subsequently obtained a Higher National Certificate in electrical engineering. His work has been concerned with design of electronic instruments for nuclear reactors and this has recently been directed towards the problems associated with electromagnetic compatibility.



involved with f.m. television and its application to radio links and satellite broadcasting. He is at present a senior engineer, principally concerned with digital sound signals and coding techniques. Mr. Gilchrist contributed to the recent International Broadcasting Convention as joint author of a paper on field trials of an experimental optical-fibre system and has had two papers published in *BBC Engineering*.



Peter Atkinson (Member 1962) graduated with honours in electrical engineering from Imperial College, London in 1955 and, as a postgraduate apprentice, he gained industrial experience with the guided weapons division of English Electric. From 1959 to 1962 he was a Lecturer in electrical engineering at North Herts Technical College and, from 1962-1964, a Senior Lecturer in control engineering at the College of Technology, Letchworth. In 1964, Mr. Atkinson became a Lecturer in control engineering at Reading University, a founder member of the Department of Engineering and Cybernetics (formerly the Department of Applied Physical Sciences), and is now a Senior Lecturer in the Department of Cybernetics and in the Department of Engineering. He is the author of two text-books, and many technical papers for two of which he has received Institution Premiums, and he holds several patents. Mr. Atkinson is an active member of the Institution, having been Chairman of the Thames Valley Section from 1972 to 1975, and he served on the Examinations Committee and on the Academic Standards Committee for several years. He is at present Chairman of the Automation and Control Systems Group Committee.



Jim Allen graduated in 1950 as an external student of the University of London with first-class honours in electrical engineering. Following an apprenticeship with the General Electric Company he obtained further industrial experience with Joseph Lucas Ltd. He entered education as a lecturer at Birmingham College in Advanced Technology (now Aston University) in 1956 and was appointed Senior Lecturer in control engineering at Farnborough Technical College in 1960. He began research on digital controllers in 1967 and gained his M.Phil. as an external student of the University of Reading in 1970. He was appointed a Lecturer in the Department of Applied Physical Sciences at Reading (now Departments of Engineering and Cybernetics) in January 1971. Apart from his teaching and research interests in analogue, digital and hybrid computing, Mr. Allen is co-author of papers on various aspects of computer-aided design and is a consultant to several industrial organizations.



Mark Porter graduated with first-class honours in cybernetics and instrument physics from the University of Reading in 1972 and obtained his Ph.D. for work on a graphically-patched hybrid computer in 1977. He is now working with Racal Electronics Ltd. at Bracknell.



Ralph Benjamin (Fellow 1975) has been Chief Scientist at the Government Communications Headquarters for the past seven years. After graduating from Imperial College, University of London, in 1944, he joined the Royal Naval Scientific Service and in 1961 he was appointed Head of Research and Deputy Chief Scientist of the Admiralty Surface Weapons Establishment as Director and Chief Scientist, also becoming a qualified Naval Diving Officer. From 1965 to 1971 he combined these appointments with that of Director of Underwater Weapons R & D at the Ministry of Defence.

In 1964 London University awarded Dr Benjamin the Ph.D. degree for a thesis on signal processing and in 1970 the D.Sc. for his contributions to general electronics. He is currently Visiting Professor in the Department of Electrical and Electronic Engineering of the University of Surrey. He published a book on 'Modulation, Resolution and Signal Processing in Radar, Sonar and Related Systems' in 1966 and is author of numerous papers in the proceedings of various learned societies, symposia etc.

Dr Benjamin has been a council member of the British Acoustical Society and has served on a number of official committees, advisory bodies and working parties in the United Kingdom, NATO and the USA.

A note on Pat Fowler's career was published in the January 1979 issue.

UDC 681.34: 681.327.13

Indexing Terms: Computers, hybrid, Computer peripheral equipment, Graphics

Development of a graphically-patched hybrid computer ('GRAPHIC')

P. ATKINSON,
B.Sc.(Eng.), A.C.G.I., C.Eng., M.I.E.E., M.I.E.R.E.*
A. J. ALLEN,
B.Sc.(Eng.), M.Phil., C.Eng., M.I.E.E.*
and
M. PORTER, B.Sc., Ph.D.*

SUMMARY

The conventional hybrid computer, although of immense value in simulation, has always suffered from one major defect, namely the need for a patch-panel with its attendant problems of patching, debugging and careful maintenance. This paper describes the development of a new machine in which the operator communicates with the analogue sub-system via a graphics terminal. A minicomputer with flexible disk backing store is arranged to interrogate the graphics terminal on which a block diagram of the system to be simulated has been drawn up by the operator. Numerical data related to the blocks are inserted via a keyboard/v.d.u. Changes in data and/or topology can be implemented at considerable speed by the operator. The machine has been extensively tested and the results of one such test have been included in the paper. It has been shown that GRAPHIC is a thoroughly ergonomic and reliable machine, capable of expansion, extension and improvement and that it could form the basis of an improved commercial hybrid computer.

1 Introduction

The use of analogue computers in simulation has largely been superseded by either hybrid computer methods or purely digital computer techniques in recent years. The analogue computer still possesses a major advantage over the digital computer in speed of solution and in combination with the digital computer, in its hybrid form, it offers a more ergonomic and faster facility than either the purely analogue or the purely digital computer. Even so, the present range of commercial hybrid computers still suffer from one major disadvantage (other than their high cost), namely the need for a patch-panel in the man-machine interface. Although the problems of patching, debugging and maintenance of patch-panel hybrid computers have been recognized virtually since the invention of the analogue computer, very few attempts have been made to eliminate the need for a patch-panel. Indeed, those that have been made have resulted in extremely expensive solutions.^{1,2,3}

The recent development of low-cost digital and analogue integrated circuits has encouraged the authors to investigate the possibility of combining the analogue and digital computers in a new form of hybrid machine in which the patch-panel has been completely replaced by a more ergonomic man-machine interface specifically designed to allow the operator to communicate with the analogue sub-system in a natural manner. The investigation has led to the development of a small-scale research machine which has been extensively tested and shown to possess the required properties. The research machine has been given the acronym GRAPHIC and the purpose of this paper is to give a description of the design, implementation, and operation of this new machine.

2 Basic Design Principles of GRAPHIC

It was decided in the early stages of the research programme to use a graphical interface between the digital computer component and the operator. Although television graphics have recently become very fashionable, it was decided that use would be made of an available cathode-ray display system with a pad-probe input.⁴ The basic philosophy is that the system to be simulated is first 'drawn up' on the c.r.o. display in the form of a block diagram representing the system to be studied. This operation is facilitated by a grid of points displayed on the centre of the c.r.o. together with a menu of 'devices' which can be picked up by means of the probe and inserted into the grid (or deleted) as required. The digital computer then interrogates the block diagram and produces a set of required connections which are subsequently implemented in the parallel analogue sub-system. The associated parameters of each block associated with the whole diagram are communicated to the digital computer by means of a conventional keyboard and v.d.u. However the digital computer is arranged to prompt the operator to give it the required data. The interface between the digital and analogue machines consists of a

* Department of Cybernetics, University of Reading,
3 Earley Gate, Whiteknights, Reading RG6 2AL.

set of digitally-controlled solid-state switches and coefficient units. The digital computer thus converts the numerical and topological data received from the operator into a set of block interconnections and numerical coefficients which are set up on a parallel analogue machine. The analogue component in GRAPHIC is not however a conventional analogue computer containing individual integrators and coefficient units. The interconnection problem with a conventional machine would be extremely complex and expensive to implement. In GRAPHIC an assumption has been made which, to a large extent, mitigates the vast switching problem. This assumption is that in simulation work a single block is often quite complex and advantage has been taken of this fact.

At the end of the setting-up phase, the operator requests the 'run-mode' and the analogue computer is then set to run in a repetitive mode so that a record (on a separate c.r.o. display or X-Y recorder) can be obtained. In the small research machine being described there are many limitations imposed by the need to keep the development costs as low as possible; for instance only step commands are nominally available, only zero initial conditions are possible and only linear systems may be studied; most, if not all, of these limitations could be removed by subsequent development.

3 System Hardware

3.1 Complete System

Much of the hardware used in the development of GRAPHIC consists of standard commercial hardware which has been interfaced to a DEC PDP8 series mini-computer for the purpose. The exception is the analogue sub-system which has been specifically developed in this project. A schematic diagram of the equipment is shown in Fig. 1. Topological data for the simulation to be studied is entered by the operator on the c.r.o. display unit A by use of the input pad/probe and associated function switches; numerical data entry and system control are facilitated by means of the v.d.u. programs, and data files are stored on a flexible Memorex disk unit which has a

capacity of over 100 k words. The simulation output can be monitored on the c.r.o. display B (for the high speed time-scaling) or alternatively for a permanent record on the X-Y recorder with low speed time-scaling.

3.2 Block Structure for the Analogue Sub-System

A consideration of typical simulation problems leads to the viewpoint that most linear systems can be simulated by interconnecting a number of blocks having transfer functions $H(s)$ of the general form

$$H(s) = \frac{n_0 + n_1 s + n_2 s^2 + \dots + n_n s^n}{d_0 + d_1 s + d_2 s^2 + \dots + d_n s^n}$$

Such a transfer function can be represented by a flow diagram as illustrated in Fig. 2(a). In GRAPHIC a decision was made to limit n to the value 2. This decision was the result of a compromise between the size of the switching problem and the redundancy of analogue components and devices. A first-order block is unsuitable in that it leads to a heavy switching problem and cannot readily be used to simulate a second-order transfer function with complex poles or zeros. The use of a block order greater than two simply increases the component redundancy problem without any real attendant advantage. A practical realization of the second-order block is shown in Fig. 2(b) and it was this scheme which has been implemented in GRAPHIC using conventional operational amplifier circuitry and digitally-set coefficient units. It was recognized that in some simulations of practical systems the derivative of a block output is required. The facility has been made available in GRAPHIC by bringing out the total input to the second integrator for one particular block only.

In the design of GRAPHIC a decision also had to be made on the total number of second-order blocks to be built into the analogue sub-system. In a pilot study of the kind involved it is necessary to study a reasonable number of simulation exercises in order to validate the system. It was considered that a four-block analogue sub-system would provide a sufficiently large number of topologies for

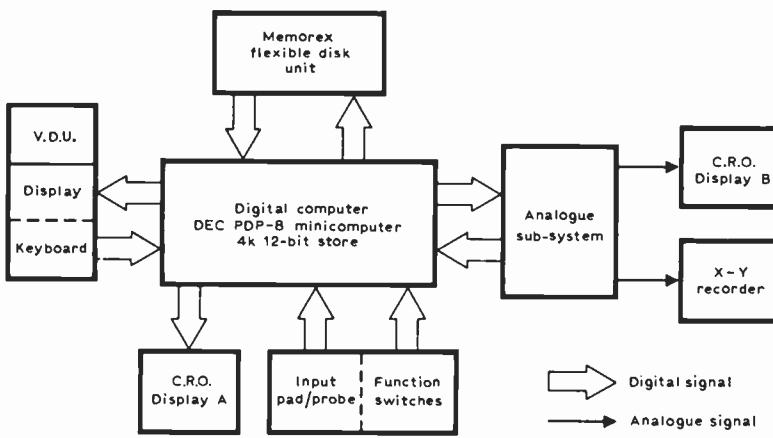


Fig. 1. Basic structure of GRAPHIC.

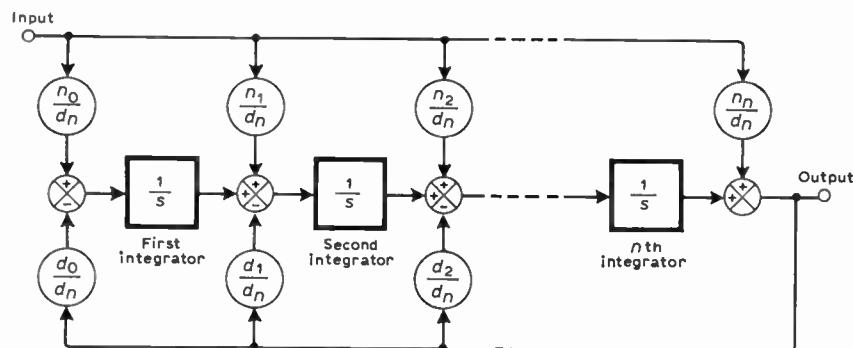


Fig. 2

(a) Flow diagram for generalized n th order transfer function.

study without incurring undue complexity of inter-block switching or high hardware costs. However for a commercial machine a minimum number of blocks would be about twenty.

A further reduction in the switching problem was achieved by arranging each block to have four inputs rather than one so that it could receive the output of any block including its own. Also the output signal from any block can be in direct or inverted form.

With the block structure described above the direct method of interconnection is more efficient than the standard three-stage matrix method^{5,6} and this was adopted in the construction of GRAPHIC. In this switching arrangement there is a controlled direct connection between each block output and each block input. This reduces the number of switches required and simplifies the routing of signals. In a system containing more than about four blocks the three-stage matrix method becomes preferable.

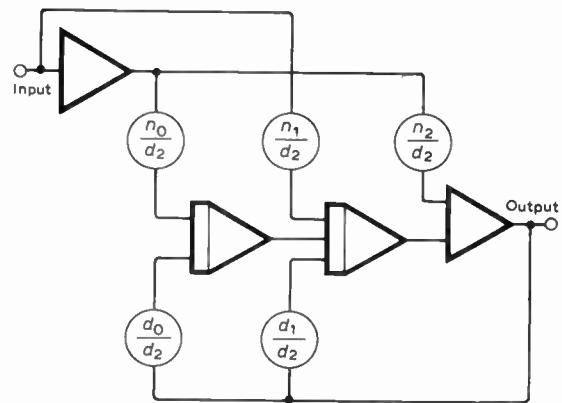
3.3 Digital Control of Analogue Sub-System

As explained previously there are a large number of switches and digitally-set coefficient units required in the implementation of GRAPHIC. In consequence considerable research effort was concentrated in this area. All the devices selected were solid state rather than electro-mechanical in the interests of high speed of operation, reliability and low cost.

3.3.1 The digitally-controlled analogue switch

The choice of solid-state switching element lies between the bipolar transistor and the f.e.t. The bipolar device exhibits an undesirable offset voltage and requires a large control current whereas these are negligible in the f.e.t. The n -channel f.e.t. was chosen in preference to the p -channel because it gives lower conducting-state resistance for the same cost.

When the analogue system is in the run-mode various switches must be open and others closed. The opened or closed condition of each switch is originally set up by the digital computer but held during the run in TTL buffer



(b) Practical implementation of a second-order block structure.

registers linked to each switch via TTL to n -channel f.e.t. interface units. In order to use the positive output voltage swing from the TTL registers, the interface unit has been designed. The operational amplifiers have been biased about +5 V rather than zero. The f.e.t. gate drive is then achieved directly from an open-collector TTL output with external pull-up resistor. The arrangement is shown in Fig. 3. All the switches, whether inside or outside the blocks, are controlled in this way, which saves many components compared with the conventional interface. The complete arrangement of switches is controlled

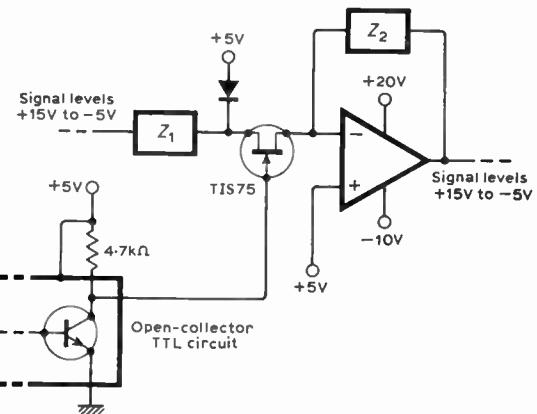


Fig. 3. Simplified TTL to n -channel f.e.t. interface, as used in GRAPHIC.

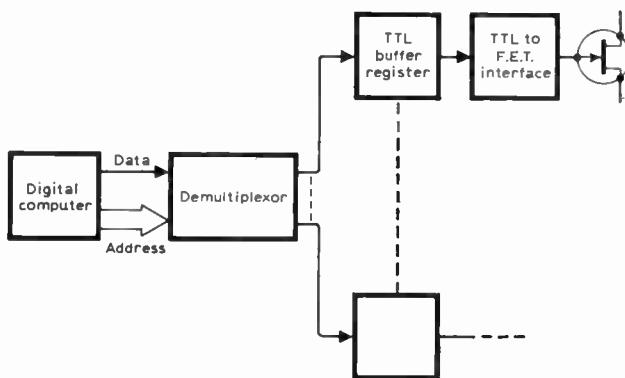


Fig. 4. Computer/f.e.t. switch control arrangement.

from the digital computer via a demultiplexer unit which routes the successive computer outputs to the correct buffer registers as illustrated in Fig. 4.

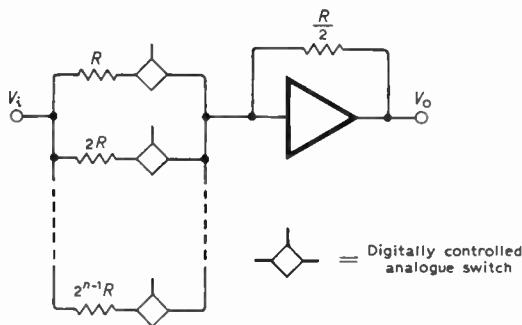
It should be noted that although the output of all the analogue computing operational amplifiers are biased to +5 V, the total output from a simulation is not biased. A final backing-off circuit has been used to eliminate the bias from the output. However the command step input is automatically biased to the false zero.

3.3.2 Digitally-set coefficient units

Twelve-bit four-quadrant multiplying d-to-a units are now commercially available at relatively low cost and would have been used in GRAPHIC had they been available during the development phase. However as they were not available at that time, the digitally-set coefficient units were constructed from discrete components. Each consisted essentially of an operational amplifier with resistive feedback and switched weighted resistors as illustrated in Fig. 5. In the actual hardware, eight-bit coefficient units were used in order to cut down the cost. These, of course, will give a resolution of 1 part in 256 which is quite sufficient for validation purposes.

3.3.3 Overload detection circuitry

The overload detection circuit is required to indicate overload voltages on the computational operational amplifiers (i.e. the integrating and summing amplifiers).

Fig. 5. An n -bit weighted-resistor d.a.c.

In GRAPHIC the operating range is -5 V to $+15 \text{ V}$ (i.e. $\pm 10 \text{ V}$ relative to the offset value of $+5 \text{ V}$). Standard commercial integrated circuit comparators are not suitable for the purpose because of their limitation on differential input which is 25 V . A special circuit was therefore designed for this purpose and every summer/integrator is connected to such a circuit in GRAPHIC. The circuit is illustrated in Fig. 6 and is based on a pair of 741 operational amplifiers with the $+15 \text{ V}$ and -5 V reference overload levels being connected to their inverting and non-inverting inputs respectively. Overload on the amplifier output will cause either one or the other op-amp to swing to the positive ($+20 \text{ V}$) rail. These swings are then limited to TTL levels (i.e. about $+4 \text{ V}$) by means of a resistor/Zener diode circuit prior to application to a TTL OR gate. The signals from every overload circuit are then combined in an OR gate to give a global indication of overload which is relayed to the digital computer and indicated to the operator via a prompt on the v.d.u.

4 System Software

The system software for GRAPHIC is very extensive as would be expected but its extension to control a larger analogue sub-system would not involve a vastly more complex development and could still be run on a mini-computer, albeit with a larger store. The amount of software required for GRAPHIC is too large for the 4 k word core-store of the PDP8 used in the project and so a flexible magnetic disk backing store has also been employed. The software package is split into a number of program files and data files which are handled by the LIBR operating system,⁷ developed at the University of Reading. This extremely efficient program requires only 128 words resident in memory and yet it is quite comprehensive.

The software package for GRAPHIC consists of six programs, which perform the following functions:

- (1) Graphical data capture and display
- (2) Graphical data processing
- (3) Numerical data capture and output
- (4) Data checking and processing for standard blocks

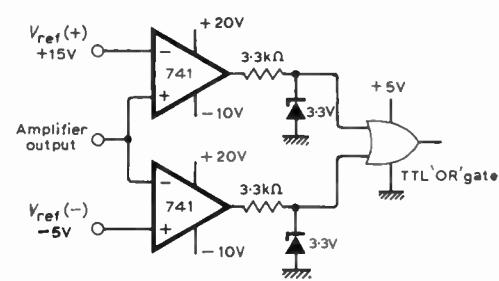


Fig. 6. Overload detection circuit.

(5) Data checking and processing for blocks with derivative output

(6) Final data processing and system control.

These programs are all written in PDP8 assembler code (PAL III) to conserve storage. In a paper of this length it is impossible to describe all the software in detail and the Sections below are limited to descriptions of what the software does rather than exactly how it does it.

4.1 Graphical Data Capture and Processing

Both the graphical input and output units operate in point mode with $X-Y$ coordinates. The symbols in the menu (shown in Fig. 7(a)) are therefore stored as sets of

$X-Y$ coordinates. The symbols in the block diagram for which an example is shown in Fig. 7(b), are also stored in this way. The block diagram is drawn up by inserting the required symbols into a 8×8 matrix of points permanently displayed on the c.r.o. As can be seen from Fig. 7(a), the main symbols are representative of the transfer function block, interconnection lines with crossovers, summing units and polarity signs, input/output symbols, the cursor, and the block descriptive numerals. The topological data associated with a given grid location is automatically specified by the symbol at that location. The operator can control the drawing process by means of the graphical input pad and associated push-button switches. With these he can select new symbols and insert a new symbol into the matrix by means of the cursor which itself is 'picked up' by locating the probe in the area of the pad associated with that symbol. Symbols at a matrix point can also be deleted in a similar manner and the transfer function blocks can be numbered. Another push button operation allows all symbols to be simultaneously deleted.

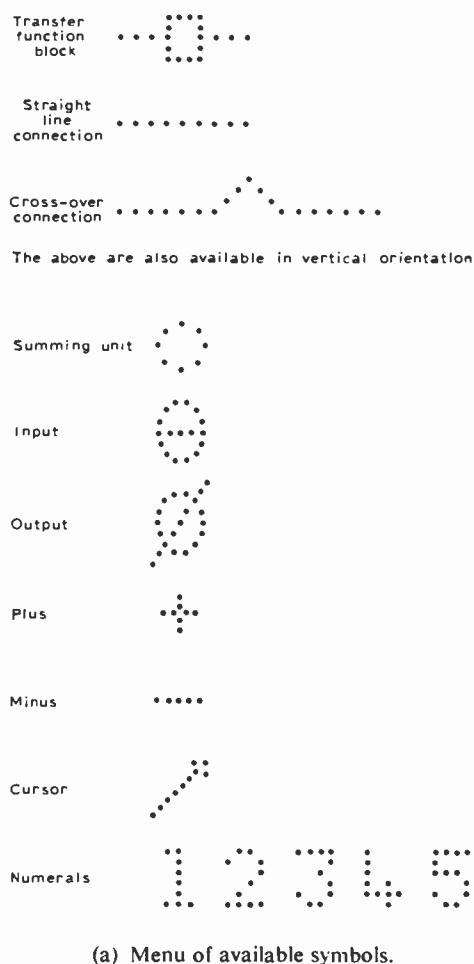
When the block diagram has been built up to the satisfaction of the operator the data capture program is initiated. After the initialization procedure, the program searches the block diagram data list to find the address of the input node. The main path from input to output is then traced. Any branches from the main path are noted, and interconnection data pertaining to the main path are built up. When the main path has been determined, each previously noted branch is examined. Again branches are noted and interconnection data are built up. Examination of each branch is terminated when that path leads to a block which has already been found.

When all branches have been examined, the interconnection data are output on the v.d.u. This gives the user an indication that the program is functioning correctly, and can also provide a permanent record of the problem topology. The interconnection data are then processed by the graphical data processing program into the form used for transmission to the analogue sub-system, the processed data being stored in a disk file for later usage.

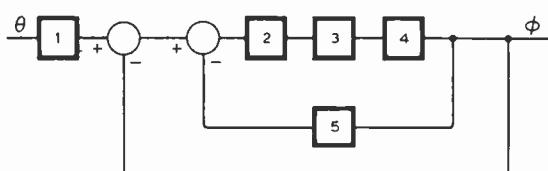
Finally, the program calls the numerical data capture program from the disk.

4.2 Numerical Data Capture and Processing

The transfer functions associated with each block are inserted in a standard format via the keyboard/v.d.u. following prompts which automatically instruct the operator what data are required next. When data for a given block are to be inserted, the operator requests the present block data and a print-out of the gain, lead constants, number of pure integrations and lag constants appears in a fixed format of numbered lines. To change a parameter, the associated line number is called up by the operator. A prompt (e.g. GAIN) appears and the operator must then punch in the gain in either fixed point or floating point format. It should be noted that whereas



(a) Menu of available symbols.



(b) A typical block diagram.

Fig. 7

all the programs have been written in PAL III, the DEC floating-point package has been invoked for numerical data manipulation; this considerably reduces the storage requirement compared with that which would have been required if a high-level language had been used.

After the data processing program has been initialized, the order of the denominator expression is checked. If the order is greater than two, the program goes to the error routine. This routine calls back the numerical data capture program so that the operator can correct the error.

The numerator order is also checked to be not greater than two, and the denominator order is compared with the numerator order. If the numerator is of higher order than the denominator, implying differentiation, the error routine is called.

If the numerator and denominator orders are valid, polynomial expression of each are formed from the numerical data in their original form. All the polynomial coefficients are then divided through by the coefficient of s^2 in the denominator to give the block transfer function in the required form.

The coefficients in the new expression are then checked to see whether they are within range. Finally the digital coefficient unit gains and computing component values are determined.

The program checks the standard blocks in turn, and if each is valid the program to deal with the derivative output block is called from the disk.

It should be noted that every hardware integrator in each block is capable of having a 'nose-gain' of 1, 10 or 100. For a given nose-gain and input resistor values in any integrator, the digital coefficient unit settings will be different. The data processing program includes a complex optimization procedure, the object of which is to set nose gains and input resistor values throughout to give the highest possible on-scale settings of the digital coefficient units. This procedure minimizes the possibility, for a given simulation, that the setting of a digital coefficient unit will be so low as to introduce severe resolution inaccuracies.

4.3 Final Data Processing and System Control

When the optimization procedure is finished, the nose gains and input resistor values of the integrators and the settings of the digital coefficient units are transmitted to the analogue sub-system under the control of the Final Data Processing program. The system control program allows the operator to set the input step size and timebase speed whilst the analogue sub-system is in the run-mode. This program also allows overload to be automatically signalled to the operator via the v.d.u. Finally the operator can request either a return to the graphical data program or to the numerical data program.

5 System Appraisal—A Typical Simulation Problem

Many simulation exercises have been performed on the system in order to demonstrate its versatility, reliability and accuracy. The system has been shown to possess a man-machine interface superior to that of the conventional hybrid computer and to be extremely reliable in operation. The accuracy of the research model is not particularly good because relatively low-cost analogue computing components have been used throughout in the interests of economy. Moderately good computing operational amplifiers were used (the RCA 108) in order to bring offsets within tolerable bounds. Recently E.A.I. have produced very high performance operational amplifiers in integrated circuit form and far greater offset accuracy could thus be achieved with proportional increase in costs. The passive computing components are all $\pm 1\%$ and the digital coefficient units have a resolution of 1 part in 256. These component accuracies are very poor by the standards of high-class commercial hybrid machines and will predictably give unacceptably large composite computational inaccuracies in the simulation of fairly complex systems. However it was not the purpose of the research to make a very accurate machine but to investigate the possibility of improving the man-machine interface without large expenditure.

This Section will be devoted to the description of the simulation of a typical control system on GRAPHIC so

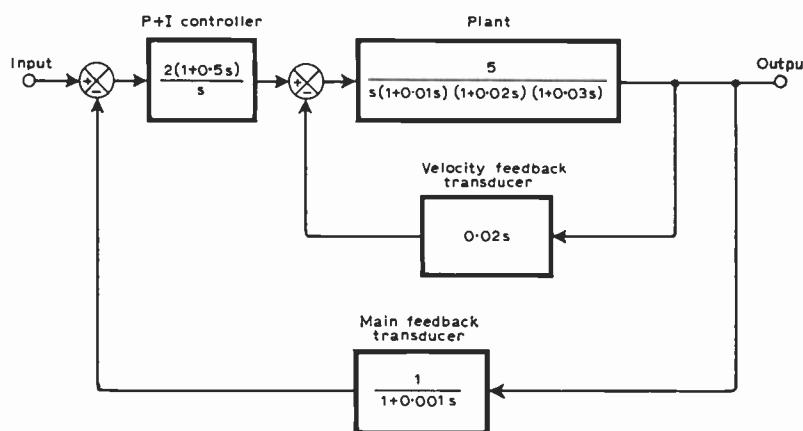


Fig. 8. Control system for simulation.

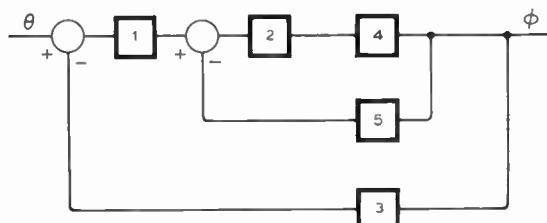


Fig. 9. Block diagram for example illustrating man-machine dialogue.

as to demonstrate the way in which the operator would use the machine and the kind of result which would be obtained.

Figure 8 shows the block diagram of the control system to be simulated. It contains a fourth-order plant with local velocity feedback having a series proportional plus integral controller and overall negative feedback via a transducer containing a single exponential lag.

The operator first calls up the graphical data capture program and draws up a block diagram of the system as shown in Fig. 9. After this has been completed, the operator keys in the symbol 'X' (for 'exit'). The machine captures the data and the following is presented on the v.d.u.

CONNECTIONS

INPUT : 1	(input signal connected to block 1 input)
OUTPUT : 4	(output signal taken from block 4 output)
1 : 2	(standard output of block 1 connected to block 2 input)
2 : 4	etc.
4 : 5	etc.
5 : 2 -	(inverted output of block 5 connected to block 2 input)
4 : 5	etc.
3 : 1 -	etc.

These data can be checked by the user to verify that the interconnection analysis program is functioning correctly.

When the interconnection data have been presented to the operator he is then prompted to give numerical data with the word BLOCK. The man-machine dialogue below shows the computer prompts with the operator responses (underlined).

BLOCK 1

1 GAIN 2
2 LEADS 1+5.0 S)

(Carriage return terminates this lead term. Typing space would produce request for term in s^2)

4 INTEGRATIONS 1

BLOCK 2

1 GAIN 0.5
5 LAGS 1+0.01 S)

(As with the lead term, carriage return terminates this lag term)

6 LAGS 1+0.02 S) (second lag)

BLOCK 3

(The gain is already set at the required value of unity, and so no explicit entry need be made)

5 LAGS 1+0.001 S)

BLOCK 4

1 GAIN 10
4 INTEGRATIONS 1
5 LAGS 1+0.03 S)

BLOCK 5

DIFFERENTIATION BLOCK

GAIN +0.000000 E+000 ↴ 0.02

(Typing space allows user to modify gain. Typing carriage return would retain current value)

RUN

(Block data modification completed. Go to run mode)

The response is now displayed. Appropriate adjustment of input magnitude and timebase period follows to give the best obtainable response. An X-Y plotter recording of this trace is shown in Fig. 10. The measured overshoot is 29%, and the time to first peak is 0.61 seconds. A more accurate digital simulation gave values of 26% and 0.63 seconds respectively, indicating that GRAPHIC has given results well within expected accuracy.

6 Prospects for System Improvement and Extension

GRAPHIC has been demonstrated to function in a reliable and ergonomic manner. As has been explained previously it has been constructed as part of a pilot study to investigate improvements in the man-machine interface of hybrid computers. There is no doubt in the

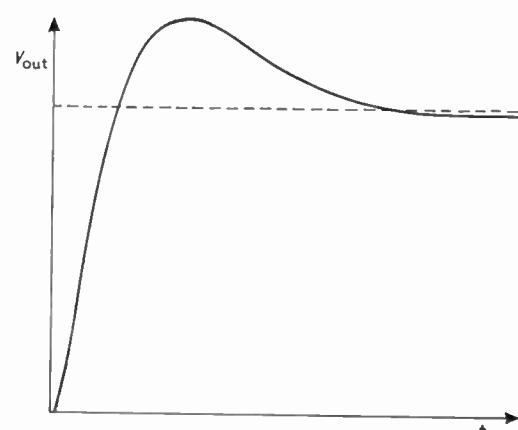


Fig. 10. Response pertaining to example illustrating man-machine dialogue.

authors' minds that the elimination of the patch-panel has brought about a major improvement in this aspect. Although the analogue facility of GRAPHIC is very limited in size, this could be increased without the development of large amounts of new software. Furthermore, the accuracy of the present machine could readily be improved by the use of more costly analogue components and twelve-bit digital coefficient units (which are now commercially available).

Obviously there is a need to introduce a range of non-linear and pure time delay blocks. These can be constructed using conventional hardware techniques but the software and hardware control aspects and the block diagram representation would call for an extension of the existing approach. Although the analogue components are optimized automatically in the sense that the settings of the digital coefficients units are kept at reasonably high values, there is of course no automatic method of amplitude scaling. Unfortunately it appears that there is no cheap and reliable method of incorporating on-line automatic amplitude scaling. The operator is however able to detect overload and reduce the level of the step input until it disappears. Automatic time scaling has not been included in GRAPHIC either but this is something that could be included as a software development which would not involve great difficulty.

Another feature which would obviously have to be incorporated in a commercial machine is a 'parameter sweep' facility. This must adjust a given parameter value in small steps over a given range. Again this is a trivial software development. In the same way facilities for providing non-zero initial conditions and inputs other than steps must also be incorporated.

A limitation in the present analogue sub-system of GRAPHIC is the range of coefficient values which can be achieved. For example, a lagging time constant in a transfer function would have to fall within the range of 10 s to 100 μ s. This is a hardware limitation imposed by the number and size of the integrating capacitors and resistors and the ratio of values could be increased by about three decades without practical difficulty but at increased cost.

Perhaps a major hope for the future is that each of the transfer function blocks may be replaced by its digital equivalent working at a very high sampling rate. In a properly conceived implementation of such a scheme, information would be passed from block to block in digital form with probably 16-bit accuracy and only one d-to-a converter would be required for the final output display. Each digital block might take the form of a microprocessor in such a scheme if this offered a financial advantage. An arrangement of this kind would greatly

simplify the interface between the controlling mini-computer and the simulator.

7 Conclusion

A graphically-patched hybrid computer, GRAPHIC, containing an analogue simulator with second-order transfer function blocks has been developed. It has been tested on a large number of problems, one of which has been included in this paper. It has been shown that the system is very reliable and ergonomic. The problem of patching and debugging of conventional hybrid computers has been successfully eliminated. The graphical method of patching a hybrid computer allows the engineer to communicate with the machine in a natural manner by using his conventional block-diagram representation directly. A further advantage is that a permanent record of the system topology and numerical data of the problem under investigation is stored on a flexible disk which can be filed for future reference.

It should be quite possible to use similar techniques on an improved and extended commercial model to obtain a more ergonomic simulator than has hitherto been available.

8 Acknowledgments

The authors wish to acknowledge the Science Research Council of the United Kingdom for financially supporting the development of GRAPHIC under a grant number B/RG 87600.

They also wish to acknowledge the theoretical and technical support of their colleagues in this work, particularly Mr. G. F. Pearce.

9 References

- 1 Korn, G. A. and Korn, T. M., 'Electronic Analog and Hybrid Computers' (McGraw-Hill, New York), 1972.
- 2 Howe, R. M. and Hollstein, R. B., 'Time-shared hybrid computers: a new concept in computer-aided design', *Proc. IEEE*, 60, no. 1, pp. 71-77, January 1972.
- 3 Rubin, A. I. and Mawson, J. B., 'Hybrid computation 1976 and its future', *Computer*, 9, no. 7, pp. 37-46, July 1976.
- 4 Walker, B. S., 'Developments in low-cost interactive graphics systems', *Computer Aided Design*, 1, no. 1, pp. 5-7, Autumn 1968.
- 5 Hannauer, G., 'Automatic patching for analog and hybrid computers', *Simulation*, 12, no. 5, pp. 219-32, May 1969.
- 6 Nakahori, I., 'Automatic patching system for hybrid computer', *Proc. 1971 Summer Simulation Conference*, Boston, Massachusetts.
- 7 Drawneek, E. A., 'LIBR Manual', Internal Publication, Dept. of Cybernetics, University of Reading, 1973.
- 8 Porter, M., 'A Graphically-Patched Hybrid Computer', Ph.D. Thesis, University of Reading, 1977.

*Manuscript received by the Institution on 7th July 1978
(Paper No. 1861/Comp 191)*

Analogue-to-digital and digital-to-analogue conversion for broadcast quality sound

N. H. C. GILCHRIST, B.Sc., C.Eng., M.I.E.E.*

Based on a paper presented at the IERE Colloquium on Interworking between P.C.M. and F.D.M. Systems held in London on 25th January 1978

SUMMARY

A 13-channel p.c.m. system forms a significant part of the BBC's national radio distribution network, and is used to carry high-quality sound-programme material hundreds of miles with minimal impairment from noise, interference and distortion.

High-quality analogue-to-digital converters (a.d.c.) and digital-to-analogue converters (d.a.c.) are required for use in sound-programme links, and other applications for these converters, such as digital sound studio equipment, can be foreseen. To date, the BBC has used 13-bit a.d.cs and d.a.cs developed within the Corporation. The next generation of digital equipment is likely to require coders and decoders giving 14 bits/sample or even higher resolution.

In this paper, some of the defects which may be encountered with various types of a.d.c. and d.a.c. are discussed, and the merits of different types of converter for high-quality sound are considered.

1 Introduction

The BBC first used pulse code modulation on a regular basis in the broadcasting service from May 1972, when a digital 'sound-in-syncs' system was installed to carry the sound accompaniment to the BBC-1 and BBC-2 television signals over the major part of the television distribution network. This particular p.c.m. sound system uses 10 bits/sample coding with a sampling rate of 31.25 kHz (i.e. twice the television line frequency of 15.625 kHz), and the sound signal is compressed using an analogue compressor prior to coding, with corresponding expansion after decoding.

P.c.m. was also introduced into the sound-programme distribution network in the same year (1972) when a 13-channel multiplex system was installed to carry signals from London (Broadcasting House) to the transmitter at Wrotham in Kent; a monochrome television s.h.f. radio link was used to carry the p.c.m. bit stream. The p.c.m. system has been expanded over the years, and now it extends into Wales, Scotland and Northern Ireland and forms a significant part of the BBC radio distribution network.

Programmes which originate in the regions are sent to London for distribution over this network but analogue contribution circuits carry the programmes into London, at the present time. The use of p.c.m. systems for these circuits would be most desirable, as these programme signals from the regions travel even greater distances than those originating in London.

The 13-channel distribution system employs 13-bit coding and this is the minimum coding resolution which can be accepted. Future developments in p.c.m. systems for use with high-quality sound-programme material are likely to use 14-bit coding. The higher resolution gives lower levels of idle-channel noise which is compatible with the rest of the transmission network and the best domestic receivers. The sampling rate in the current system is 32 kHz and this will be retained in future systems for the distribution of sound programmes.†

There are applications for p.c.m. in the studio as well. Digital recording is an obvious use, and the increased signal-to-noise ratio obtainable by the use of digital techniques in tape-recording equipment would be of considerable benefit. Studio presentation and mixing equipment would benefit from the increased dynamic range of digital systems; it is likely that even higher resolution a.d.cs and d.a.cs could be of value here in order to achieve lower levels of quantizing noise in signals which undergo digital processing. There may also be some advantage in using a higher sampling rate than 32 kHz in studio equipment, but this has yet to be decided.

* British Broadcasting Corporation, Research Department, Kingswood Warren, Tadworth, Surrey KT20 6NP

† The use of 32 kHz sampling rate for digital links carrying high-quality sound programmes has been agreed within Europe.

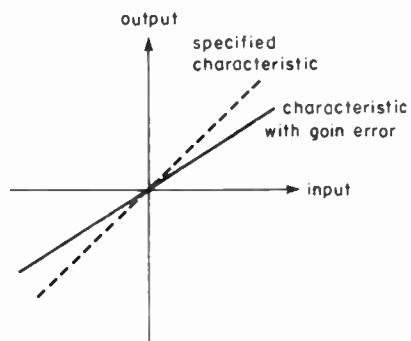
The conversion of the analogue programme signal into digital form and back again is the heart of any p.c.m. system and it is this interface between the analogue and digital forms which creates the most difficulty. Apart from the fundamental distortions which arise out of the quantization process, many converters suffer from instrumental defects which can produce audible impairments.

2 Errors Encountered in Practical Analogue-to-digital and Digital-to-analogue Converters

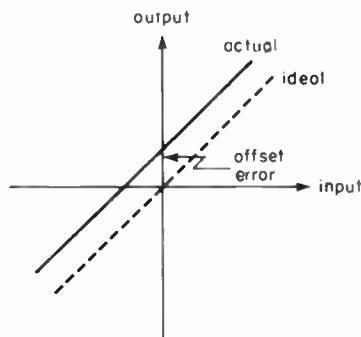
An ideal a.d.c.-d.a.c. combination (codec) would have a linear transfer characteristic, although this linear characteristic would comprise a large number of very small, equal quantizing steps. In a practical codec, the transfer characteristic may differ from that of the ideal codec in a number of ways. The principal differences found are in the slope and linearity of the transfer characteristic and in offset effects caused by d.c. drift.

Figure 1(a) shows the effect of gain error upon the transfer characteristic, which then has a slope differing from the design value. Gain error is unimportant for sound signals, as the analogue circuits in the equipment can be used to compensate for this. The effect of offset error is not too disastrous, either. With offset error (see Fig. 1(b)) the d.c. shift in the transfer characteristic results in asymmetry of the overload characteristic, and may restrict dynamic range somewhat. It can be more serious if a codec with offset error is used in a digitally companded[†] system;¹ low-level signals may suffer an increased quantizing distortion and programme-modulated noise may be enhanced.

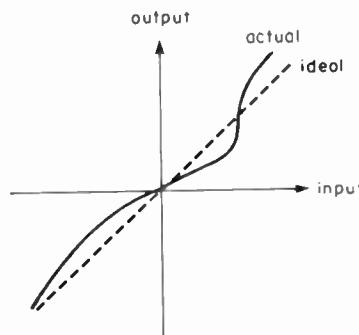
Non-linearity of the transfer characteristic (Fig. 1(c)) is very important, and the degree of non-linearity which can be tolerated is the same as for analogue sound equipment. In fact, when non-linearity occurs it normally does so in the associated analogue circuits. But the non-linear distortion can occur in the digital circuits, if the quantum steps which make up the transfer characteristics are not of uniform size. This type of distortion, known as differential linearity error, is illustrated in Fig. 1(d). If the differential linearity error exceeds the magnitude of one least significant bit, this can cause the slope of the transfer characteristic to reverse over part of the coding range; this non-monotonicity would have serious consequences in digital audio equipment. An example of a non-monotonic d.a.c. transfer characteristic is shown in Fig. 2. Under some circumstances, severe differential linearity error causes a convertor to omit codes (one such situation would be if a non-monotonic d.a.c. were to form part of a successive-approximation a.d.c.). Figure 3 shows an a.d.c. transfer characteristic which exhibits missed codes.



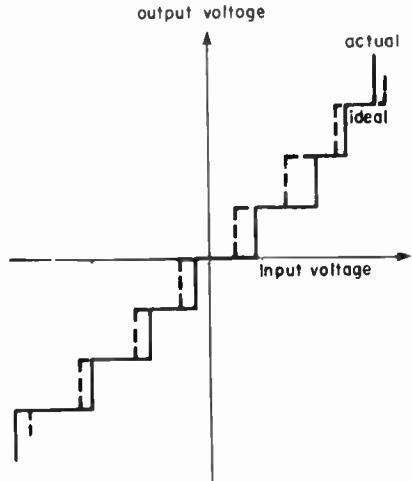
(a) Gain error



(b) Offset error.



(c) Linearity error.



(d) Differential linearity error.

[†] Digital companding (compressing and expanding) techniques can be used to reduce the bit-rate requirements for the transmission of digital sound signals.

Fig. 1. Errors in a.d.c.-d.a.c. combinations. (a) Gain error.

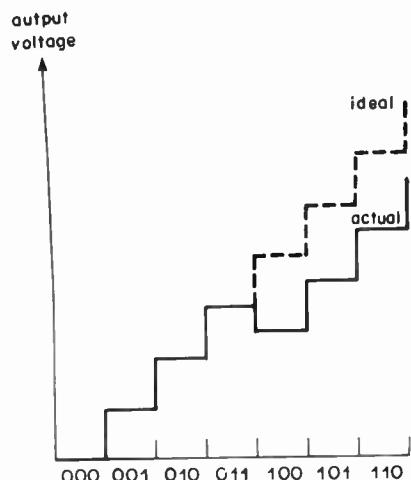


Fig. 2. Non-monotonicity in a d.a.c.

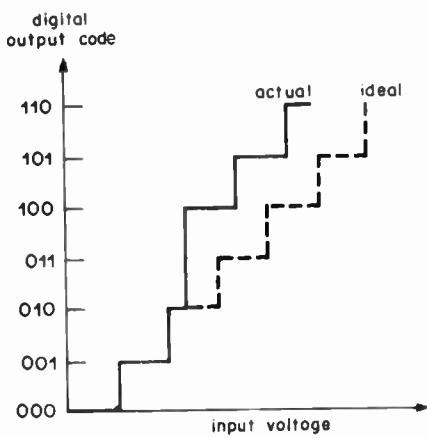


Fig. 3. Missing code in an a.d.c.

If the signal at the input to the a.d.c. changes during the conversion process, this can sometimes introduce errors in coding. Sample-and-hold circuits are therefore often used at the inputs of a.d.cs so that the signal is held constant during conversion. They can also be used after d.a.cs to remove spurious transients (sometimes known as 'glitches') from the signal, and thereby ease the task of low-pass filtering the decoded analogue signal. This is illustrated in Fig. 4. As a result of non-linearity in the sample-and-hold circuits, audible intermodulation products can be formed by signal components beating with the sampling frequency. It is therefore necessary to ensure that sample-and-hold circuits for use with a.d.cs and d.a.cs do not introduce any significant amount of non-linear distortion.

3 Types of A.D.C. and D.A.C.

As stated in the Introduction a relatively large number of bits (at least 13) is needed in order to code a sound signal sufficiently accurately for sound-programme purposes,² and the available conversion time is about 30 µs for a 32 kHz sampling rate. In contrast, for coding broadcast quality video signals 8-bit resolution is normally considered to be sufficient but the conversion time is very much shorter (100 ns or less).

In the following descriptions of conversion techniques digital-to-analogue converters are considered first, as some types of audio analogue-to-digital converters employ a d.a.c. within a feedback loop.

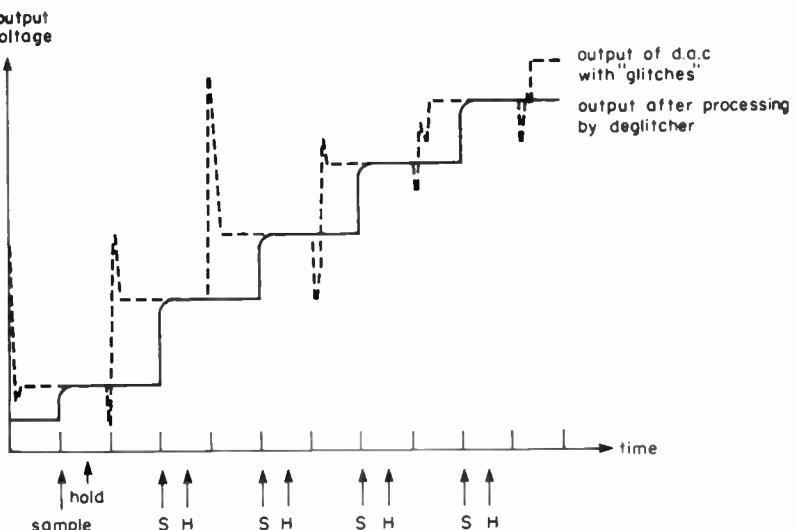


Fig. 4. Operation of a deglitcher.

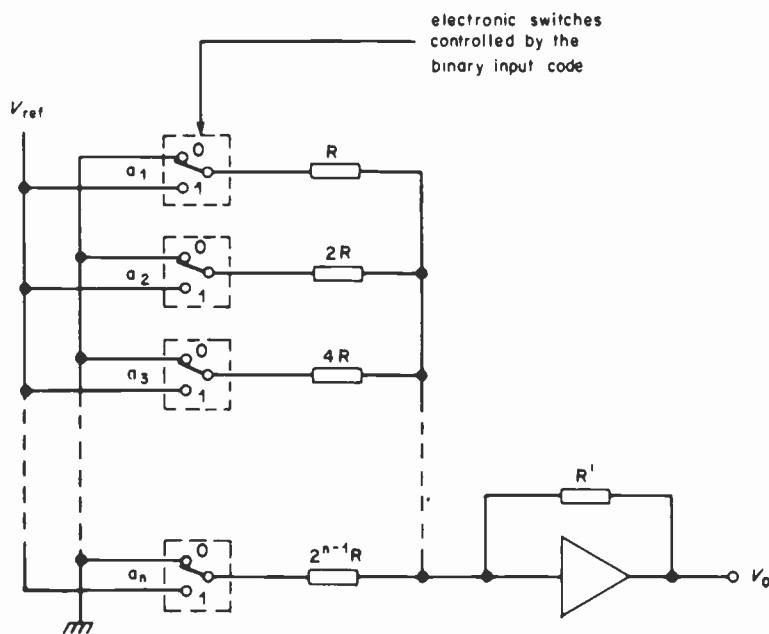


Fig. 5. Weighted current d.a.c.

3.1 Techniques for Digital-to-analogue Conversion

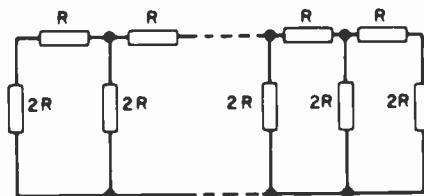
Figure 5 shows a weighted current d.a.c. in which a number of precision resistors produce binary-related currents from a reference voltage source. The binary input code (in parallel form) controls the switches which turn the currents on and off. The currents are added in the summing amplifier. The main problem with this type of d.a.c. is the extensive range of precision resistor values which is needed. An n -bit d.a.c. requires n precision resistors over a range of $1 : 2^{n-1}$ in value, and the ratios must remain constant over the operational temperature range and life of the decoder. An error of 0.012% in the resistor supplying the current controlled by the most significant bit of a 14-bit decoder will cause it to become non-monotonic. Another problem with this circuit is that resistance in the switches will affect accuracy, and, if the switches do not operate simultaneously, 'glitches' will be induced in the output as illustrated in Fig. 4.

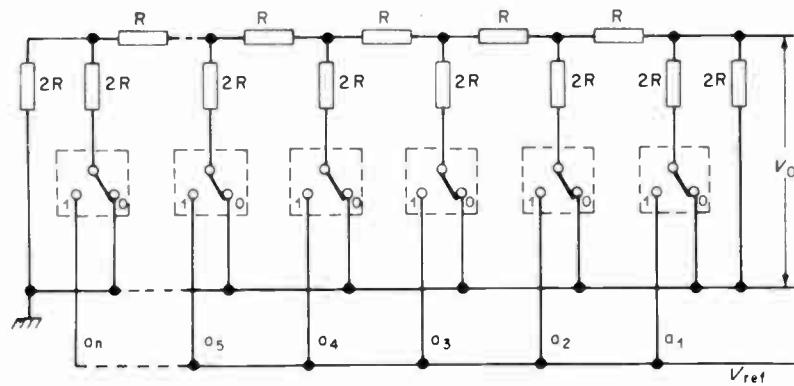
Some of the problems can be overcome by using a resistive ladder network of the form shown in Fig. 6. Only two resistor values are involved in the ladder network type of d.a.c. and these are in the ratio 1 : 2. This network has the characteristic that the resistances of the three branches associated with any node are equal ($2R$) so that a current fed into a node from one branch splits equally between the other two branches. One could, therefore, make a parallel d.a.c. using the simple arrangement in Fig. 7(a). As before, the switches are operated by the input code.

It is, in fact, better to adopt the arrangement shown in Fig. 7(b) and drive the network from one end with the reference voltage whilst currents from the shunt arms are switched into a summing amplifier. This arrangement does not depend upon network time-constants, as the

currents are constant (the switches operate between earth and 'virtual earth' points). Consequently, resistor values may be made higher to reduce the significance of switch resistance.

This type of modified ladder-network converter is quite popular in the commercial field where 13-bit or greater resolution is required. An error of 0.012% in the value of the resistors determining the most significant bit (m.s.b.) current in a 14-bit d.a.c. can make it non-monotonic at its mid-range point, and an error of 0.024% in the resistors determining the current for the next m.s.b. causes discontinuities at the $\frac{1}{2}$ and $\frac{3}{4}$ range points as well. Discontinuities can be introduced at other points on the transfer characteristic by correspondingly larger errors in the other resistors of the ladder network. Most ladder-network converters use thin-film resistor networks in order to obtain resistances of the required accuracy. Thin-film resistor networks can be made with sufficient accuracy and stability for use in 13-bit resolution converters;³ however it may not be possible to obtain sufficient accuracy and stability using this technique for converters with 14-bit or greater resolution without providing for adjustment of the m.s.b. resistors.

Fig. 6. $R : 2R$ ladder network.



(a) Using voltage switching.

(b) Using current routing switches.

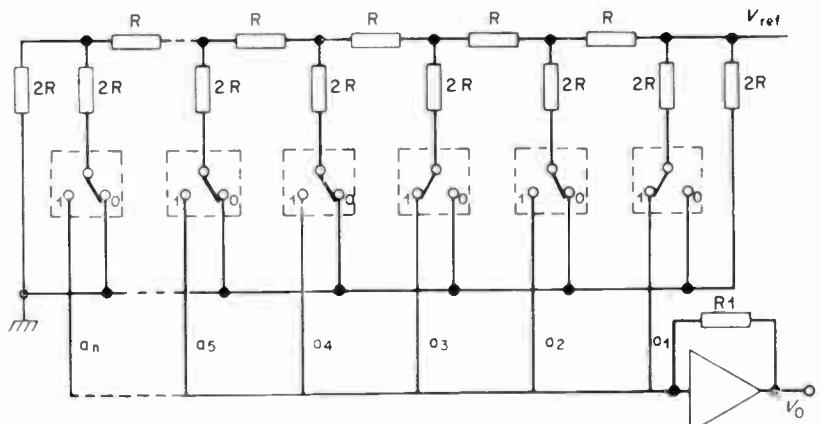


Fig. 7. Ladder network d.a.cs.

3.2 Techniques for Analogue-to-digital Conversion

Probably the most popular type of commercial analogue-to-digital converter is the successive approximation a.d.c. shown in Fig. 8. This converter uses a parallel d.a.c. (see the previous Section) fed from logic circuits which adjust the d.a.c. input code until its output is as close as possible to the analogue input voltage. Each bit of the d.a.c. input code is set to '1' in turn, starting with the most significant. If the d.a.c. output is then less than the analogue input signal to be coded, the bit remains set to '1'; if it is greater the bit is reset to '0',

and so on. When the process is complete, the d.a.c. input code is taken as the a.d.c. output.

The accuracy of the successive approximation a.d.c. depends upon that of the associated d.a.c. This type of a.d.c. gives missed codes if the d.a.c. becomes non-monotonic. During conversion, the input signal to the successive approximation a.d.c. must be kept constant, so a sample-and-hold circuit is essential at the input.

Another technique for analogue-to-digital conversion which has been studied uses a delta-modulator¹ with subsequent conversion to p.c.m. A basic delta modulator

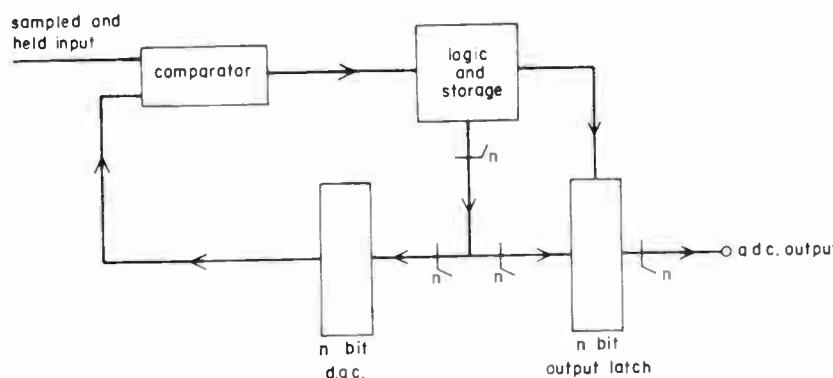


Fig. 8. Successive approximation a.d.c.

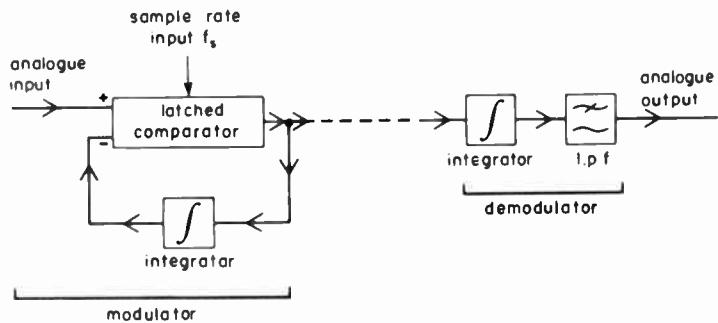


Fig. 9. Block diagram of delta modulator and demodulator.

with demodulator is shown in Fig. 9, and operation is as follows. The comparator compares the analogue input signal with the output of the integrator in the feedback path. If the analogue input level is greater than the integrator output, the comparator gives a logical '1' at its output which causes the integrator output level to increase by a defined amount. If the analogue input level is less than the integrator output, the comparator output is logical '0' causing the integrator output to decrease (by the same defined amount). Thus the feedback system in the modulator causes the integrator output to follow the analogue input signal in steps, and the output of the modulator is a one-bit p.c.m. signal.

The delta demodulator is simply an integrator which is identical with the integrator in the feedback path of the modulator. A low-pass filter after the integrator removes the residual components at $f_s/2$ and harmonics.

A delta modulator may be used to convert analogue signals to p.c.m. using the arrangement shown in Fig. 10. The comparator, up-down counter and 9-bit d.a.c. form a digital delta modulator, with the up-down counter and d.a.c. fulfilling the same function as the integrator in the

feedback path of the delta modulator shown in Fig. 9. The up-down counter effectively converts the one-bit p.c.m. signal into a 9-bit p.c.m. signal at the same sampling rate (20 MHz). This p.c.m. signal is then passed through a digital low-pass filter and re-sampled at 32 kHz. It was hoped, when investigations into this technique began, that it would be possible to construct an a.d.c. having at least 14-bit resolution. However, instrumental problems restricted resolution to little better than 13-bit,⁵ and the delta modulation-to-p.c.m. technique has so far proved to be more complicated to implement than the dual-slope ramp counter converter (see next Section).

3.3 The Ramp Counter Converter: a Technique applicable to A.D.Cs and D.A.Cs

The ramp counter converter⁶ is a technique which can be used both for analogue-to-digital conversion and for digital-to-analogue conversion.

A block diagram of a ramp counter a.d.c. is shown in Fig. 11. In this type of a.d.c., the input voltage

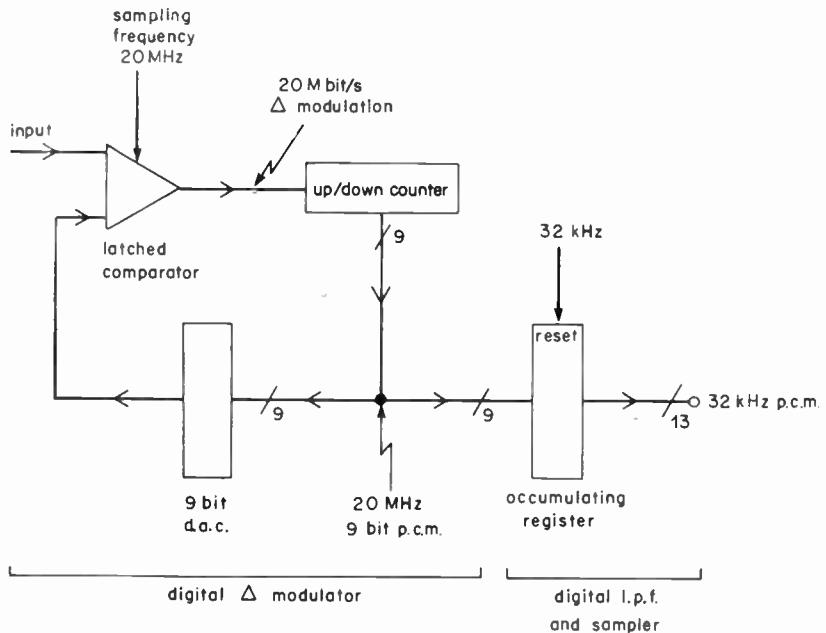


Fig. 10. Digital delta-modulator with low-pass filter and resampler.

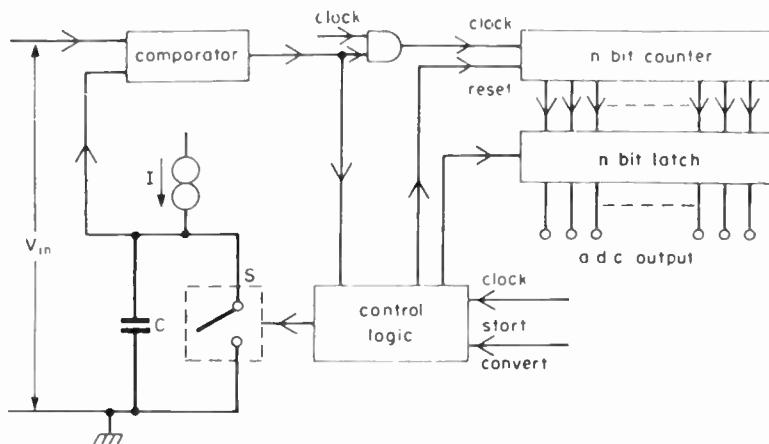


Fig. 11. Ramp counter a.d.c.

is converted to a time interval which is then measured to give a digital output, using the following sequence of operations. Initially, the counter is set to zero and the switch S is closed. Conversion starts when switch S is opened and the counter is enabled. The counter counts clock pulses as the capacitor charges linearly, from the constant current source, until the potential difference across the capacitor reaches the input voltage; the comparator then changes state and halts the counter. The control logic then instructs the output latch to accept the number held in the counter, switch S is closed to discharge the capacitor and the counter is reset to zero ready for the next conversion. It is clear that the time taken for the capacitor to charge to the level of the input signal voltage (V_{in}) is directly proportional to V_{in} , and in turn the final output of the counter is proportional to the time interval, and hence to V_{in} .

This type of convertor must be preceded by a sample-and-hold circuit. Without a sample-and-hold circuit, sampling would occur at irregular intervals, even if conversion were started regularly, and the noise performance of the convertor would suffer.

The ramp counter d.a.c. operates in the reverse manner to the a.d.c. and uses very similar circuitry. The input digital code is loaded into a down counter, and upon receiving the start conversion command the counter commences counting towards zero. At the same time, a constant-current source is connected to the ramp capacitor. When the counter reaches zero, the constant-current source is switched off, and the voltage across the ramp capacitor is transferred to a sample-and-hold circuit at the output of the d.a.c. After discharging the capacitor, the d.a.c. is ready for the next conversion.

Although the ramp counter converter offers very low differential non-linearity, the need for very high counting speeds presents problems. A 13-bit sound codec operating at a sampling rate of 32 kHz would require a counter clock at a minimum rate of 270 MHz. The comparator also presents problems, as it must have a high gain to give the necessary resolution and must be able to halt the counter within a time period which does not vary by more than a fraction of one clock pulse, if a good noise

performance is to be obtained.

A variant of the ramp counter converter has been developed within the BBC for 13-bit sound coding and decoding and is in use with the 13-channel p.c.m. distribution system. This converter is the dual-slope ramp type (sometimes referred to as the 'change-gear' converter).† In the BBC's dual-slope ramp a.d.c., a fast-rising ramp voltage is compared with the input signal, and the time taken for it to overtake the input voltage (V_{in}) is taken as an approximate measure of V_{in} . This value is used to set the most significant bits. The ramp voltage then drops a small fixed amount before rising more slowly to determine V_{in} more accurately and set the least significant bits. The sequence of operations is illustrated in Fig. 12.

Generation of the dual-slope ramp voltage for an a.d.c. is a relatively straightforward matter, using the arrangement shown in the simplified schematic diagram of Fig. 13. Before conversion, S1 is closed and so the capacitor C is charged to $-V$ (which corresponds to the negative limit of the coding range). At the start of conversion, S1 is opened and S2 closed. Initially the voltage across the capacitor rises linearly with time at a rate given by $dV/dt = 64I/C$. The time taken for the voltage across the capacitor plus the voltage across R to reach the sampled-and-held audio input voltage is recorded by a 7-stage counter. The 7-bit number obtained from this counter represents the 7 most significant bits of the conversion. At this point the comparator changes state, switch S2 is opened and the capacitor charging current reduces by a factor 64 : 1. The voltage across R drops so that the voltage across the capacitor rises at a slower rate given by $dV/dt = I/C$. When the voltage applied to the comparator by the ramp circuit reaches the sampled-and-held input voltage, the comparator changes state once again.

† The terms 'dual ramp' and 'dual-slope ramp' have been used to describe a number of conversion techniques developed from the basic ramp counter converter, and some confusion can arise between the different types as a result. The alternative name 'change-gear' is therefore often used to describe the BBC's dual-slope ramp converters, although this does not describe the operation of the converter as satisfactorily as 'dual-slope ramp'.

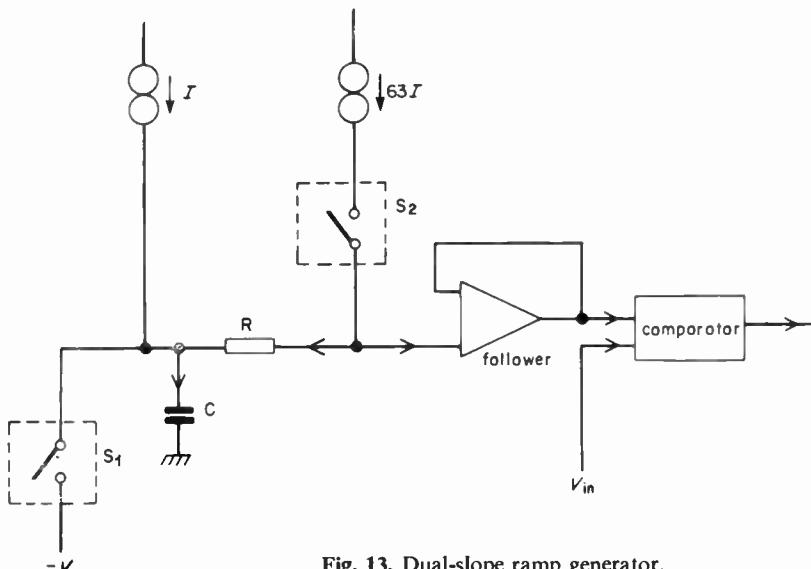


Fig. 13. Dual-slope ramp generator.

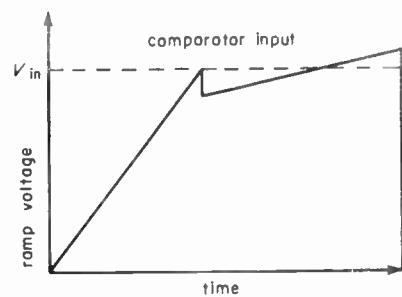


Fig. 12. Operation of dual-slope ramp a.d.c.

The duration of the slow ramp is measured by a 6-stage binary counter to give the least significant bits of the conversion.

The dual-slope ramp d.a.c. operates in exactly the reverse manner. The 7 most significant bits determine the period for which a capacitor is charged by a current of magnitude $64I$, and the 6 least significant bits determine the period of charging by a current of magnitude I .

The great advantage of the dual-slope ramp converter is that counting speeds are reduced significantly. For the 13-bit converters, the counters can use a clock frequency in the region of 12 MHz instead of 270 MHz, giving reduced cost and heat dissipation in the counting logic and easing the problems of keeping high-speed digital waveforms out of the analogue circuits. The principal disadvantage with this type of converter is the difficulty of ensuring that the capacitor charging currents remain in the ratio 64 : 1. For a 13-bit counter, an error of 1.56% in the ratio results in a discontinuity equivalent to one least significant bit.

4 Future Developments in A.D.C.s and D.A.C.s for Sound-programme Use

As explained in the introduction to this paper, the BBC's future requirements will be for a.d.cs and d.a.cs with at least 14-bit resolution. Any developments in the field of a.d.cs and d.a.cs undertaken by the BBC are likely to involve the already well-tried dual-slope ramp converter technique. A successful 14-bit codec has been made using this principle, but further development would be necessary before the production of significant quantities of these could be undertaken. One or two commercial codecs using ladder-network d.a.c. and successive-approximation a.d.c. techniques may be suitable for sound-programme coding and decoding applications, and might be able to offer resolutions of up to 16 bits/sample for this purpose. Some examples of

these tested by the BBC have given encouraging results, but most commercial equipment is either too slow or suffers from errors such as those described in Section 2. The equipment which has proved satisfactory has required extensive modification for use in BBC applications.

For the present, therefore, p.c.m. sound equipment under development within the BBC will use the existing 13-bit dual-slope ramp type of a.d.c. and d.a.c., even though the use of higher resolution codecs is envisaged with the new generation of NICAM (near instantaneous companding audio multiplex) equipment. Provision will be made for the new equipment to accept 14-bit a.d.cs and d.a.cs, which will be designed as 'plug-in' replacements for the 13-bit units, when they become available.

5 Acknowledgment

The author is indebted to the Director of Engineering of the BBC for permission to publish this paper.

6 References

- 1 Cattermole, K. W., 'Principles of Pulse Code Modulation' (Iliffe, London, 1969).
- 2 Croll, M. G., 'Pulse code modulation for high-quality sound distribution: quantising distortion at very low signal levels'. BBC Research Department Report No. 1970/18, 1970.
- 3 Kaneoya, R., 'Studies of high-accuracy Ni-Cr thin-film resistors, *Electronics and Communications in Japan (USA)*, 52-C, no. 11, pp. 162-70, November 1969.
- 4 Dalton, C. J., 'Delta modulation for sound-signal distribution: a general survey'. BBC Research Department Report No. 1971/12, 1971.
- 5 Manson, W. I., Moore, T. A. and Belcher, R. A., 'Digital sound: an investigation of delta modulation to pulse-code-modulation analogue-to-digital conversion. BBC Research Department Report (in course of preparation).
- 6 Chew, J. R., 'Pulse-code modulation for high-quality sound signal distribution: coding and decoding'. BBC Research Department Report No. 1968/29, 1968.

Manuscript first received by the Institution on 28th September 1978 and in final form on 1st December 1978.

(Paper No. 1862/Comp. 175)

Interference immunity testing requirements

E. P. FOWLER, M.A., C.Eng., M.I.E.E.*

Based on a paper presented at the IERE Conference Electromagnetic Compatibility held at Guildford from 4th to 6th April 1978

SUMMARY

The more significant sources of electrical interference are outlined and the means whereby they can couple into electronic equipment and systems are described. Estimates are given of the levels of disturbance to be expected in different parts of instrumentation and control systems. Design and installation practices which need to be followed to avoid the unwanted effects of interference sources are outlined. Methods for testing units are described, followed by their extension to complete systems. Brief descriptions are given of an interference test unit for injecting interference and a pulse generator.

* Control and Instrumentation Division, Atomic Energy Establishment, Winfrith, Dorchester, Dorset DT2 8DH.

1 Introduction

It is to be expected that with the growing demand for electricity, electrical interference sources are proliferating. There is also increasing emphasis on electronics in all aspects of control and instrumentation so the number of systems that may be affected increases and is compounded by the trend to digital instrumentation with its susceptibility to transients. On the credit side there is greater awareness of the problem and in some areas, such as the limitation of disturbance from vehicle ignition systems, an adequate cure appears to be almost complete.

The greatest single source of electrical interference lies not surprisingly in the mains distribution network. Perhaps less well-known is that the disturbance from this network couples to sensitive instruments through the 'earth' or other conducting metalwork.¹ This paper will list the more important sources and coupling paths with their characteristics and show how in order to measure interference immunity appropriate artificial disturbance can be generated to simulate them.

Interference immunity testing requires somewhat specialist test equipment that is easy to use. It is not usually sufficient to establish that an instrument or system is, or is not, adequately immune to interference. Approximate degrees of immunity must be established and diagnosis of the cause of poor immunity treated as part of the testing programme. Because of the way interference couples there are two series of tests necessary; first on the individual instruments or 'black boxes', and then later on a complete system. Recent advances in cable design and studies of connector and screening box performance make the system test a search for accidental design, manufacturing and installation faults rather than, as previously, a trial and error approach to settle earthing philosophy arguments!

Some of the procedures described are applicable to all instrumentation. Others are designed more specifically for low-level analogue instruments. Recently, there has been emphasis on the problems of digital instruments, including computers, and tests have been developed specifically for this class of problem.

2 Sources of Interference

Most of the larger sources of electrical interference are transient in nature and it is these that will be discussed here. Continuous interference at a low level whether narrow or broad band may upset broadcast radio and television reception and radio communications. However, any instrument with an automatic trip or alarm function will be more affected by infrequent high level transients. Similarly, digital equipment is even more susceptible to spikes than to continuous low level disturbance.

The sources that require attention are listed in Table 1. Some sources can be considered under two headings as indicated in the last two columns, first to find the effect of direct coupling to the instrument system and then to

Table 1.
Transient interference sources and levels

Source	R.F. Levels			Coupling Path	
	Potential	Current	Rise-time	Direct	Earth
Distribution mains	400 V	8 A	10 ns	✓	✓
High voltage mains	11 kV	—	10 ns	✓	✓
Relays (unsuppressed)	800 V	10 A	3 ns	✓	✓
Welding equipment	400 V	8 A	10 ns	✓	✓
Lightning strike	—	100 kA	1 μ s	✓	✓
Close radio transmitter	— 1 W —	—	900 MHz	✓	✓
Static discharge	8 kV	15 A	2 ns	✓	✓

study the indirect paths. It is to increase attenuation in the indirect paths that a code of practice or 'good engineering principles' are specified for cable layout and earthing. For other sources, the direct coupling is considered too unlikely to be worthy of serious study while for static discharge indirect earth coupling levels are so low they can be ignored.

2.1 Earth-coupled Interference

Earth-coupled interference or ground-coupled interference is defined as an indirect form of coupling in which the disturbing circuit couples to the instrument circuit through one or more grounded or partially grounded conductors; the screens and protective armour of any cable may form such an intermediate conductor, as may stanchions, water pipes and concrete reinforcing bars.

A rough sketch of a typical coupling path is shown in Fig. 1 which can be used to outline the mechanism of indirect coupling through the earth structure. Each transient starts as a single or multiple voltage step at the disturbing source and travels along a transmission line of which the return path may well be the neighbouring earth structure (cable tray, trunking or structural steelwork). The disturbing source transmission line may resonate and will couple to any other transmission line in close

proximity. The mode of coupling which may be predominantly magnetic (with mutual inductance) or electric (with direct capacitive coupling) will depend on the resonant impedance of each line at the point under consideration. A single passive line b-c is shown in Fig. 1 which is grounded at one end and open circuit at the other end. Good magnetic coupling is possible at b and good electric coupling at c. If the instrument cable does not run close to the passive cable at c the mechanism of coupling can be repeated several times until ultimately the disturbance couples to a line which is the screen of the instrument cable. All these lines are resonant, being short circuit or open circuit at either end. Each intermediate transmission line is a conductor which need not be connected with the disturbing source or instrument system in any way.

The attenuation of the coupling path is a function of the degree of coupling at each point in the chain, the spacing of the resonant frequencies in the intermediate transmission lines and the losses in the system (concrete and PVC are lossy dielectrics and steel is a poor r.f. conductor). The degree of coupling, which can reach unity, varies with the mode (electric or magnetic) and the length of each cable in close proximity. When simulating the different coupling modes using steel cable trays and PVC jacketed cables, it is possible to achieve overall gain at a passive line resonant frequency between a non-resonant disturbing source and a similar non-resonant receiving cable screen. However, despite the theoretical possibility of coupling path gain, obtained in attempts to simulate different coupling modes, good layout practice ensures a reasonable separation of power and signal cables and a minimum attenuation of 20 dB can be expected where there is no obvious direct coupling between disturbing source and instrument system.

2.2 Mains Power Supply Switching Transients

It is accepted that no effective control can be exercised over the wide proliferation of mains power supplies in the range 110/200 V to 240/415 V and that instrument systems must tolerate the direct coupling of switching transients to their power terminals. They must also be immune to the indirect consequences of spikes and transients emanating from unscreened power wiring wherever it may run. It is good practice to segregate power and instrument cables by running them in separate trunking and conduit and with a limited separation on cable trays. A separation of 0.3 m has been cited as existing practice² though a spacing of half this might be adequate if rigidly adhered to. Given this practice, the curve of current against frequency shown in Fig. 2 provides a useful upper limit to the currents that may be induced in instrument cables and therefore flow to earth through the screens of instrument boxes. Figure 2 is based on European distribution networks of 220/240 V single phase. Approximately half this value can be expected from a 110 V system.

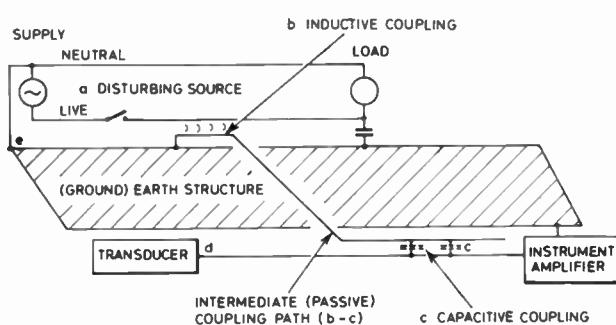


Fig. 1. Earth-coupled interference.

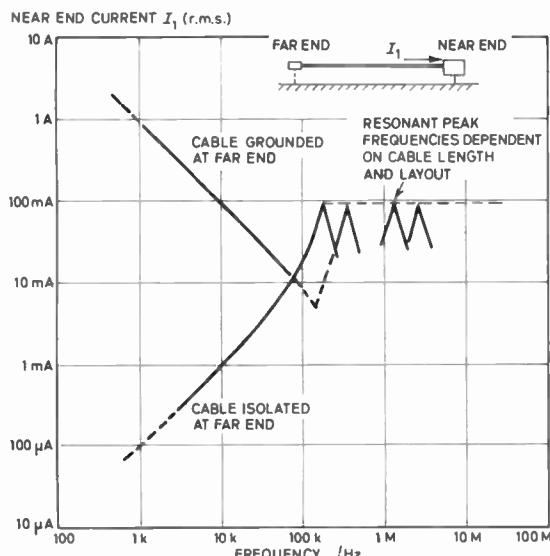


Fig. 2. Maximum interference current in instrument cable ground coupled from 415 V switching surges.

2.3 High Voltage Mains Switching

In electricity substations, supply voltages up to 400 kV are found. With uninsulated and hence unscreened conductors, electromagnetic field conditions may be very different from those found in other industrial plant and to achieve interference immunity in instruments may require a different approach.³ There remains in industrial plant a lot of electricity distribution at voltages above 415 V.

Disturbance emanating from higher voltage power systems (for example 3·3 and 11 kV) will be larger than shown in Fig. 2 unless greater effort is made to reduce the indirect coupling. It is known that lead-covered power cables have extremely good screening properties and that if the lead covering is properly grounded as near as possible to the frame of the plant at either end of the cable, then indirect coupling will not cause trouble. When mains power cables are unscreened (using steel wire armouring and polymers for physical protection), it has been found that a minimum spacing of 1 metre from instrument cables is adequate for power circuits of 3·3 kV to reduce the indirect coupling to that from 240/415 V circuits. This spacing is necessary between the power cables and any cabling associated with instruments, taking care to include other (instrument) cables in close proximity to those under consideration.

2.4 The Operation of D.C. Relays

Devices of this type store energy which is released when they are de-activated. For a simple circuit break, the relay coil energy will be transferred to the connecting line capacitance resulting in a high voltage. The energy will subsequently be dissipated in the relay coil resistance as the line discharges.

The potential to which the line would charge usually

exceeds the breakdown potential of the contacts which initiated the breaking of the current flow. Consequently, these contacts break down repeatedly until a large part of the stored energy is dissipated (Fig. 3). A whole series of contact breakdown pulses will be generated each of which will give large earth currents similar to those from the single transient induced by a mains supply switch-on. The resulting current amplitudes of up to 10 A peak can in theory be dealt with by using filters as with mains supplies. It is, however, a better practice to incorporate suppression devices across the relay coils which can take up the stored energy without the cable voltage reaching contact breakdown level. This process need not degrade relay release time and may improve the life of the associated contacts. Unlike suppression across contacts, coil suppression techniques should generally fail to safety.

2.5 Arc Welding

A great deal of arc welding takes place near to instrumentation during the commissioning phase of large plant and during maintenance when parts of the plant are still running. For conventional electric arc welding, although disturbances occur more often, levels are no worse than in normal mains switching transients, provided the welding operator takes care to ground his return lead close to the place he is welding.

In some classes of welder, r.f. discharges are initiated at intervals of less than 1 ms to aid striking. These r.f. discharges couple into the mains supply and directly to earth through the workpiece. Again, levels are no greater than with mains switching but the rate of occurrence has increased by many orders of magnitude.

2.6 Lightning Strike

Nearby lightning produces transient currents in exposed conductors somewhat greater in value than those from close-coupled mains power switching. These can be ignored in situations where instrument cables are *not*

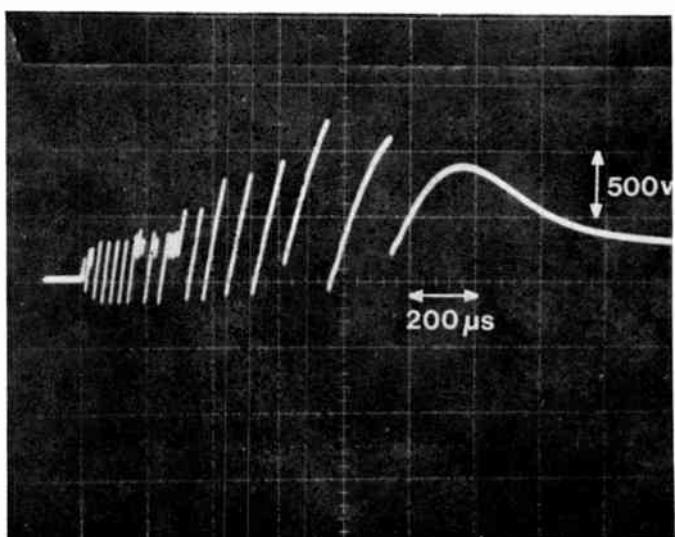


Fig. 3. Unsuppressed relay—voltage across opening contact.

exposed, as the building structure can be relied upon to give adequate additional screening.

2.7 Radiated Electromagnetic Field

Nearby high power radio transmitters and especially hand-held portable (walkie-talkie) radios, which may be found actually touching instruments, have been found a hazard to correct operation of instruments. It is probable that the radiated field introduces r.f. currents in the chassis or immediate screen of the sensitive instrument. If so, it is likely that testing against radiated electromagnetic fields need not entail subjecting the instrument to test in a screened room, or worse still on a remote site, to achieve plane far-field conditions. The subject is presently under study but it is hoped that appropriate magnetic probes can be specified for immunity tests.

2.8 Static Discharge

The problems of electrostatic build-up on operators first came to prominence with the use of man-made fibres in carpets. Studies of personal tolerance⁴ suggest that 2 kV is the highest voltage that should be allowed to build up. Recent work indicates that higher voltages are now possible even on conducting floors due to the widespread use of man-made materials for shoe soles. A level of 7.5 kV on 200 pF discharging through 500 Ω has been suggested as an adequate test level. If discharge takes place to an instrument panel, the source is directly coupled to the sensitive circuit.

3 Recommended Cabling and Earthing Practice

If earth disturbance coupling to instrument cables and screened boxes is to remain below the level shown in Fig. 2, the following practices should be observed.

3.1 Power Supply Cables up to 240/415 V

Power supply cables up to 240/415 V are segregated from instrument cables by running in separate trunking and conduit and by using significant spacing between cable sheaths (~30 cm). Close crossings should be arranged with the cable axes perpendicular.

3.2 Power Supplies above 240/415 V

Power supplies above 240/415 V should preferably be screened (lead covering is suitable) and these screens connected to the plant frame at either end by copper earth straps of length less than 30 cm. Alternatively, it is necessary to separate all unscreened power cables from cables with which the instrument cables may be associated, electrically or physically. A minimum separation of 1 m is required for 3.3 kV power supply cables.

3.3 Relay Suppression

All e.m.f.s from relay and contactor coils associated with the instrument system should be suppressed to a standard which ensures that the potential difference across the breaking contacts or supply cable cannot build up to the contact breakdown level.

3.4 Arc Welding

Arc welding ground currents should be minimized by clamping the welding set return conductor to a point close to the work place.

3.5 Instrument Earthing Practice

In a well-designed system, protection against r.f. interference need not depend on the earthing arrangement employed which can be used to mitigate against power frequency pick-up. There is every reason also to follow the National Electrical Safety Regulations in specifying protective earthing on the system.

If reliance is to be placed on earthing to minimize common impedance to r.f. disturbance and so reduce the current flowing in instrument cables below that intimated in Fig. 2, it is essential that the local earth should have low inductance. This is achieved by using wide earthing strips and multiple paths and bonding all metalwork to these strips where they pass. Individual cubicles can be connected by similar low impedance strips.

4 Basis of Instrument Design and Construction

In a complete instrument system the current levels shown in Fig. 2 can be expected to flow in a proportion of the cable screens and through connector shells to the instrument screen enclosures. For unscreened instrument cables and circuits the currents will be found to flow in the cables themselves and in earth return wires. A preliminary assessment of the suitability of any instrument system can be based on the signal levels at the more sensitive parts of the system and the disturbance levels (100 mA r.m.s. in most cases) shown in Fig. 2. The quotient of these two gives a guide to the total transfer impedance that is required of the screen.

To enable suitable cables, connectors and screening boxes to be selected or the adequacy of recommended components to be assessed, it is necessary to specify the maximum levels of radio frequency transients, including frequencies outside the normal passband of the instrument, which can be tolerated at any inter-connections. For input connections which rely on common mode rejection, either by using a balanced and screened arrangement or simply by bringing out an additional 'earth' or 'ground' wire, acceptable levels should be specified for signal mode (signal line to signal line or signal line to return line) and for common mode (both lines to ground or line and return to ground) over a range that extends to 100 MHz and possibly beyond. Interference immunity at high frequencies is often degraded by non-linearity in the active circuits. As transient interference is unlikely to consist of pure tones it can be assumed that the presence of significant instrument non-linearity makes it necessary to take level into account over the whole frequency domain.

It is not proposed to go any further into the selection and specification of cable and connectors but attention is drawn to the great strides that have been made recently

in screening of these components. Superscreened cables⁵ now have screening properties five orders of magnitude better than a single-braid coaxial cable. Connectors⁶ also can be selected to have appropriate matching performance. Screening enclosures also can be designed to have exemplary screening properties⁷ though the design of a good demountable joint presents problems.

There are some practices in the design and layout of instrument systems that improve interference immunity by keeping disturbing currents out of the screens. Such techniques as increasing the screen impedance of a cable by loading it with ferrites (which does not affect the screened circuit in any way) are very effective but, in view of the good cables mentioned above, should be kept for remedial action during commissioning of plant.

5 Immunity Tests on Individual Units

To establish adequate immunity in an instrument it is necessary to inject currents into its screen or metal case to the levels suggested in Fig. 2. The instruments or amplifiers should be connected to a simulated transducer or signal source with appropriate and recommended cables and set up to operate correctly. Long cables can often be simulated in d.c. low bandwidth circuits using capacitors. If it is preferred to test parts of a system individually, interconnecting cables which are normally terminated in their characteristic impedance can be simulated by the equivalent terminating resistor. When simulating cables with resistors or capacitors, it is essential that these extra components are properly screened.

A power amplifier capable of supplying 100 mA r.m.s. into a short circuit or a voltage of 10 V r.m.s. on open circuit should be fitted with a transmission line transformer so that the current output is returned to the amplifier through the correct terminal rather than through stray circuits. One method of achieving a line transformer of this type is to wind several turns of coaxial cable through a ferrite toroid. The power amplifier is driven from an oscillator having a frequency range of 10 kHz to 100 MHz. For the shine tests listed later a parallel injection line of 200 Ω impedance is used. For this reason, and also because the higher impedance is necessary for system tests described in Section 6, an amplifier with 200 Ω output impedance is recommended.

Experience with digital equipment which may be sensitive only during gate transitions indicates that the above disturbance levels are inadequate. A pulse disturbance of 5 A peak amplitude and 10 ns rise-time is a useful alternative. Pulse duration is not important but repetition rate must be kept high to give any chance of hitting the transition time mentioned above. Brief details of instruments available for these tests are given later.

5.1 Injection Tests

For analogue instruments the output current from the power amplifier is injected into the instrument chassis

over paths mentioned below and any deviation from normal operation in the instrument is noted. In some instruments there are monitoring points and clearly defined levels of disturbance are acceptable (for example, in a straight amplifier output disturbance in excess of the minimum detectable wanted signal may be unacceptable). In other instruments it may be necessary to look for maloperation, as in computers, or for unacceptable output indication.

For digital instruments such as computers, pulses from a pulse generator replace the variable frequency injected from a power amplifier. In other respects the process is similar and maloperation when the instrument is operating (such as on a self-check program) is used to find the tolerable level of injected current pulse.

Injected current should be applied over paths that any random interference current could follow. For example:

- (a) between two load-bearing metal parts of the chassis;
- (b) from a remote load-bearing or projecting part to the safety earth point; and
- (c) from connector shells or preferably cable screen to the safety earth point.

For unscreened cables capacitive coupling should be made to each of the conductors in turn with the return path again from the safety earth point. An appropriate value for the capacitor is 0.1 μF which will introduce a series impedance of < 15 Ω at frequencies above 100 kHz.

5.2 Shine Tests

'Shine' is a term which has been coined to describe the magnetic coupling which occurs in connectors and screening enclosures from a nearby conductor. Coupling is greatest near holes in the screen and it appears as if the field shone through these holes. The actual phenomenon is not so easily explained.

The design and layout of some parts of an instrument circuit may be such as to minimize deliberately the magnitude or effect of stray earth currents (for example, by insulation and spacing from earth). A suitable test for the effectiveness of such methods employs a pair of parallel injection lines with the nearer of the two placed slightly closer to the instrument under test than the nearest metalwork is expected to be during service. Such a line can be made of two parallel tubes, 10 mm diameter, fixed at 30 mm centres and of any convenient length (say 0.5 m). If terminated in its characteristic impedance of about 200 Ω there need be no significant reflection back into the amplifier and the length of the line is therefore unimportant. A sketch showing this suggested method of test is given in Fig. 4(a) while Fig. 4(b) shows how this equipment (a head amplifier) might be expected to be mounted in service. The current level injected into the 200 Ω line is the same as that normally injected into the earth, i.e. 100 mA r.m.s.

The use of an injection line is also required above and below a unit normally placed in a rack to simulate earth

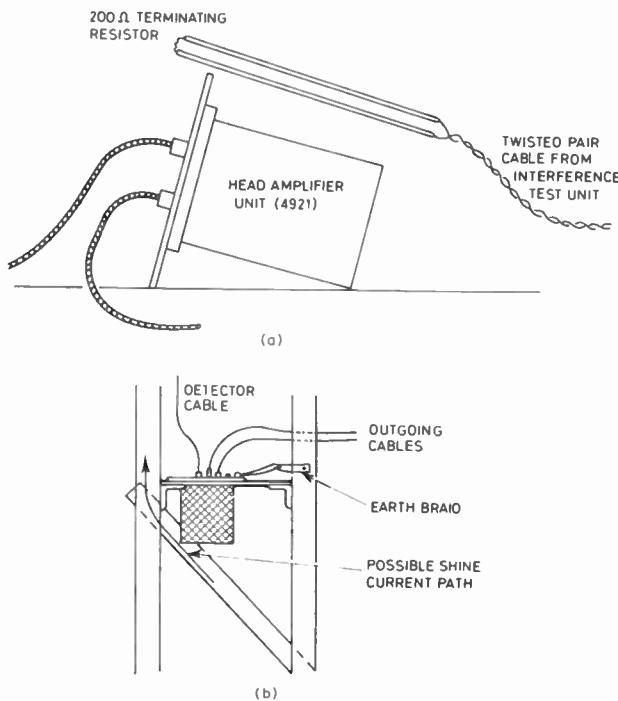


Fig. 4. Interference immunity—‘shine’ test.
 (a) Shine test in laboratory
 (b) Typical head amplifier mounting.

currents flowing in neighbouring equipment. The shine test line is also extremely useful in locating the area of penetration of an injected test current.

5.3 Additional Pulse Testing

There are occasions when the shine test detailed in Section 5.2 is inadequate. In particular, if the mains supply to a neighbouring instrument in a rack of equipment is unscreened, a large portion of the mains disturbance on that equipment may flow close to the case of the instrument under test. To guard against this it is helpful to make a ‘shine test’ with a pulse of 4 A and rise-time 10 ns.

In the similar situation where the instrument being tested is digital a pulse of 5 A is used in lieu of the r.f. burst in any event. This should also be applied to the shine test.

Direct injection of 100 mA r.m.s. (Sect. 5.1) may be inadequate if the mains supply of the instrument under test is unscreened. An additional test with 4 A pulses is required here.

5.4 Mains-coupled Interference Tests

Unlike interference induced in other cable screens which has been shown to be coupled through the earth structure, the mains supply constitutes a possibly direct link between the disturbing circuit and the instrument under test. As the mains r.f. impedance is of the order of 50Ω at frequencies above 100 kHz and a likely disturbance may exceed 340 V peak amplitude, an

immunity to 8 A in a properly matched system is appropriate. In practice the supply mains approximates to an r.f. transmission line with low impedance termination at the fuse box or distribution point and open circuit at the instrument terminals. Such a mismatch, often made worse with interference filters, can cause peak-to-peak voltages in excess of 1 kV to appear on the instrument mains supply terminals.

The required disturbance level for mains transient simulation is an 8 A pulse injected into the supply from an impedance of 50Ω . An artificial mains impedance buffer should be used if it is desired to avoid disturbance to other (more sensitive) equipment and ensure repeatable results. The repetition rate of injection is not critical for analogue instruments but should be kept high (~ 1000 p/s) for digital instruments for the reasons given at the head of this Section.

The pulse is capacitively coupled to the mains first from live line to neutral and then common-mode (live line plus neutral to earth). The peak power required from the generator is high but as a pulse duration of 1 μ s is adequate the mean power is quite low. Provision must be made to reverse the pulse polarity as many instruments are more sensitive to one polarity. The pulse generator described later is also suitable for this duty.

6 Test Methods and Criteria for Complete Systems

When a complete instrument channel is being commissioned it is recommended that further tests be made for interference immunity to establish that adequate immunity is obtained under operating conditions. They also provide a check on the following points:

- (a) that correct cables have been specified and fitted;
- (b) that connectors are adequate and correctly fitted;
- (c) that unexpected interference coupling paths do not occur;
- (d) that the production instrument units (as opposed to prototype units) have adequate interference immunity.

It is necessary to test separately for interference which can couple through the earth structure, that which is mains coupled and, where necessary, for low frequency interference.

6.1 Earth Injection for Analogue Instruments

The levels of interference shown in Fig. 2 are the maximum expected in instrument cables. Practical levels may approach this at only one or two frequencies and cable systems may have been specified with this in mind. A realistic test is obtained by injecting test currents at the same level into the earth structure surrounding the instrument channels. This can be achieved with an earth injection line and has the advantage that it includes part

of the coupling route taken by the interference as well as testing the system itself.

It is not proposed to describe the test in detail which is covered in a published specification for nucleonic equipment.⁸ It is sufficient here to state that the line should be laid roughly following the cable(s) under test (within 1 metre) but spaced 50 to 200 mm from metal-work. Any insulated cable is suitable and at this spacing it will be found that the line's characteristic impedance to earth is about 200Ω . It should be terminated to earth at one end with a 180 or 220Ω resistor.

The test equipment used to drive the line must generate 100 mA r.m.s. from an impedance of 200Ω . Details of a purpose-built unit known as the Interference Test Unit type 4201 are given in Appendix 1. The test unit has been developed with diagnosis of trouble in mind and is always used with an oscilloscope. Modulation of the disturbing signal is obtained from the oscilloscope time-base. A typical response shown as a photograph of the oscilloscope display is given in Fig. 6 where the top two traces record the injected current and the lower two its effect on the instrument under test (in this case one with a monitor socket). The actual waveform injected is also sketched in Fig. 6. By using pulses the dominant resonance can be seen readily and the burst frequency tuned for measurement at this frequency.

6.2 Diagnosis

Diagnosis involves finding where in the instrument screen the interference, or in this case the earth injected disturbance, is penetrating. Some information is available from the resonant frequency where immunity is poor as this will point to cables of specific lengths. Similarly the time delay to the onset of response to the injected pulse can indicate the distance to the troublesome part of the circuit. Final location of a fault in screening comes from connecting up the different parts progressively starting from the final item in the chain. This is illustrated in Fig. 5 for a transducer, pre-amplifier and main amplifier working at megahertz frequency (a nucleonic pulse counting channel). At each step the interference immunity is recorded and different levels between steps can pin-point the faulty screen location. As the complete system is built up more of the sensitive screening is included in the test. For example, the difference between test (a) and (b) in Fig. 5 is that in (a) no current flows in the shell of the input socket but in the latter any interference current that is flowing in the cable sheath is allowed to take its normal path through the socket body.

6.3 Earth Injection for Digital Equipment

Testing arrangements for installed digital equipment are similar to those for analogue systems except that the disturbance is a pulse as in testing individual units. The pulse generator requires an output impedance of 200Ω and the 5 kW pulse generator described in Appendix 2

was developed primarily for this duty. It has been found that the ability to tolerate 5 A pulses having rise-time 10 ns and duration 1 μ s on the injection line demonstrates adequate immunity in the system. With a repetition rate of 1000 p/s it is important to apply the disturbance for over half a minute.

6.4 D.C. Earth Injection

Some instruments are susceptible to interference at frequencies below 10 kHz especially if they are earthed at more than one point. A simple and effective test for this is to initiate a current of 10 A from a 12 V battery through the earth injection line. For this test the terminating resistor is short circuited. The circuit is completed to any point on the instrument that could possibly be touched by a grounded metal object.

6.5 Mains Immunity of Installed Equipment

There are some instances when an instrument having passed the test described in Section 5.4 still suffers from directly-coupled mains disturbance after installation. The same test needs to be repeated but without the isolating buffer so that mains cable resonance may increase the severity of the test.

If the mains supply cable to an instrument is unscreened the mains injection test of Section 5.4 may be

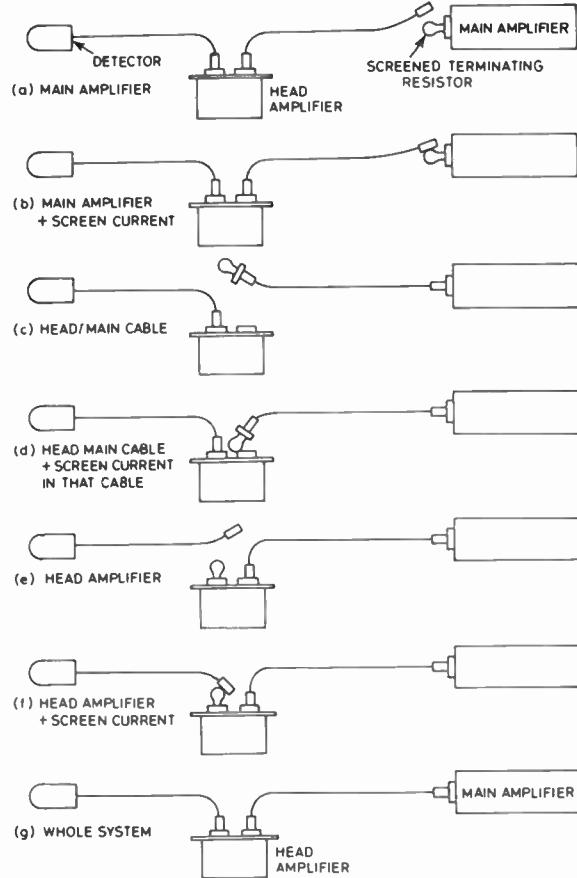


Fig. 5. Step-by-step screening fault location.

inadequate. Under these circumstances both the shine test of Section 5.2 and the injection test of Section 5.1 should have been carried out with a 4 A 10 ns rise-time pulse as detailed in Section 5.3.

6.6 Static Discharge

The fast rise pulse from discharging a small capacitor direct to an instrument panel is more onerous than the pulse of similar current from a pulse generator having limited rise-time (10 ns). Present development is aimed at making a portable calibrated test set generating up to 15 A from a charged 100 pF capacitor. It is not thought that denying access to a sensitive panel is a reasonable long-term solution.

7 Conclusions

Just as earlier Table 1 summarizes the more important sources of interference, the following Table summarizes the testing thought necessary to guard against their effects.

Although the levels quoted as adequate are necessarily empirical they are based on a study of the fundamentals of the subject. It is fair to say that equipment tested to the levels specified above has not suffered from subsequent transient interference. Exceptions to this claim have been shown by further measurement to have become degraded below their original satisfactory level. The specifications for interference immunity listed here are being applied to nucleonics control equipment in nuclear power stations and on other nuclear reactors. They are also being applied successfully to a growing number of the more sensitive instrumentation schemes in other fields including computers and digital processing applications.

Table 2
Interference immunity test levels

Test Condition	Ref. Section	Instrument		System	
		Analogue	Digital	Analogue	Digital
Injection to chassis	5.1	100 mA r.m.s. (Note 1)	5 A (Note 2)	—	—
Injection to chassis (no screen on mains lead)	5.3	4 A	(5 A)		
Earth injected r.f.	6.1/6.3	—	—	100 mA r.m.s.	5 A
Earth inject d.c.	6.4	—	—	10 A (Note 3)	10 A
Mains injected	5.4/6.5	8 A	8 A	8 A	8 A
Shine test (screened mains lead)	5.2	100 mA r.m.s.	5 A	—	—
Shine test (no screen on mains lead)	5.3	4 A	(5 A)	—	—
Static discharge	6.6	15 A (Note 4)	15 A	15 A	15 A

Notes: 1. 100 mA r.m.s. from 10 kHz to 100 MHz
 2. pulse height + or - with $T_R \approx 10$ ns, duration 1 μ s
 3. d.c. step only
 4. static discharge from 100 pF only, $T_R \approx 2$ ns

8 References

- Harrison, D., 'The mechanism of interference pick-up in cables and electronic equipment', *The Radio and Electronic Engineer*, 29, no. 3, pp. 149-52, March 1965.
- Buisson, J., 'Materiel electronique nucleaire pour tableau de commande et de controle—susceptibilité du materiel d'électronique nucleaire à impulsions aux parasites', CEA-MCH/MENT 7, July 1972.
- Martin, R. E., 'The avoidance of electrical interference in electronic systems within high voltage substations', CERL RD/L/N14/77, March 1977.
- Brundrett, G. W., 'A review of the factors influencing electrostatic shocks in offices', Electricity Council, Capenhurst, ECRC/M1046, April 1977.
- Fowler, E. P., 'Superscreened cables', *The Radio and Electronic Engineer*, 49, no. 1, pp. 38-44, January 1979.
- Fowler, E. P., 'Screened coaxial connectors for high sensitivity systems', Paper presented at IEEE Symposium on Electromagnetic Compatibility, Montreux, May 1975, EMC 75/G7.
- Cake, B. V., 'Aspects of the design of screened boxes', Paper presented at IEEE Symposium on EMC, Montreux, May 1975, EMC 75/G2 (not available in Symposium record).
- Fowler, E. P., 'Interference immunity tests for nucleonic instrumentation', AEEW-R 919, 1974.

9 Appendix 1: Interference Test Unit 95/4021-3/4

9.1 Brief Description

When used with an oscilloscope the Interference Test Unit generates a controlled disturbance to meet the requirements of AEEW-R 919 for earth-coupled interference. The test unit is connected to an appropriate oscilloscope with four coaxial cables. It is connected to drive an injection line generally following the line of the cable system under test but spaced away from earthed

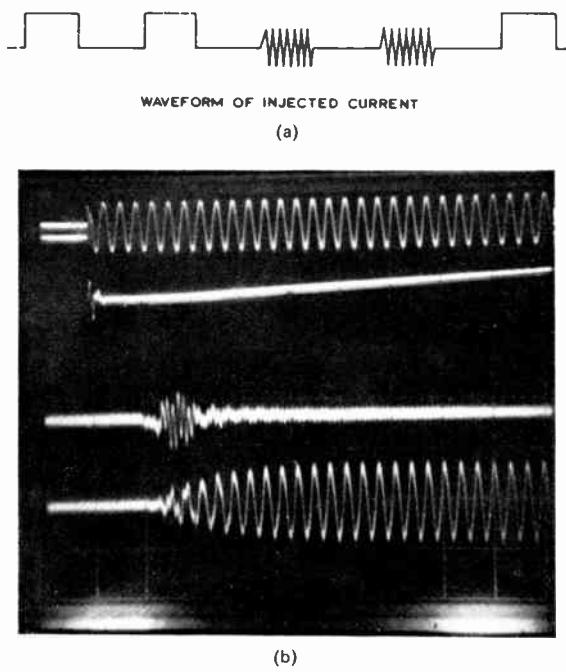


Fig. 6. Typical interference immunity record.
 Trace 1 and 2: injection current 10 mA/cm
 Trace 3 and 4: monitor output 50 mV/cm (into 50 Ω)
 Discriminator threshold: 18 mV Time: 1 μ s/cm

metalwork by about 100 mm. The far end of the line is taken to earth through a $200\ \Omega$ resistor.

The test unit generates a wave train of alternately two pulses and two bursts of radio frequency (Fig. 6(a)). With one channel of the oscilloscope viewing the injected signal through a current transformer (built into the test unit) and the other set to observe the output of the instrument under test a display of four traces is obtained (Fig. 6(b)). Shift in the two extra traces is given by the trace separation controls on the test unit.

9.2 Specification Details

Output Waveform—Train of two pulses followed by two bursts of radio frequency (Fig. 6) at a repetition rate controlled by the oscilloscope time-base.

Oscillator—A single calibrated five-turn potentiometer controls the burst frequency from 10 kHz to 100 MHz.

Output Power—Maximum output is 100 mA r.m.s. (during the burst) into a resistive impedance of $200\ \Omega$ from a source resistance of $200\ \Omega$. The output is provided on two spring terminals for direct connection to the injection line. An alternative output of 200 mA r.m.s. into a $50\ \Omega$ load is available on a series N socket.

Attenuators—Independent control of step and burst amplitude. 0–30 dB in 3 dB steps and 0–10 dB in 1 dB steps.

Delay Control—Adjusts the position of the beginning of the step and burst on the oscilloscope traces. At lower sweep rates this position is independent of the sweep rate.

Power Supply—100/125 V or 200/250 V, 50 to 60 Hz. Consumption about 80 VA.

Trigger—A small removable interface unit matches the ITU to the oscilloscope with which it is used. Any good quality oscilloscope with time-base gate signal accessible may be used such as Tektronix 465 and 7000 series or Hewlett Packard 1740 and 180 series.

Construction—A single unit $400 \times 330 \times 200$ mm. Weight approximately 13 kg.

10 Appendix 2: 5kW Pulse Generator 95/4221-1/4

10.1 Brief Description

A battery-powered pulse generator with fast rise-time pulses having limited width. The pulse generator has been developed for testing all instruments for interference immunity against mains-coupled transients. It is also useful for earth-coupled interference immunity in data processing and computer complexes.

The pulse has a rise-time of 10 ns and duration of 1 μ s with a maximum output current of 10 A into a $50\ \Omega$ load (or 5 A into a $200\ \Omega$ load). Repetition rate is up to 1000 p/s. At low repetition rates a longer pulse with 10 μ s decay time constant is available.

10.2 Specification Details

Pulse Amplitude—3 mA to 10 A from $50\ \Omega$ source impedance into $50\ \Omega$ load. + or – polarity (outputs at $200\ \Omega$ impedance are half those at $50\ \Omega$).

Pulse Shape—Short pulse 1 μ s duration with 10 ns rise-time and 100 ns decay time. Long pulse 10 ns rise-time and 10 μ s decay time-constant.

Pulse Rate—Short pulse 0·1, 1, 10, 100 and 1000 p/s
Long pulse 0·1, 1 and 10 p/s
50 or 60 Hz triggered with delay giving 360° phase control (short pulse only).

Monitor Outputs—Current transformer 1 V/A into $50\ \Omega$. Pre-trigger output +1 V into $50\ \Omega$.

Pulse Output— 50 or $200\ \Omega$ impedance on spring terminals in parallel with series N socket.

Power Supply—Rechargeable battery. 12 V d.c. or 110 to 250 V a.c. recharging.

Construction— $330 \times 90 \times 180$ mm (high). Weight 4 kg.

*Manuscript received by the Institution on 8th November 1977
(Paper No. 1862/MI 9)*

UDC 621.391.823

Indexing Terms: Electromagnetic compatibility, Signal interference, Suppression

Diagnosis and cure of some e.m.c. and interference immunity problems

E. P. FOWLER, M.A., C.Eng., M.I.E.E.*

and

J. R. TAYLOR*

*Based on a paper presented at the IERE Conference
on Electromagnetic Compatibility held at Guildford
from 4th to 6th April 1978*

SUMMARY

Several recent interference investigations are described in some detail. They demonstrate that the technique of injection of radio frequency currents into the earth is effective in locating the weak points in system screens. The use of suitable cables, connectors, filters and remedial techniques can transform what appears to be in some cases a useless system into a trouble-free one. The use of a specially developed pulse generator is shown to be particularly effective when investigating problems in digital systems.

* Control and Instrumentation Division, Atomic Energy Establishment, Winfrith, Dorchester, Dorset DT2 8DH.

1 Introduction

Interference immunity and electromagnetic compatibility are really two titles for the same problem. The inference from studying e.m.c. is that as much effort should be spent in reducing the emitted interference from disturbing equipment as in improving the immunity of susceptible equipment. Interference immunity on the other hand implies that an instrument system is being engineered to work in a specified natural environment. The fact that most electrical interference is initially man-made does not detract from this approach as many transient disturbances are rarely suppressed. In the examples described here it may be obvious whether they are best described as e.m.c. or interference immunity problems.

Some sources of electrical interference are listed in a companion paper¹ which also describes the testing techniques which the authors have used. Details are given here of how these can be applied in specific instances and the sort of problems encountered. It will be seen that all are special cases. In a way this is universal in this field as in the systems without unusual characteristics, e.m.c. or interference tests are either not carried out or specialists in the subject are not consulted.

The examples are selected from a variety of disciplines. These include University research projects (Sects. 2 and 3), industrial testing (Sects. 4 and 8), digital processing and control equipment (Sects. 5 and 6) and the effect of unsuppressed relays in a power station (Sect. 7). An attempt is made to summarize the lessons learnt for the guidance of those who may have similar problems.

2 University Research—Electrical Excitation Phenomena in Gases

In some chemical experiments it is necessary to excite unstable states electrically. For a gaseous material this can be done without direct contact by placing the gas in an intense radio-frequency magnetic field. In a typical experiment the field is generated in a coil 10 cm diameter by 20 cm long tuned to resonate at 7 MHz with a variable capacitance. Although nominally screened, the stray electromagnetic fields generated are considerable as the total dissipated power is 1 kW.

Just as the unstable states in the sample are induced electrically, the detection of the return to a stable state uses electronic techniques with the more sensitive part of the circuit being necessarily in close proximity to the power circuits mentioned above. In the case cited, the detector is a photo-multiplier tube with its end window some 30 cm from the r.f. coil, connected by cables to remote sensing equipment (a commercially available phase-sensitive amplifier and detection system). As found the cross-talk from power side to detecting side was so great that the phase-sensitive amplifier was grossly overloaded with no hope of correct operation. Remedial action had already been attempted but with insufficient attention to detail. Notably the phase-sensitive detector

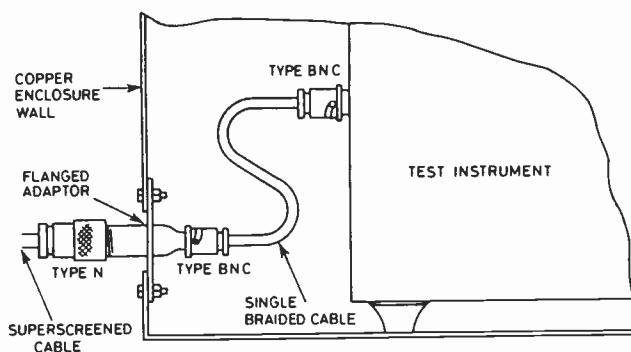


Fig. 1. Cut-away view of an extra screen for a poorly-screened instrument.

which comprised three units had been enclosed in a copper box located some 10 m from the possible sources of r.f. disturbance. The r.f. power signal was modulated at 100 kHz and this same modulation signal used as the reference in the phase sensitive detector. A filter had been made to restrict the amount of 7 MHz signal on the reference line.

The copper box was less effective than it might have been because the signal cable screens were not grounded to it as they entered. The most likely coupling path for cross-talk is through currents induced in the cable screens and if insulated at entry these currents run to earth through the instrument cases whether or not the copper box is present. With the cables connected as in Fig. 1 a good connector could be used on the external cable and the copper box screening potential realized. To complete the screening a mains filter should be mounted on the copper box in a similar way, isolating the instruments from disturbance on the incoming mains supply.

It was easy to show that superscreened cables² were necessary outside the copper box and when these had been fitted it was appreciated that the power circuits would also benefit from such cables. The power rating of the superscreened cable then available was less than 500 W at 100 MHz and 20°C. For trial purposes the system could be run at half power and a worthwhile improvement recorded. Subsequently a length of high-power-rating cable was installed. The screening was completed by changing critical connectors from those in series UHF or BNC to series N. This last has screening properties comparable with those of the better superscreened cables and some three orders of magnitude better than the first.

The testing in this experiment was partly carried out on the sensitive instruments using conventional earth injection methods described in Ref. 1. For the power system investigation the source of disturbance was already present and measurements could be taken from the earth injection lines. The outcome of incorporating the detailed changes recommended was complete success. One bonus was that the copper box became a sufficiently good screen

to permit the sensitive measuring instruments to be moved back close to the rest of the experiment.

3 University Research—Film Scanning Equipment

Particle tracks in a bubble chamber can be recorded by photography. The photographic film records are later magnified by projection onto a table to enable accurate measurement of each track length to be made. Track length is measured by positioning manually a pointer, called a 'puck', at each end of the track and recording its position. From the co-ordinates of the puck position a digital processor calculates the length and feeds this information to a computer for storage.

Film scanners using this principle had been in successful use for two years before increasing malfunction suggested that they were suffering from electrical interference. To operate the scanner the puck, which carries a 400 Hz transmitting coil, is aligned with a point on the table. Search coils below the table, position driven by two independent servo systems, automatically follow the puck to a horizontal resolution of 0.1 mm. The X and Y co-ordinates of the search coils and hence of the puck are recorded by counting the servo motor rotation. Two-phase sinusoid outputs are converted to square waves, differentiated and combined by logic into a series of pulses for displacement and a d.c. signal showing increase or decrease from the last recorded position. All this circuitry is mounted under the table with the two outputs from each table fed by cable to the common digital processing equipment. Maloperation was manifest by a return to zero position not being properly indicated by the logic although the servo system followed the puck faithfully. Of the two tables sharing the same digital processing equipment, one appeared more sensitive to the interference than the other. For this reason it was thought that the unwanted coupling occurred in the table electronic circuits.

The switching-on of other equipment constitutes the most likely source of transient interference on the mains. A pulse generator has been developed to simulate the resulting fast rise pulses. At the time of this investigation a pre-prototype was available capable of generating 6A pulses into 50 Ω. A special mains injection and monitor box was constructed (Fig. 2) which enables the pulse generator output to be applied to a 13A supply system either in series mode (live to neutral) or common mode (live and neutral to earth). A carefully-constructed monitor attenuator allows safe observation of mains disturbance at frequencies above 50 kHz. When terminated in 50 Ω mains volts appear as mV on the oscilloscope trace. Before interference testing began, occasional main spikes in excess of 50 V were observed. The full capability of the pulse generator gave 240 V on the mains monitor indicating the impedance to be about 40 Ω. It will be noted that the injection and monitor unit has capacitors of 0.15 μF connected to the live and neutral

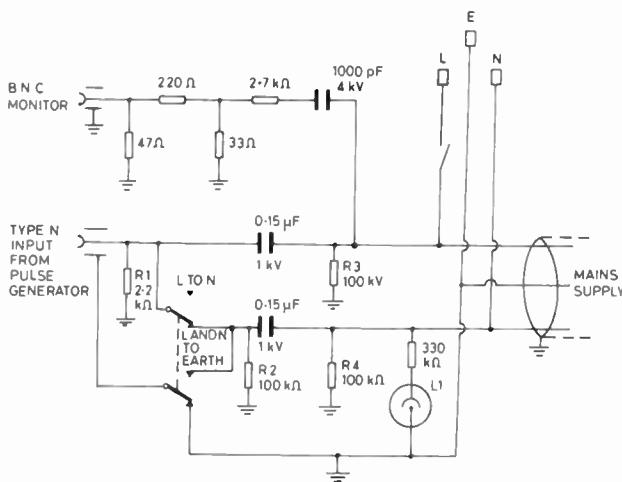


Fig. 2. Mains injection and monitor box.

line. This does not accord with national safety regulations which allow about 5000 pF in portable equipment. Great care must be taken in carrying out mains injection tests using personnel of appropriate training and experience, always with direct supervision. Accidental danger is minimized by fitting discharge resistors (R1 to R4 in Fig. 2) and a live box indicator lamp (L1). This last is a neon indicator which will come on if the unit is not earthed or if the neutral and live lines have been accidentally interchanged.

The position sinusoid from the scanner is converted to a square wave by a zero crossing discriminator. As the maximum frequency from the servo system position recorder is 25 kHz, an input filter was incorporated to restrict the discriminator to less than 30 kHz. At the same time the ± 12 V supply lines were decoupled on the printed circuit card. These two changes made a more than four times improvement in mains disturbance immunity as shown in the first three lines of Table 1.

Although now immune to mains interference with the puck stationary, while it was moving the system was still prone to maloperation. A fault was discovered on the circuit immediately following the discriminator but

Table 1
Peak amplitude of mains disturbance (L and N to E) to cause malfunctioning

Action	'Puck' stationary	'Puck' moving
1 As received	60 V	
2 Modified discriminator card input filter	150 V	
3 Decoupled supplies	> 240 V	
4 Repaired fault on discriminator card	> 240 V	
5 Replaced coupling cable table to logic chassis	> 240 V	100 V
6 Decoupled logic chassis at PS input. Connected incoming earths to the chassis at point of entry	> 240 V	> 240 V

rectification had no effect on the dynamic interference immunity. It was realized that while logic circuits may have a wide threshold to guard against unwanted spikes, this threshold is considerably reduced during gate transitions. To prove adequate immunity the logic must be operating and to this end a test pattern generator was connected to the rack containing the digital processing equipment and the mains injection pulses applied as before. The equipment was completely immune until the test pattern generator was applied to the circuit through the cable normally feeding the scanner output. Mains disturbance was inducing 800 mA peak-to-peak high-frequency ringing pulses into this cable.

The connecting cable was improved in two ways. Initially the two circuits for X and Y co-ordinates had independent screens which were taken to earth through pins in the connectors. These were replaced with a multi-core cable with the screen taken to chassis through the connector shell. A ten-fold reduction in screen current (to 80 mA peak-to-peak) was also obtained by threading the cable through ferrite rings at either end. Testing revealed that these very real improvements had not cured the system which was still only immune to 100 V mains disturbance pulses with the test pattern generator running.

Investigation of earthing inside the logic cubicle revealed again that decoupling and improved logic earthing could help. Two further decoupling capacitors on the supply lines and earth connection at the signal input plug were all that was necessary to make the system immune to 240 V pulses on the mains supply with the test pattern generator running. Similar immunity was found with the puck in use in the normal way.

It is concluded that the apparent degradation of the scanner system occurred because of increased mains switching in or near the laboratory where it is situated. The problem could have been avoided completely if the following precautions had been taken at the design stage:

- (a) Signal interconnecting leads should be suitably screened with the screens made off at each end to the shells of appropriate connectors.
- (b) D.c. supplies to printed circuit cards and each individual chassis should be decoupled on entry to eliminate the circulation of high-frequency currents.
- (c) The bandwidth of sensitive circuits should be limited to that required for satisfactory operation. Otherwise high-frequency interference may be amplified, leading to overload on subsequent stages.

4 Industrial Testing—Pulse Breakdown Tests at High Temperatures

Transducers used for some applications at high temperature need to be processed to the same or higher temperatures. During this process, it is necessary to check that the transducer insulation is not degraded in any way. A test procedure for this involves applying a

high voltage across the insulation and looking for pulse breakdown. The breakdown pulses of interest are small (about 10^{-13} coulombs) and the insulation may have a total capacitance of 10000 pF giving a pulse height of only 10 μ V. The set up is prone to electrical interference as the whole transducer with its cable is 20 m long and made of stainless steel. To improve its immunity it is encased in a copper braid before being placed in the oven.

Electrical interference was still rife during test and came particularly from the thermostatic switching of the oven heaters. Using the interference test unit described in a companion paper¹ as an injection source of radio-frequency disturbance the following problem areas were found:

- (a) The heavy copper braid round the transducer had been applied in two pieces and poor contact was found between them. This was not surprising because the high oven temperature that the braid was subject to oxidized it considerably.
- (b) The current in the braid ran also in the screen of the cable coupling the transducer to the measuring amplifier. A cable with improved screen was fitted.
- (c) The current in the improved cable still disturbed the measuring amplifier. An amplifier with adequate screening would be unaffected but the amplifier used here is a very old one using thermionic valves. Thermionic valves are less susceptible than transistors to the damaging effects of catastrophic breakdown in the transducer under test. For this reason they have continued in service for factory test duty. Rather than re-engineer the amplifier for improved immunity the disturbing current can be reduced by threading the signal cable through ferrite toroids.
- (d) Earth coupling of heater switching surges still occurred through the structure of the oven. Provision of a mains supply filter in a screened mains lead effectively cured this.

Of the changes listed above, threading the cable through ferrite rings gave the most dramatic improvement. It is a cure for many instrumentation faults so long as there are alternative paths for the disturbing current. It is a cure which is self-defeating if applied to all of the cables of an instrument system.

5 A Multi-channel Analyser in a Clinical Laboratory

An automated blood sampling analysis system in one hospital uses a small computer for process control and to interface with the hospital central data processing facility. Electrical interference was suspected of inducing malfunction and an investigation was carried out to assess this and hopefully suggest a cure. Apparently spurious 'power clear' commands were received every few hours with consequent loss of analytical results.

Preliminary tests were carried out using an interference test unit (i.t.u.) on a prototype analyser in the manu-

facturers works. The i.t.u. is capable of generating disturbing bursts of radio frequency at up to 100 mA r.m.s. from 10 kHz to 100 MHz. With this current applied by an injection line between the earthed frames of two parts of the analyser, significant pick-up was observed on lines inside the digital processor. Specifically the 'power clear' line should respond to a negative 2 V excursion so measurements were made on this line. Resonant pick-up was observed when injecting at 20 MHz with 1.6 V peak-to-peak recorded for an injected current of 120 mA peak-to-peak, equivalent to 1.9 V peak for 100 mA r.m.s., the injection level it is thought an instrument should stand. The injected burst did not disturb the system but appeared to be near to doing so.

The analyser is arranged in two blocks. The main control console and analytical reaction consoles stand together and are largely electromechanical in operation. Separated from them are the process controller (a PDP8) with teletype, line printer and tape cassette system. Similar injection tests on the hospital system yielded very similar results to the prototype with the same high level of pick-up at 20 MHz.

To cover the wide frequency range required the i.t.u. used had two output transformers. A 'power clear' fault was induced frequently when switching from l.f. to h.f. output transformer on the i.t.u. This would also induce the computer self-checking facility to enter E7 (unidentified error fault). Subsequent examination of the i.t.u. revealed that switching l.f. to h.f. gives an output surge of up to +150 V. With the 150 Ω load resistance being used in the injection line this was resulting in a +1 A current pulse being injected at this instance.

Subsequent diagnosis used a 1 μ F capacitor discharged through a mercury-wetted relay to give up to 10 A pulses and was effective in locating the place where earth induced currents were entering the system. It was found that injection between the line printer frame and the process controller frame was most onerous and resulted in a large amount of disturbance to the interface logic with random setting and widespread clearing occurring. A fast rise pulse of 0.8 A would still bring up the audible alarm.

An unscreened multicore cable connected line printer and process controller (Fig. 3(a)) and an attempt was made to screen this. As a temporary measure a braid was run alongside the signal conductors and the whole wrapped tightly in aluminium foil. This was effective in raising the apparent threshold to nearly 10 A so long as it was earthed to the process controller frame as it entered the console as sketched in Fig. 3(c). With its primitive design and especially because its capacitor is only charged to 300 V the pulse generator has a low output impedance of only 30 Ω at 10 A. The rise-time of the higher current pulses is therefore longer than that of the lower current pulses.

Injection of pulses into the mains supply of the line printer also upset the operation of the process controller

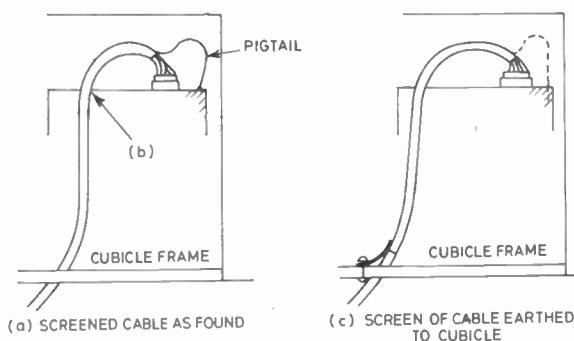


Fig. 3. Earth connection for screen of cable.

- (a) Screened cable as found
 (b) Screen of cable earthed to cubicle.

so the following changes were suggested and implemented to improve the system:

- (a) Line printer (and other peripherals) should be connected to the process controller through screened cables. Screens should be made up without pigtails to a good earth on the console, and to the frame of the peripheral.
- (b) The system mains r.f. filter should be mounted on the process control cabinet which should be used as a screen between input and output.
- (c) All peripherals should be powered from the output side of the mains filter, not separately from independent mains sockets nearby.

Since these changes there have been no known reports of spurious operation. The manufacturer is known to have carried out similar modifications on other installations and to have built for himself another pulse generator. For our own part we very soon put in hand the development of a pulse generator with $50\ \Omega$ or $200\ \Omega$ output impedance capable of supplying 10 A at a repetition rate of 1000 p/s. It is this pulse generator that is now specified for mains injection tests and has been used successfully on other computer installations.

6 Digital Processing—Numerically Controlled Machine

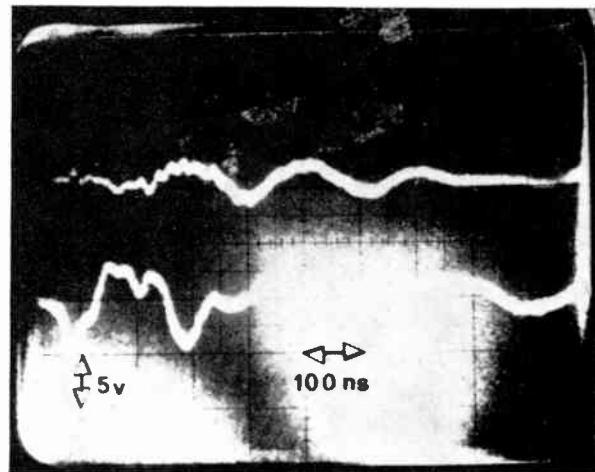
A large automatic lathe is controlled completely with the aid of a pre-programmed magnetic tape and small computer. Position sensors on head and tool slides are used in the digital feedback controls of the tool position sensors and work piece drive. Obvious electrical interference problems occurred which the computer makers remedial action only made worse. As it was thought the interference was mains pick-up from the machine's own power system, it had been suggested that the computer should be separately powered, which is contrary to the action taken on the analyser described in Section 5.

The machines were located quite close to a welding bay containing several different welding sets. It was known that this was not the only source as malfunctions had

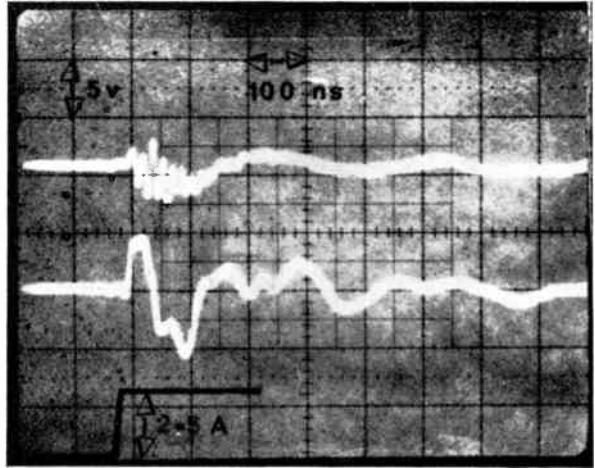
occurred when all welders were not in use. Wherever it came from, the effect of the disturbance was dramatic, once with a jump in tool position in excess of 9 mm which resulted in it gouging pieces out of the chuck holding the work piece.

The digital processor has a 5 V power supply line with its 0 V return independent of the cubicle's earthed frame. Monitoring the power supply lines on an oscilloscope showed that disturbance levels in excess of 5 V were present on both 5 V and 0 V lines with respect to the earthed frame (Fig. 4(a)). Study of the two traces show that they are not coincident (or in phase) so that the difference voltage is sufficient to induce malfunction. A short injection line was laid between the machine frame and the processor earth and 2.5 A pulses injected into this line induced similar 5 V disturbance on the 5 V and 0 V line (Fig. 4(b)). While these pulses were being injected the machine was unable to operate correctly.

It was thought that the disturbance was entering the processor through the sensing leads and that improved immunity might be obtained with a better common

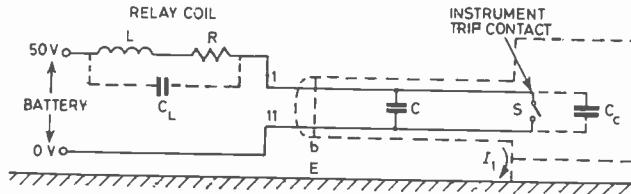


(a) Welder-initiated disturbances

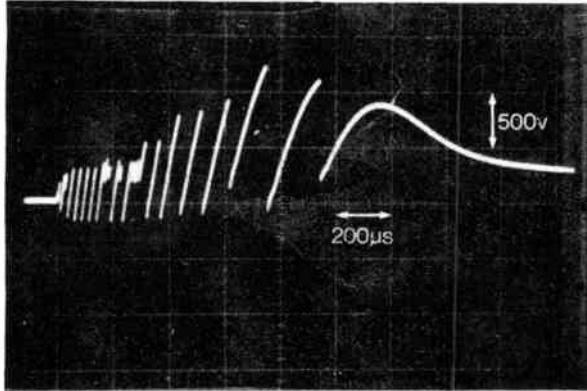


(b) Artificially-injected disturbances.

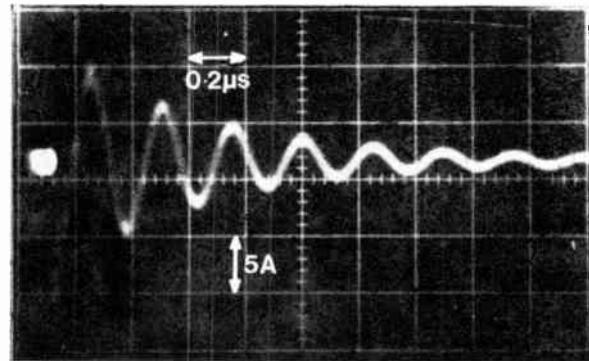
Fig. 4. Processor supply line disturbances.



(a) Typical relay circuit



(b) Voltage across opening contact (S)



(c) Cable screen to ground current.

Fig. 5. Unsuppressed relay disturbance (I).

earth. To this end a large sheet of metal was placed in the floor and attached to the machine frame. The digital processor was placed on this sheet and the edge bent up for about 30 cm. The mains supply filter was attached to the bent up portion and care taken to separate the cable before filtering from any other nearby cables. The effect of the improved earth was to reduce the disturbance from 5 A injected pulses to less than 1 V on the 5 V and 0 V supply lines. No further malfunction occurred due to welding or other mains transients.

The numerically-controlled machine tool is as sensitive to mains disturbance as any other digital circuit. Not only must mains supply filters be properly earthed, but there must be good screening or separation between the incoming supply and the protected circuits. In situations where transducers are connected to a processor, a low impedance earth is very desirable.

7 Unsuppressed Relays in Power Stations

The stored energy from a relay coil must be dissipated when that relay is de-energized and when it is not suppressed a large number of very fast transients are generated. It has been shown³ that these transient voltages appear on the relay coil supply lines which not being terminated in their characteristic impedance may resonate violently. The disturbance generated is little greater than occurs on the mains when switching equipment. Unfortunately it occurs on or near lines which may be taken into a sensitive equipment.

Many instruments used for measuring power station parameters have trip and alarm circuits controlling relays. These and other relays if unsuppressed can wreak

havoc in the very instruments from which they are controlled. Alarm circuit currents are shown in Fig. 5 to reach 20 A peak-to-peak at a frequency of 2 MHz, a level it is unreasonable to expect the instrument to tolerate. It must also be remembered that such a surge is not an isolated occurrence. More than 100 such transients may occur in less than a millisecond for each relay de-energization.

8 Instruments for Acoustic Emission Detection (Stress Wave Analysis)

When materials are under strain, such as steel pressure vessels, they begin to crack, generating noise which travels as Rayleigh waves along the surface of the material. Initially the cracks may be extremely small but with the prolonged application of strain each crack lengthens in steps and the longer the crack the longer and the more frequently do the steps occur until a catastrophic break results. It is possible to detect the occurrence of the cracking if sufficiently sensitive transducers are fixed at appropriate points on the structure surface. Initially, when the elongation of the cracks are occurring at a low rate, it is possible, by using a network of transducers and comparing the arrival times from a single step, to compute the position of that crack. From the rate of occurrence it is possible to predict when a catastrophic break is imminent. The instruments required for this analysis must have high sensitivity and hence must use low-noise amplifiers. It is evident that extremely good interference immunity is essential.

In one particular system for stress wave analysis up to 20 transducers were distributed over a pressure vessel. It was decided that to ease installation the low-noise

amplifiers should be mounted centrally together with the processing and computing equipment, connected to their transducers through up to 100 m of superscreened cable. The transducers were small blocks of piezoelectric material having an undamped resonance at about 300 kHz. At this frequency a good match is obtained between transducer and coaxial cable by using a step-down pulse transformer. The transformer was mounted in a small metal housing covering the transducer which for adequate screening and acoustic coupling had to be earthed to the structure. The use of the transformer in this circuit was extremely effective in isolating the system from low-frequency electrical disturbance which might otherwise have presented a serious problem.

The interference immunity of the system was established using an interference test unit and tests detailed in the companion paper.¹ This was carried out at initial commissioning and during the first demonstration trials of the system. With 100 mA r.m.s. injected into earth at any frequency the pick-up on the signal line was barely distinguishable from amplifier noise. As amplifier noise was less than 0.5 µV r.m.s. the effective total transfer impedance on each channel was less than 5 µΩ.

At a later date it was suspected that interference was beginning to upset the system and further tests initiated. These confirmed that the interference immunity had indeed degraded, largely because of wear on the mating faces of the connectors (which were series N) and failures in their cable braid clamp. An additional disturbing finding was that the cables themselves had degraded considerably in their screening performance, due to flexing.

While it was possible to repair the faulty connectors and replace the degraded cables, the fairly rapid deterioration alerted the authors to the long-term need for a cable flexing specification for superscreened cables and of course cables that would meet it. The development of such cables has been successfully completed.² The new cables will stand a lot of punishment and the specification includes measurement of surface transfer impedance after bending 100 times to the minimum bending radius of the cable. There remains a need for connectors with good screening properties which are not degraded by frequent connecting and disconnecting operations, but no difficulties are now foreseen here.

9 Conclusions

It can be seen from the selection of interference problems described that there is no common solution. They do appear to have a common major cause, that of high-frequency currents flowing in system screens and minimizing coupling between these currents and the system

circuitry will improve its interference immunity. The techniques described in Ref. 1 enable a satisfactory solution to be achieved by a systematic investigation. However, a little experience and a knowledge of the ways in which interference is propagated can indicate where the possible weak points in an installed system are and enable a quicker solution to be obtained.

The other major interference source, that of mains-borne interference, dictates that a suitable filter in the supply to any sensitive system is essential unless the power unit circuits have been constructed in a way to minimize coupling. However, it cannot be stressed too much that an installed filter is only as good as its surrounding screen and that it is essential to keep the supply wires away from the filtered circuitry and provide a low-inductance earth return path for the unfiltered circuit. In other words it cannot be assumed that an installed mains filter is effective: it is necessary to test it. Systems which are difficult to screen because of their physical construction, for example a plug-in printed circuit card system, can be effectively screened by encasing the unit in a screening enclosure. All leads entering the enclosure are then either filtered or have their screens firmly bonded to the enclosure screen. If a difficult system requires only marginal improvement it may be possible to examine the circuit operation and look for design weaknesses like excess high-frequency bandwidth and supply lines which are not effectively decoupled to high frequencies. The screening effectiveness of a poor coaxial connector can be improved by minimizing the high-frequency interference currents which flow through it. This can be achieved by threading ferrite toroids onto the cable adjacent to the connector and then bonding the cable screen to the chassis near the connector.

It should not be forgotten that for interference to exist there must also be a generator. If the generator is known then screened leads and enclosures are as effective at preventing interference escaping as preventing it entering a system. And so we return to Electromagnetic Compatibility!

10 References

- 1 Fowler, E. P., 'Interference immunity test requirements', Conference on Electromagnetic Compatibility, Guildford, April 1978, IERE Conference Proceedings No. 39, pp. 5-22; *The Radio and Electronic Engineer*, 49, no. 2, pp. 85-93, February 1979.
- 2 Fowler, E. P., 'Superscreened cables', Conference on Electromagnetic Compatibility, Guildford, April 1978, IERE Conference Proceedings No. 39, pp. 213-28; *The Radio and Electronic Engineer*, 49, no. 1, pp. 38-44, January 1979.
- 3 Phillips, P., Cake, B. V. and Fowler, E. P., 'Suppression of Relay Interference with particular reference to Nuclear Reactor Safety Circuits', AEEW-R 1031, November 1975, Atomic Energy Establishment, Winfrith.

*Manuscript received by the Institution on 8th November 1977.
(Paper No. 1864/CC 300)*

Real-time spectrum analysis using hardware Fourier and chirp-Z transformations

R. BENJAMIN, D.Sc., Ph.D., C.Eng., F.I.E.E.,
F.I.E.R.E.*

1 Introduction

On-line frequency analysis is being used on an increasing scale for signal processing, in radar, communications, sonar, acoustics and other applications. It is at best very expensive to do this on general-purpose computers, and indeed often only special array processors can provide the required digital computing power. However, analogue circuit technology, including surface-acoustic wave and charge-coupled devices, offers prospects of more economical solutions in many situations.

This paper seeks to indicate the wide variety of distinct 'block-schematic' approaches which could be followed, in such analogue implementations (some of them probably not previously considered). By presenting these in a quasi-'evolutionary' sequence, it will also demonstrate their mathematical equivalence in simple physical terms. The choice actually adopted in any given application must then depend on its specific engineering desiderata and constraints, and the paper provides some guidance to these.

2 Fourier Analysis by Correlation

The 'discrete Fourier transform' (DFT) analyses a waveform segment $G(t)$, of duration T and bandwidth B , into $BT \equiv n$ frequency components $F(i)$, such that

$$F(i) = A(i) \sin \omega(i)t + B(i) \cos \omega(i)t.$$

where

$$A(i) = \frac{1}{T} \int_0^T G(t) \sin \omega(i)t \, dt$$

and

$$B(i) = \frac{1}{T} \int_0^T G(t) \cos \omega(i)t \, dt$$

and

$$\omega(i) = 1/T, 2/T, \dots, n/T.$$

Within the limits $0 < t \leq T$, this gives

$$\sum_{i=1}^n [A(i) \sin \omega(i)t + B(i) \cos \omega(i)t] = G(t).$$

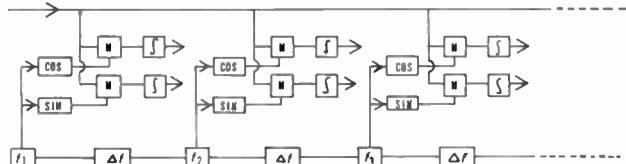


Fig. 1. Fourier analysis by correlation.

SUMMARY

A number of distinct ways of performing near real-time spectrum analysis by 'hardware' are outlined in block-schematic form. It is shown that these are theoretically equivalent, but differ substantially in their design implications and interface requirements.

Translating this well-known relation into analogue hardware, the DFT of such a waveform is obtained by correlating (i.e. multiplying) it with a set of BT reference frequencies, spaced by $1/T$, and integrating the correlator outputs over the segment's duration, T . Two quadrature

* Government Communications Headquarters, Oakley, Cheltenham, Glos., GL52 5AJ.

versions of each of the reference frequencies must be so correlated. (If the power spectrum is required, the quadrature components must be combined subsequently.)

This is illustrated in Fig. 1, where $\Delta f = 1/T$, the frequency increment between consecutive Fourier reference frequencies, and the correlators are formed by modulators, driven both by the signal to be analysed and the appropriate reference, each followed by an integrator to average the output over the analysis time T .

Readers not familiar with spectrum analysis and transformations may refer to any of the excellent text books on the subject, for example reference 1.

3 Chirp-Z Analysis by Correlation

If both the signal to be analysed and the set of reference signals were first subjected to a common frequency transposition, these correlations (which are a function of the frequency difference) would be unimpaired. This remains true even with a common *time-varying* frequency modulation. Furthermore, if this modulation takes the form of a linear frequency sweep over $2B$, at a rate of B/T , then (for our purpose) a time displacement by $(1/T)/(B/T) = 1/B$ will be equivalent to a frequency shift of $1/T$, i.e. to the difference between the discrete reference frequencies. Hence a single linear frequency sweep could be used both as 'local oscillator' for the frequency modulation and as the source of all the reference frequencies. A tapped delay-line of length T would then have to be inserted in the path of the subject waveform or the f.m. sweep generator, so as to produce the required BT relative time displacements, prior to correlation over the integration interval of T .

This scheme is illustrated in Fig. 2(a). The taps on the delay line differ by the time delay $1/B$ derived above.

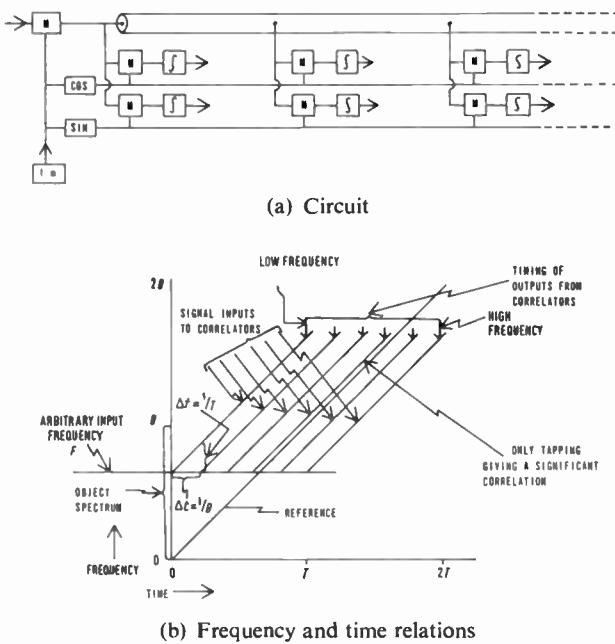


Fig. 2. Chirp-Z analysis by correlation (delayed signal).

The frequency and time relationships are illustrated in Fig. 2(b), for a simple single-frequency input. Equivalent relationships will then also pertain to all the other frequency components contained in a more complex input spectrum. Note that the signal and f.m. inputs to the delay line can be limited to the interval $0 < t \leq T$.

In order to cope with two quadrature phases of the frequency components analysed, the process has to be duplicated, using two quadrature phases of the starting frequency for the two f.m. sweeps.

The technique here illustrated in physical terms is that known mathematically as the 'chirp-Z' transform. Appendix 1 adapts the method of Bluestine² to illustrate its equivalence to Fourier analysis more formally.

4 Variants of Chirp-Z Correlation

With the above scheme, the BT integrators attain their full outputs consecutively, in the time interval from T to $2T$ after the start of the process. Alternatively, all the integrators could start operation simultaneously, as soon as the line is filled with a frequency-modulated waveform segment of length T , and stop integration simultaneously T seconds later (with the f.m. input active from time 0 to $2T$). The BT frequency 'lines' so defined, although read simultaneously, would then be derived from overlapping but staggered waveform segments, of individual duration T , within a total (input) time span of $2T$.

The required relative time displacements between the f.m. ramp and the mixer output can be obtained in at least four distinct ways:

- (i) f.m. ramp starts at bottom of transposed band to be analysed, signal is delayed;
- (ii) f.m. ramp starts at top of transposed band to be analysed, reference is delayed;
- (iii) f.m. ramp starts at bottom of transposed band to be analysed, reference is advanced;
- (iv) f.m. ramp starts at top of transposed band to be analysed, signal is advanced.

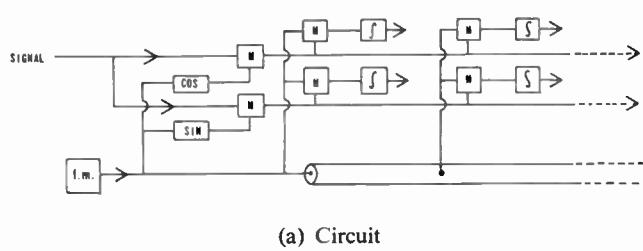
Variant (i) is that described in Section 3 and Figs 2(a) and (b);

Variant (ii) is illustrated in Figs 3(a) and (b);

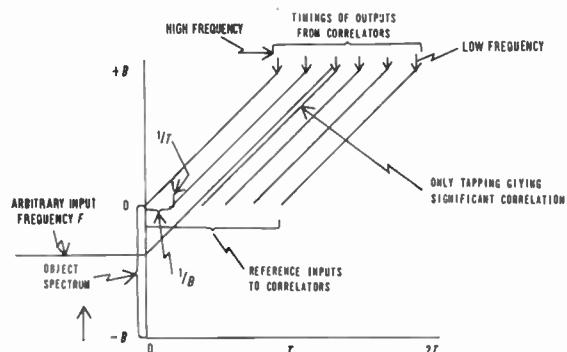
Variant (iii) is illustrated in the block schematic of Fig. 4.

Except for a shift of the time origin, the timings for variants (iii) and (iv) are essentially equivalent to those of (i) and (ii) respectively, as illustrated in Figs 2(b) and 3(b).

In all cases the 0 frequency shown on the diagram is the value of the sweep frequency at the start of the sweep. This is made to be the top or bottom of the transposed band to be analysed, by taking either the upper or lower sideband output of the mixer. Choosing options (i) or (iii) where it is at the bottom of the band has the advantage that the total band over which the circuits have to operate is $2B$, rather than the $3B$ necessary in options (ii) and (iv). (Four further variants, involving negative frequency slopes, would also be produced by reversing

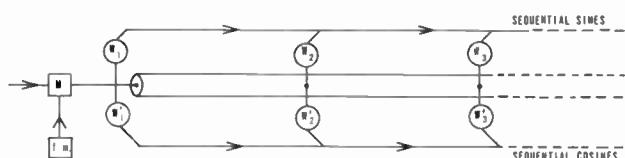


(a) Circuit

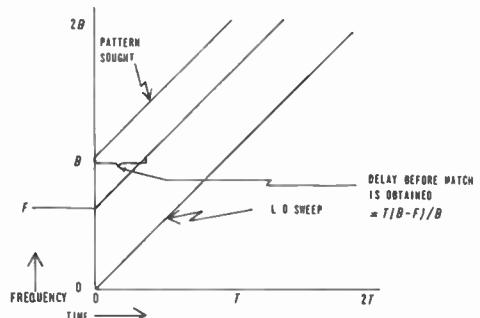


(b) Frequency and time relations

Fig. 3. Chirp-Z analysis by correlation (delayed reference).



(a) Circuit



(b) Frequency and time relations

Fig. 5. Chirp-Z analysis by matched filtering.

the direction of the frequency scale on Figs. 2(a) and (b). As a further option, with variant (iii) (see Fig. 4), a suitably stored ramp waveform, representing the first half of the f.m. sweep, could be loaded into the delay-line in parallel, rather than generating it serially over time T in advance of using it (or the full waveform could be loaded into a double-length line). This would compress the whole process to T , the duration of the object waveform segment. Variants delaying the f.m. ramp avoid any degradation of the signal by the delay-line.

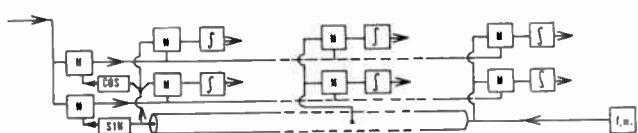


Fig. 4. Chirp-Z analysis by correlation (advanced reference).

5 Chirp-Z Analysis by Matched Filtering

Looking at the mixer 'the other way', each frequency component F in the subject signal imposes the corresponding frequency shift on the local-oscillator signal.

In view of the linear frequency modulation of the local oscillator, this frequency shift is equivalent to a proportional time displacement of $F/(df/dt) = F/(B/T) = T(F/B)$. Let us then make the last T seconds of the output of such a mixer accessible in a tapped delay line. (See the block schematic of Fig. 5(a).) As soon as the f.m. segment of length T , corresponding to the highest frequency component (if present) will have filled the line, we can look for this f.m. segment. This involves matching the line taps to this waveform in magnitude and sign, and summing the output. (In practice one network would sum the positively-weighted taps, and a second one would sum the negatively weighted ones and subtract this result from the first one.) Due to the bandwidth B , this coherent summation will give an impulsive resultant of duration $\Delta t = 1/B$. However, as soon as that impulse is over, the line will be filled with the similarly matching f.m. segment due to the frequency component df/dt . $\Delta t = (B/T) \times (1/B) = 1/T$ lower, etc. Thus the spectrum of all BT resolvable frequencies will be produced sequentially, over an interval T , as the amplitude profile of the output waveform from the matched-filter summation network. (See the timing diagram, Fig. 5(b).)

Note that any given time increment represents different phase shifts at the different frequencies of the f.m. sweep. Thus any phase misalignment cannot be put right by a corresponding time displacement, and so the

matched filter is phase selective. Hence two separate weighting and summing networks may be attached to the line-taps, to yield the two quadrature sets of spectral components, as shown in Fig. 5(a).

6 Matching the Chirp Waveform with a Dispersive Delay Line

We have seen how we can eliminate the need for BT separate reference frequencies (each in two quadrature phases), by the appropriate use of linear frequency modulation and time delay. Further, we have seen that we can avoid the need for BT separate correlators and integrators, by using the tapped delay line as a sequentially-scanning matched filter, and that we can perform two quadrature analyses of this type in parallel, using the same delay line.

In yet a further variant, we can also dispense with the two BT -element matching networks. This is achieved by designing the line so that its delay diminishes with increasing frequency at a rate of $d\tau/dF = T/B$.

This is illustrated in the block schematic of Fig. 6(a) and the timing diagram of Fig. 6(b). The right-hand side of Fig. 6(b) shows the frequency-dependent delay characteristic of the line. It will be seen that this causes the start of the f.m. sweep, associated with input frequency component F , to arrive at the final output τ seconds ahead of the maximum delay, where $\tau = TF/B$, and so τ is linearly proportional to F .

ΔT seconds later, this input frequency component will have been increased by ΔF , due to the linear frequency modulation applied to the input spectrum. However, the slopes of this frequency modulation and that of the dispersive characteristic of the line are equal and opposite. Hence this frequency shift ΔF causes the delay in the dispersive line to be diminished by $\Delta\tau$, so that this (later and frequency-transposed) sample of initial frequency F arrives at the final output with exactly the same differential time, $\tau = TF/B$. Clearly this is equally true for all other values of ΔF within the applied f.m. sweep. Thus, as before, each spectral component of the input is converted into the corresponding, frequency-shifted f.m. sweep, but now all parts of this f.m. sweep are caused to arrive simultaneously and mutually phase coherently at the far end of the line, to give an impulsive output of duration $1/B$. Furthermore, the timing of this impulse will still vary linearly with the starting frequency of this f.m. segment. Hence, as before, we obtain an output representing, sequentially, the amplitudes of the BT resolvable frequency components, each being the resultant of coherent integration over duration T .

With this scheme, too, the output depends on the relative phase of the f.m. sweep and the frequency component being analysed. Hence two parallel systems, two orthogonal sweeps and two dispersive lines are required to cover two quadrature sets of spectral components. (See Fig. 6(a).)

7 Some Features Common to the 'Chirp-Z' (f.m.) Systems

With the schemes of Figs. 5(a) and 6(a), the frequency spectrum is generated as a continuous function of time (with the given resolution of $1/T$). Thus these techniques avoid the frequency-quantization effect of constraining the definition of the spectrum to the relative amplitudes (and phases) of equally-spaced 'lines' of pre-determined frequency. This makes no difference when the spectrum is itself a continuous function, but it can be a real advantage when dealing with discrete actual frequency lines spaced by more than $1/B$.

Furthermore, the sequential nature of these two systems allows two squaring circuits (one for each quadrature output line) and one adder to generate the power spectrum sequentially, when this is required.

Where the input signal (and the analysis circuits) are sufficiently stable, each of the three f.m.-based schemes above may be reduced to a single-phase variant, used consecutively first with one f.m. reference and then with the orthogonal one, if desired.

We may also note again that all the schemes based on the f.m. ramp (chirp-Z transform) can be made to function with positive-going frequency sweeps, starting at one end of the frequency band of interest, or negative-going ones starting at the other end of the band. Reversing the slope of the ramp merely reverses the resulting output frequency scan.

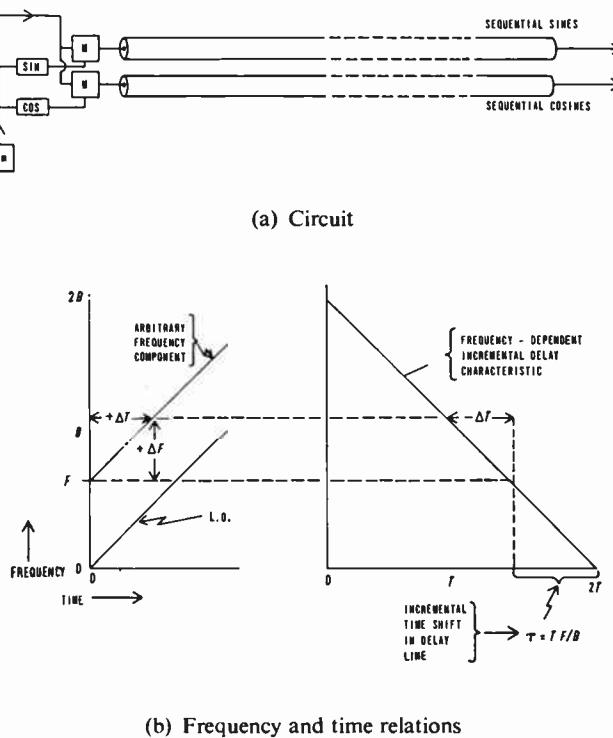


Fig. 6. Matching a waveform with a dispersive delay line.

8 Fourier Analysis by Transversal Filter

A delay-line may also be used for spectrum analysis in the absence of any frequency modulation. In this case we exploit the fact that it provides *in parallel* the full waveform segment, over which we wish to integrate in performing the DFT correlations with the various reference frequencies. Hence these reference functions can then also be provided in parallel, as a set of weights, of appropriate magnitude and sign, applied to the signals appearing at the taps of the line. Given suitable buffer amplifiers, *BT* separate weighting and summing networks can be connected to one line, to match to the *BT* resolvable frequencies. (See Fig. 7.) (In practice, each summing network would probably use one 'bus-bar' for all positively-weighted contributions and one for all negatively-weighted ones.)

This configuration will act as a set of mutually orthogonal transversal filters: each output line will pass signals at its own matched frequency, and will give a null for signals exactly on any of the other frequencies (in the absence of taper at the edges of the integration interval)—as is true for all other implementations of the DFT.

Note that this process performs an exact analogue to the DFT, but by filtration, rather than by the normal 'homodyne' detection of the various frequency constituents. Phase information can then be obtained by phase comparison of each filter output with a reference signal at the nominal frequency of that filter channel. Conversely, however, in the absence of any reference signal, this scheme is not phase selective, and hence a single set of *BT* parallel outputs and linear rectifiers can then be used to give the scalar amplitude spectrum, or square-law detectors can be used to give the power spectrum directly (avoiding the need to square and add two quadrature components). This simplification can be a real advantage for some applications, but clearly it would not be acceptable for others.

This solution differs from all the previous ones in two important respects:

(i) it provides a *continuous* output of the DFT spectrum over the immediately preceding *T* seconds, rather than a succession of discrete spectra for (normally) alternate consecutive segments of duration *T*;

(ii) it retains the original signal, segregated into channels, rather than merely providing a set of measurements describing that signal.

9 Some Relevant Technologies

For *non-dispersive* delay-lines, charge-coupled devices (c.c.d.s) offer a convenient technology. This has the considerable advantage that an instrument, designed to cover a given time-bandwidth product, can resolve the corresponding number of discrete frequency channels, over a very wide range of carrier frequencies and bandwidths, by merely changing the frequency of the driving 'clock'.

Such c.c.d. 'delay lines' can take the form of an analogue 'shift register'—generally the most economical implementation. When this offers insufficient precision *m* parallel binary digital shift registers (not necessarily c.c.d.) can be substituted, for an accuracy of 1 in 2^m . A potentially attractive intermediate compromise would use say two c.c.d. shift registers, one to give the 'coarse' amplitude in a multi-level quantized form, and one to give the 'fine' amplitude, probably in continuous analogue form. With coarse and fine representation, multiplication of two such quantities (for correlation) would have to be synthesized from several sub-products. If *K* denotes the coarse/fine ratio, and α, β are two quantities to be multiplied:

$$\alpha \equiv KA + a$$

$$\beta \equiv KB + b$$

$$\alpha\beta = K^2AB + K(AB + Ba) + ab.$$

The final term could probably be disregarded as insignificant.

Surface acoustic waves (s.a.w.s) can provide good compact delay-lines of quite high time-bandwidth product, but since the range of actual delays attainable is rather limited, such instruments would be less universal than c.c.d.-based ones. However, s.a.w. devices are almost uniquely good at providing high-quality 'dispersive' delay-lines of precisely-determined frequency/delay characteristics. Hence, *within their range of frequencies and delays*, they are admirably suited to the techniques adumbrated in Sections 6 and 7. For similar time-bandwidth products, but involving longer times and lower frequencies than those suitable for s.a.w. devices, c.c.d.s could then be used as a speed-translating interface, recording the input at real speed and then releasing it into the s.a.w. circuit at the appropriate higher speed.

Non-dispersive s.a.w. circuits can use the coarse/fine techniques suggested above, if required. However, the coarse/fine segregation in the *input, time domain* would produce inconsistencies in the frequency domain which appear to rule out this technique for dispersive lines, in this application. In some appropriate applications, dynamic-range problems could be eased by the use of a.g.c. techniques and/or by a pre-analysis equalizing

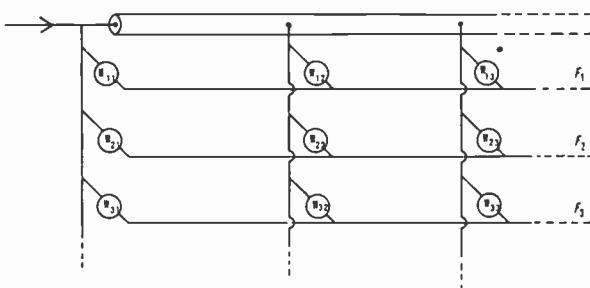


Fig. 7. Power spectrum Fourier analysis by transversal filter.

filter, to 'iron out' any known wide variations in the likely signal amplitudes over the spectrum. (The inverse of the a.g.c. and equalizing functions could then be applied to the output spectrum found by the analyser.) Some examples of c.c.d. and s.a.w. applications to spectrum analysis are listed in references 3-5.

10 Side-lobes

The basic DFT has a $[\sin(\Delta\omega T/2)]/(\Delta\omega T/2)$ frequency response (where $\Delta\omega$ is the displacement from the nominal line frequency). This gives complete mutual orthogonality between frequency components exactly on the nominal 'lines' analysed—at the expense of rather poor side-lobes elsewhere. Hence, when the object spectra do not have a known regular line spacing, side-lobe reduction is usually desirable—at the expense of broader 'main-lobes' and imperfect mutual orthogonality. This is normally achieved by tapering off the signal to be integrated, at the beginning and end of the analysis interval T . Such time weighting can be applied to the input waveform segment, to the reference function, or at the delay-line taps, as appropriate. In each case, it can thus be applied once, to serve all BT single-phase outputs, or (with some of the schemes) even to serve the two quadrature outputs of all BT frequency lines to be resolved.

Alternatively or additionally, some 'super-resolution' weighting may be applied at these points. This entails an increased number of 'quasi-Nyquist' sampling points within the waveform segment, and sign reversals between samples. At the expense of much reduced sensitivity (and hence normally reduced signal/noise ratio) this can at times improve the frequency resolution by factors up to about 2 or 2.5. It is however preferable to achieve such extra resolution by the use of a longer integration time T , whenever that option is available (as it usually is).

11 Discussion and Conclusions

It has been shown that quite a wide diversity of apparently distinct types of frequency analyser are essentially equivalent, theoretically. Subject to some minor variations, they give the same performance and, more specifically, the same resolution of BT 'lines', for an input covering the bandwidth-time product BT . (However, most of the devices need a total operating times of $2BT$.)

The choice adopted in any given application will depend on the relative financial, engineering and performance costs of, e.g.:

- (i) multiple discrete frequency synthesizers *vs.* a linear f.m. sweep generator and a tapped non-dispersive delay line;
- (ii) parallel frequency-channel outputs *vs.* a sequential spectrum scan;
- (iii) regularly-spaced analysis 'lines' *vs.* a 'continuous' spectrum of the same resolution;

- (iv) spectrum analysis of a common waveform segment *vs.* frequency components measured on only partially overlapping segments of the input waveform;
- (v) matched-filter 'weighting' networks *vs.* correlators;
- (vi) matched filters or correlators *vs.* s.a.w. or other delay lines of precisely-defined dispersive characteristics;
- (vii) phase defined by the phase of a single output *vs.* the amplitudes and signs of two quadrature outputs;
- (viii) the complex (frequency and phase) spectrum *vs.* the scalar amplitude spectrum *vs.* the power spectrum;
- (ix) a continuous spectrum as a set of continuous parallel time function *vs.* a succession of discrete sample spectra;
- (x) a channelized (and re-constitutable) signal *vs.* a set of spectral parameters.

Whereas these diverse considerations do not permit a universal 'optimum' to be specified, the essential 'cleanliness' and circuit simplicity of the dispersive delay-line solution of Section 6 will make it the favourite for a wide range of applications. As shown in Section 7, this is also a strong contender when the desired output is the power spectrum. Furthermore, Section 9 shows that its combination with a c.c.d. speed-translating interface can make it a very flexible tool. However, in view of the extra complexity of the c.c.d. interface, a c.c.d.-only version of the matched-filter chirp-Z technique of Section 5 would then be a strong competitor. When a very wide dynamic range is required, this matched-filter chirp approach, implemented with the coarse/fine refinement of Section 9, may well normally emerge as the strongest contender. The transversal-filter solution of Section 8 is amenable to the same artifice, to increase its dynamic range. It will probably provide the best answer (of those described) when the spectrum is required as a continuous time function, and/or when the channelized true signal is required in addition to its spectrum. In particular, this scheme permits the spectral information to be used to determine amplitude weightings, phase corrections etc., to be applied to the various frequency components, segregated by the same transversal filter, to meet the needs of a specific application. Indeed, if required the resultant components can then be recombined to reconstitute the signal as a single composite (and appropriately modified) waveform.

Each of the schemes discussed will probably offer the best balance of advantage in some applications, and no choice should be made without assessing its specific conditions in the light of criteria, such as those listed in (i) to (x) above.

12 Reference

- 1 Lathi, B. P., 'Communication Systems', chap. 1 (Wiley, New York, 1968).
- 2 Bluestine, L. I., 'A linear filtering approach to the computation of the discrete Fourier transform', NEREM Record 1968, 218-9.

- 3 Mayer, G. J., 'Chirp-Z transformation—c.c.d. implementation (signal processing)', *RCA Rev.*, 36, no. 4, pp. 759–73, December 1975.
- 4 Alsup, J. M., Means, R. W. and Whitehouse, H. J., 'Real-time discrete Fourier transformations using surface acoustic wave devices.' *Intl Specialist Seminar on Component Performance and Systems Applications of Surface Acoustic Wave Devices*. Aviemore, Scotland, 25th–28th September 1973 (IEE Conference Publication 109), pp. 255–69.
- 5 Heighway, J. and Paige, E. G. S., 'Analogue signal processing with s.a.w. devices'. *Intl Specialist Seminar on the Impact of New Technologies in Signal Processing*. Aviemore, Scotland, 20th–24th September, 1976, pp. 27–43. (IEE Conference Publication 144)

13 Appendix 1: Equivalence of the Chirp-Z and the Discrete Fourier Transform

A chirp-Z transform using the same data as the corresponding discrete Fourier transform (DFT) ought to give the same result. Adapting the work of Bluestine,² this can be demonstrated as follows:

The Fourier transform derives the frequency coefficient $A(f)$ from the time samples $A(t)$ in the form

$$A(f) = \sum_T A(t) \exp(-2\pi jft),$$

where \sum_T represents summation over the duration T of the waveform. This may be written as

$$A(f) = \sum_T A(t) \exp j\pi[(f-t)^2 - f^2 - t^2]$$

and

$$A(f) \exp j\pi f^2 = \sum_T A(t) \exp [-j\pi t^2 + j\pi(f-t)^2].$$

The exponential term on the left-hand side of this equation corresponds to a frequency-dependent phase 'calibration' applied to $A(f)$. On the right-hand side, $\exp -j\pi t^2$ represents a linear change of frequency, applied to the input waveform, and $\exp j\pi(f-t)^2$ is a linearly dispersive function, in which a frequency change is equivalent to a proportional time displacement. Thus the Fourier coefficient $A(f)$ is identical with the output of a corresponding dispersive-delay chirp-Z transformer.

*Manuscript first received by the Institution on 30th March 1978, and in revised form on 21st August 1978
(Paper No. 1865/CC301)*

Electromagnetic compatibility from the design engineer's point of view

B. PRIESTLEY, B.Sc., C.Eng., M.I.E.R.E.*

Based on a paper presented at the IERE Conference on Electromagnetic Compatibility held in Guildford from 4th to 7th April 1978

SUMMARY

Ideally electromagnetic compatibility should be designed into a system *ab initio* rather than as a result of tests and modifications at a later date. This requires a broad awareness of e.m.c. technique on the designer's part which is often only acquired by experience. Based on experience both of general design and e.m.c. work several areas of knowledge are highlighted whose neglect contributes to present-day e.m.c. problems.

* EMI Electronics Ltd., Hayes, Middlesex.

1 Introduction

The design and realization of a piece of electronic equipment involves many skills. Whilst it may not be impossible to learn them all inside one man's lifetime, as is the case for some high technology products, it is certainly difficult and does not fit perfectly to any academic training.

The solution often adopted is to allow the designer a more or less free hand to realize the electronic performance and then clean-up the design for production. After a clean-up by specialists in mechanical, thermal, production, reliability and e.m.c. engineering it is hardly surprising if the design shows the bad features of a compromise. Clearly a better device would be produced by taking the early advice of these specialists and evaluating the trade-offs at that stage whether this is a formal procedure or simple common sense on the designer's part. This will also result in less inter-departmental friction.

Dealing specifically with e.m.c., on the face of it an electronics engineer would seem less in need of specialist help since the subject is part of his own discipline. However, this is by no means the case in practice, so let us examine how the training of electronics engineers might be improved so that they are competent general practitioners in the e.m.c. area and do not present the specialist with a system which is almost impossible to clean up without a redesign.

2 Basic Principles

Firstly, it cannot be over-emphasized that an e.m.c. situation exists and needs to be considered *ab initio* rather than being a matter of bad luck.

For example, nearly all electronic equipment contains amplifiers which can have parasitic oscillations, often without serious degradation of desired performance. This is well known in r.f. design and the theoretical basis established, but it seems to be implied that the same principles do not apply to, say, audio amplifiers or logic inverters. A remedy sometimes met is an embargo on the use of emitter followers or other conditionally stable amplifiers but often the possibility of parasitic oscillation is simply ignored, probably because any radiation will upset someone else's circuit! It would be a salutary lesson for such designers to live with their problems not just from 9 till 5 but for 168 hours a week as a radio amateur has to do, preferably in the sort of area where any r.f. interference, real or imaginary, produces a strongly worded protest.

Secondly, having accepted that there is an e.m.c. situation, this suggests that every piece of equipment has an e.m.c. specification even if it is not written down but implied by the Sale of Goods Act which requires that goods shall be of 'merchantable quality'.

For example, a tape recorder is not expected to blot out radio reception over a half mile radius due to bias oscillator radiation. This is avoided by somewhat

nebulous 'good practice' rather than a standard specification, and apparently this is not completely successful in avoiding interaction between a recorder and a receiver linked to it. Someday the public will realize this is a defect of the equipment and not a device by the BBC to prevent recording. Good practice will then have to make a quantum jump and this is a constant problem with the implied specification.

An apparently more serious example of failure to recognize an implied e.m.c. specification was reported in the *British Medical Journal*. An 'on demand' cardiac pacemaker was triggered by test transmissions from a local radio station. This resulted in the collapse of the patient. Fortunately being in hospital, immediate attention was available so no permanent harm resulted, but the effect had the patient been living alone could have been fatal. It is now standard practice to fit filters to the leads of an on-demand pacemaker, but it seems a serious reflection on our profession if this situation was not foreseen.

3 Detailed Techniques

Passing from these two general points on the existence of e.m.c., let us go on to some specific areas which experience suggests as occasional blind spots in engineers' training. They are in the main not as concerned with the higher learning of the principles of electronics as the lower learning of its application. However, at least some of them could be introduced into the practical part of an electronics course without laying the lecturer responsible open to a charge of over-concentration on technical details.

Firstly, some broad knowledge of frequency allocations is essential. Even the clock frequency of a computer should be considered in relation to the expected environment, rather than fixed at the most convenient round number. For example, a frequency of 500 kHz could be highly unpopular on shipboard, falling as it does on the marine distress frequency. A choice of 530 kHz would hardly embarrass the computer and would transfer the interference problem to a Swiss broadcast station which is unlikely to be receivable on a ship anyway.

Frequency allocations also need to be considered in the reverse direction. At one time, television sets were designed with an intermediate frequency in a radio amateur band. The i.f. rejection of some 10 dB was not adequate to deal with a nearby transmitter. This was curable with an external filter but a better choice of i.f. has subsequently eliminated the problem.

It is also important to consider local frequency allocation wherever the equipment is to be used. An example of what not to do is the no doubt well-designed forward scatter transmitter installed at a US airbase. The frequency chosen was allocated to forward scatter in the USA but it happened to cover the local television channel in the UK.

Obviously no one can be expected to memorize the whole of the world's complex system of allocations, but these examples indicate the need to be broadly familiar with them at least to the extent of knowing when to take a more detailed look.

Secondly, interference specifications do exist and whilst admittedly not perfect do provide standards both of performance and measurement. They also allow an engineer to give some quantitative basis for his good practice. For example, if a power supply driving a linear regulator needs a certain degree of filtering to meet BS 3G100† then clearly no less filtering will be needed for a switching regulator to meet the same performance. Whilst this is not exact information, testing to a fixed specification does give some ranking of interference potential which is not available if each case is dealt with on an *ad hoc* basis. Also, testing to a specification makes some balance between suppression and protection whereas *ad hoc* fixing a system can unload all the burden on either the source or the susceptible unit.

Turning to more theoretical topics, negative feedback is a most useful tool in defining gain and hence reducing distortion. Unfortunately, as well as the reduction in gain the price to be paid includes an over-wide bandwidth. This is not always recognized as a penalty, in fact the wide bandwidth seems to be viewed in some quarters as a criterion of the goodness of an amplifier, possibly because it is related to the loop gain and hence distortion which is rather more difficult to measure. As a criterion for the amplifier this is justifiable, but as a criterion for the final system it is damnable since it makes a virtue out of failure to reject unwanted frequencies. Remembering that in a feedback amplifier the gain can only fall off above the cut-off frequency at a controlled rate, the open-loop amplifier must have gain to a very much higher frequency than the working bandwidth, depending on the degree of feedback. Since pickup is no respecter of feedback loops the result is that this laudably distortionless audio amplifier may respond to any strong radio transmission up to 100 MHz or more and amplify it to a sufficient level to cause detection by amplifier nonlinearities. Obviously the approach should be to build a good amplifier in the first place, improve it with the minimum of feedback and then limit the bandwidth of the resultant system with filters outside the feedback loop.

Filters are obviously one of the fundamental tools of electronics, not just e.m.c. It does seem that before plunging into the details of the Butterworth, Chebychev or elliptic responses and how to synthesize them, a little time should be devoted to the essentials of any filter. In particular it is not clear to all engineers that a passive filter works by modifying the power transfer between source and load, so that if they are not initially power matched, the insertion of a filter can result in a power

† BS 3G100 General requirements for equipment for use in aircraft.

gain. This is probably due to a hang over from the transmission line ancestry of filters causing us to regard equal resistive source and load impedance as somehow fundamental and natural and fostering the other fallacy of measuring voltage loss, squaring it and calling the result power loss.

If the electronics student were taught to synthesize a bandpass filter working not between 1Ω and 1Ω but between 1Ω and 5Ω , he would come straight up against a potential 2.5 dB 'gain' and it is to be hoped, would avoid the above fallacies as well as being mentally conditioned to accept the possibility of insertion gain from a lossless filter when the source or load are unknown. Note that this involves no more than a little additional arithmetic which is not an unreasonable imposition with a pocket calculator.

Turning from filters, coaxial cables seem a safe, almost trivial subject and certainly there are good accounts of the simple theory and the more advanced work of Schelkunoff. Unfortunately, when faced with the problem of running a cable through a metal panel, nine engineers out of ten open the cable out and treat it like a 50 Hz circuit. Sometimes this causes no problems but sooner or later the loop so formed picks up interference and/or pickup on the outside of the braid finds its way inside at this point. Admittedly the latter effect can be reduced with a suitable mode filter but this is simply attacking symptoms rather than getting at the basic cause. The conical metal shroud has apparently disappeared although it formed a simple and inexpensive way of maintaining the sheathing integrity through the panel. (Fig. 1.)

Finally, although all engineers possess at least qualitative knowledge of Fourier analysis, there seems to

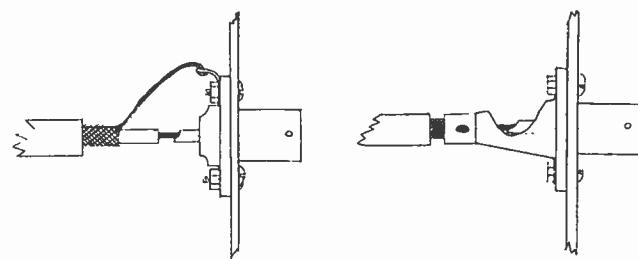


Fig.1. (left) The common way of terminating a coaxial cable has a pickup loop for interference.

(right) With the addition of the metal cone the integrity of the sheathing is maintained.

be some reluctance to apply it to logic waveforms. TTL in particular can generate measurable harmonics to 200 MHz or beyond and is a frequent source of r.f. interference. If the trainee logic designer had to calculate the harmonic structure of various logic families, he would realize that the aesthetic satisfaction of negligible rise and fall-times has to be paid for in other ways, and have a better appreciation of which family to use.

4 Conclusions

With attention to such above points the engineer can be trained to be an adequate general practitioner. The e.m.c. specialist will still be needed but will never have the impossible task of cleaning up a design which is basically unsound.

*Manuscript first received by the Institution on 25th October 1977 and in final form on 26th September 1978
(Paper No. 1866/AMMS 89)*

The Author



After graduating in pure science at the University of Sheffield and further education at Marconi College, Barry Priestley (Member 1974) entered industry, working mainly on circuit design at a variety of power levels from multi-megawatt radar downwards. After seven years with Racal Instruments Ltd. as Senior Project Leader working on frequency synthesis, he joined EMI Electronics Ltd. in 1973, since when he has been concerned with airborne radar. Mr Priestley has held an amateur radio licence for 24 years and in that time has published a number of articles and a book, 'Television Interference Manual'.