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Computer-aided design

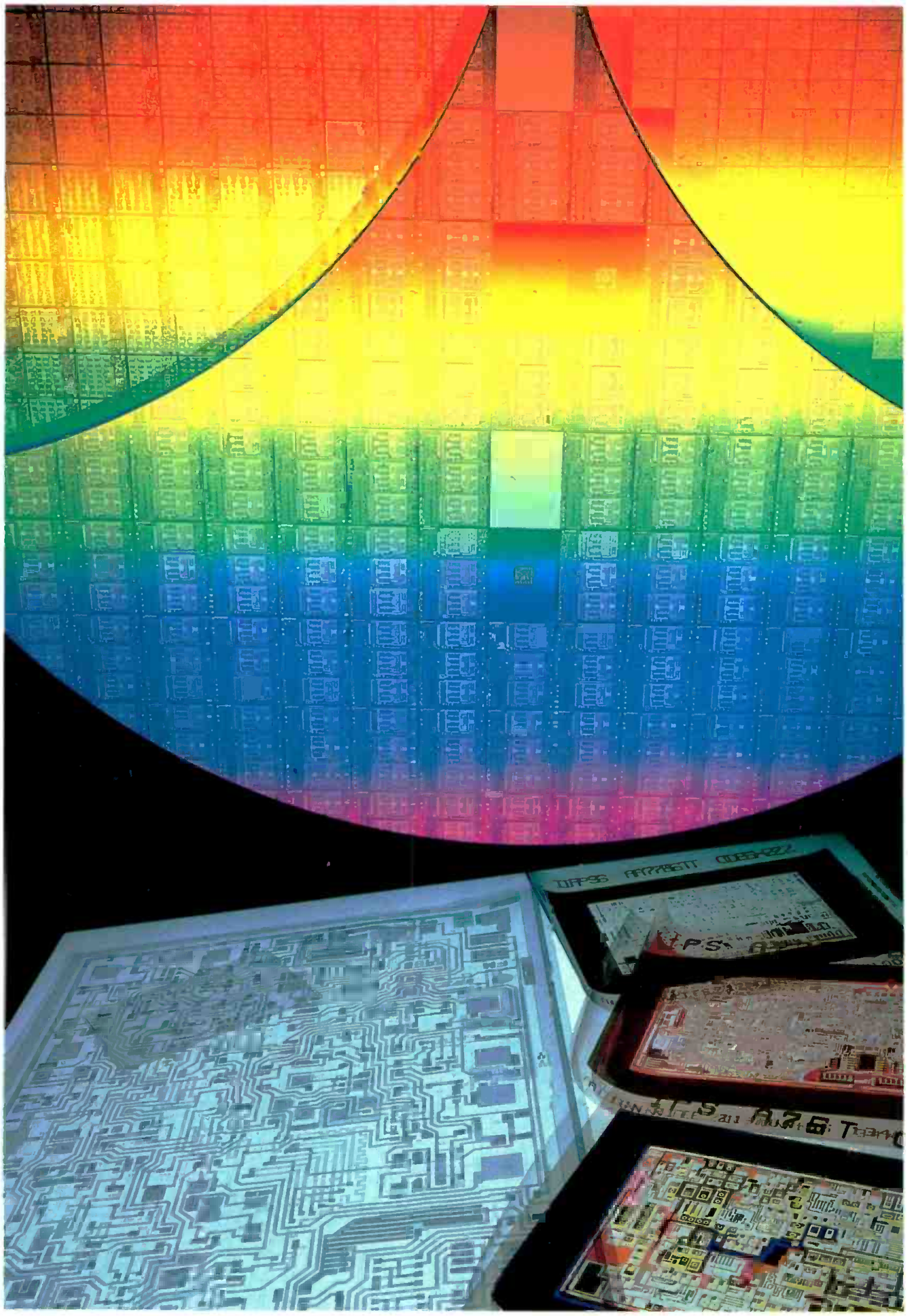
Small-signal modelling

Moving-coil head amplifier design

Waveform timing diagram display

Integrated-circuit pioneer

Dimensional and relational analysis



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COMMENT

Revolution in Europe

The convergence of telecommunications and computing is revolutionizing the industry and socio-economic scene. This so-called "telematics revolution" requires, in Europe in particular, a fundamental change of attitude by telecommunications administrations which are generally organized as monopolies. The European commission has the goal of achieving an integrated European internal market for telecomms by 1992.

Its recently approved Green Paper of Telecommunications sets forth proposals aimed at unifying telecomms across Europe. After an initial policy discussion, the Commission intends to move on to discussions which, it is hoped, will produce more formal proposals by the end of the year.

By the turn of the century, about 60% of jobs in the Community will be affected by telecommunications through information technology. In Europe, the demand for data communications capacity in large companies is growing at between 20% to 40% a year.

Unfortunately, the Community is fragmented, with no single country accounting for more than 6% of the world telecomms market, while the USA has a 35% share and Japan 11%. However, taken as a whole, the Community market share comes mid-way between its two main competitors at 20%. The Community needs competitive market structures: the average per capita purchase (in US$) of telecomms equipment of 32, 46 and 80 in the EEC, Japan and the US respectively during the early 1980s demonstrates that the potential in Europe is far from being fully exploited.

If telecommunications were still based on the telephone, telegraph and telex, national monopolies would still have some relevance. However, the i.t. revolution is breaking new ground. If the challenge is to be taken up, Europe cannot leave the existing national monopolies to organize everything: regulations, supplies, operations and pricing. The legitimate expectations of users could not be satisfied.

The US and Japanese have reacted in their own ways. Europe, with its different social, technological and economic characteristics, must also readjust its telecommunications structure. The Green Paper proposes not a "free-for-all" opening of the market, but a gradual transition towards a competitive market which, first of all, should provide a Continental base from which European manufacturers can fight the i.t. battle on equal terms with their competitors. At the same time, users should be allowed to develop and use the new services at the lowest possible cost. The debate initiated by the Commission will be open, including not only the regulators and providers, but also users and trade unions.

Main actions proposed include the opening up of the telecommunications services market, with the exception of some public services; the gradual but complete opening of the equipment market; the separation of the regulatory and operational functions of those organizations who manage networks; and a recognition that tariffs must follow costs. There must also be co-operation between organized labour and employers.

One Commission recommendation is the creation of a European Standards Institute, with a small core team co-opting experts from industry.

Because the per capita income differs from one part of Europe to another, a high-technology – and therefore capital-intensive – service that might be ideal for industrial countries may appear too expensive to others. The initiative could founder if a pan-European solution cannot be found.

A.J.M.

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De mystifying the black art of analogue design

This article looks at some of the areas that cause problems in analogue circuit design, and urges that education gives more emphasis to training Britain's electronic engineers of the future in coping with them. With the help of low-cost, computer-aided design tools, this will help electronics companies compete successfully for business in many applications areas of increasing importance.

MARTIN GEORGE

An understanding of fundamental analogue design principles is vital to the design of cost-effective and reliable electronic circuits. In the final analysis, such understanding also has a significant effect on competitiveness of products designed, and therefore on profitability.

So much emphasis has been put on digital techniques in recent years, both in industry and in education, that 'analogue' has almost become synonymous with 'obsolete'. Yet even digital circuits are affected by analogue processes. For example, propagation delay is an analogue effect.

UNDERSTANDING BEHAVIOUR

A major obstacle to understanding the behaviour of analogue circuits is that they don't behave in black and white, or 1s and 0s. They are distinctly grey with an infinite variety of shades, and with a highly interdependent set of elements, any changes to which may have extensive ramifications in the final performance specification of the design.

Even relatively simple circuit designs need considerable work with a calculator, or a "design-by-soldering-iron" approach, wasteful of components and still not giving any real insight to prevent the same problems occurring again in the next design. Expensive test and measuring equipment is then needed to check the design performance for gain and phase/frequency response, and input and output impedance at each stage. If designs that use integrated circuit building blocks such as operational amplifiers give rise to complex calculations of performance, those that use discrete components are positively fraught with traps for the unwary.

GREEN-FINGERED ELITE

There exists of course an elite of analogue designers who seem to be able to bypass these problems, producing consistently effective analogue circuit designs in many applications areas. Their 'green-fingered' experience has been hard fought for in the days when there was no alternative to the slog, but sadly that experience is not being replenished.

Help is at hand, though, because the complex matrix maths required to solve analogue circuit design problems can be handled readily by any reasonable personal computer, and there are now some inexpensive programs on the market to assist and to help demonstrate the art of analogue circuit design.

FREQUENCY RESPONSE OF A.C. LINEAR CIRCUITS

In designing linear a.c. analogue circuits, which make up the great majority of analogue applications, frequency response is the primary subject of interest, and in particular four parameters that vary with frequency (and other factors). These four are gain, phase, input impedance and output impedance.

Thus a design can be expressed as a circuit block with an input signal (voltage or current) and an output signal (voltage or current), whose transfer function (how the output signal varies with changes in the input signal) can be described in terms of these four parameters (see Fig.1). Note that the input signal will not be an ideal source, and any impedance associated with it must

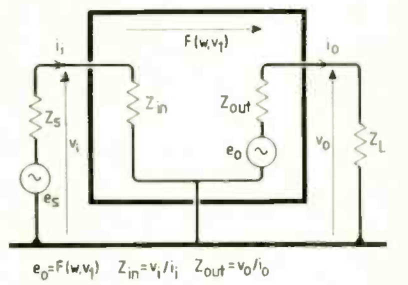


Fig.1. Block representation of circuit-transfer function. Large circuits can be broken down for analysis by chaining several such blocks, perhaps with a simpler transfer function.

COMPUTER-AIDED DESIGN AND THE ELECTRONICS ENGINEER

Computer-aided design was originally used to denote computer-controlled drawing systems and these could equally be used by any draughtsman to replace conventional drawing boards in architecture and mechanical engineering as well as electronics designs. Systems became specialized when they could store in memory regularly-used images of the elements used in specific systems so that an electronics circuit design drawing program would include images (icons) of transistors, capacitors, integrated circuits and the like. A p.c.b. design program would include tracks of different widths and icons of connector pad patterns, such as dual-in-line or 'fingers' for edge connectors.

When 'intelligence' is introduced to such systems it is possible to connect separate programs. So that the system can translate the circuit diagram into a p.c.b. pattern, or check that after such translation the correct components are connected.

Regularly used parts of circuits can be stored in a computer as 'macros' so that when another memory block, for instance, is needed it can be called up in its complete form and added to the circuit, or layout.

The next step is for a program to analyse a design and simulate its function. This can provide a full theoretical test which can indicate the operating speed, bandwidth or frequency response, without building the circuit at all. Integrated-circuit designs also need rule-checking software to make sure that conductors are correctly spaced, and that components do not adversely affect each other by stray capacitance or inductance. Simulation software needs to run a test pattern on the design to verify its function. Such patterns can also be used to generate a test program for the manufactured i.c. Various levels of design are needed for integrated circuits, from complete i.c. designs to metal overlays to connect ready-built cells in logic-array or application-specific i.cs.

With the emergence of 'fifth-generation' computers more of these processes are becoming integrated so that it becomes possible for a computer to design an i.c. in response to a list of required functions. Ultimately there could be the *Hitch-hikers Guide* prediction of a computer that can design another computer better than itself!

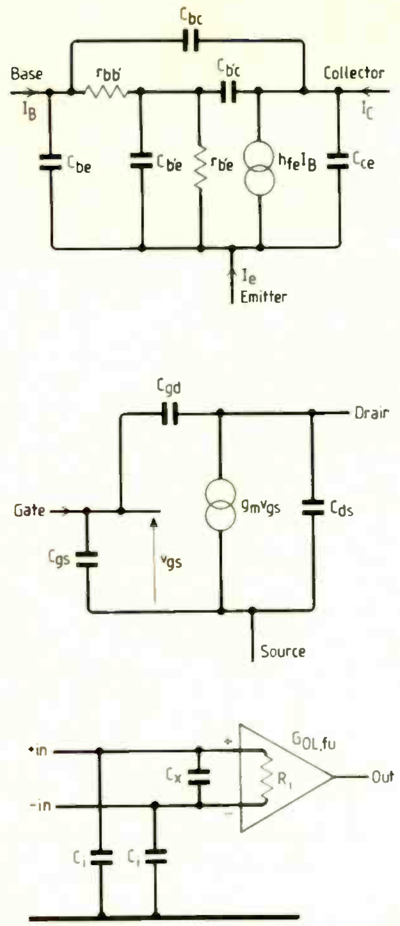


Fig.2. Active component models used within Analyser. Hybrid-pi bipolar-transistor model (a), field-effect-transistor model (b), and operational-amplifier model (c).

Number One Systems Ltd. Linear Circuit Analysis Program. ANALYSER II (C)1986

Analysing FIG3 14th October 1987

Simple transistor amplifier stage with peaked bandpass response around 5MHz

Component list:

C1	Capacitor	0	1	1n			
R1	Resistor	1	3	100K			
R2	Resistor	1	3	10K			
QA1	ZTX239	1	2	3	300	5	300
L1	Inductor	2	3	10u			
C2	Capacitor	2	3	100p			
R3	Resistor	2	3	100K			
P	Ports	0	2	3			

Analysed Results

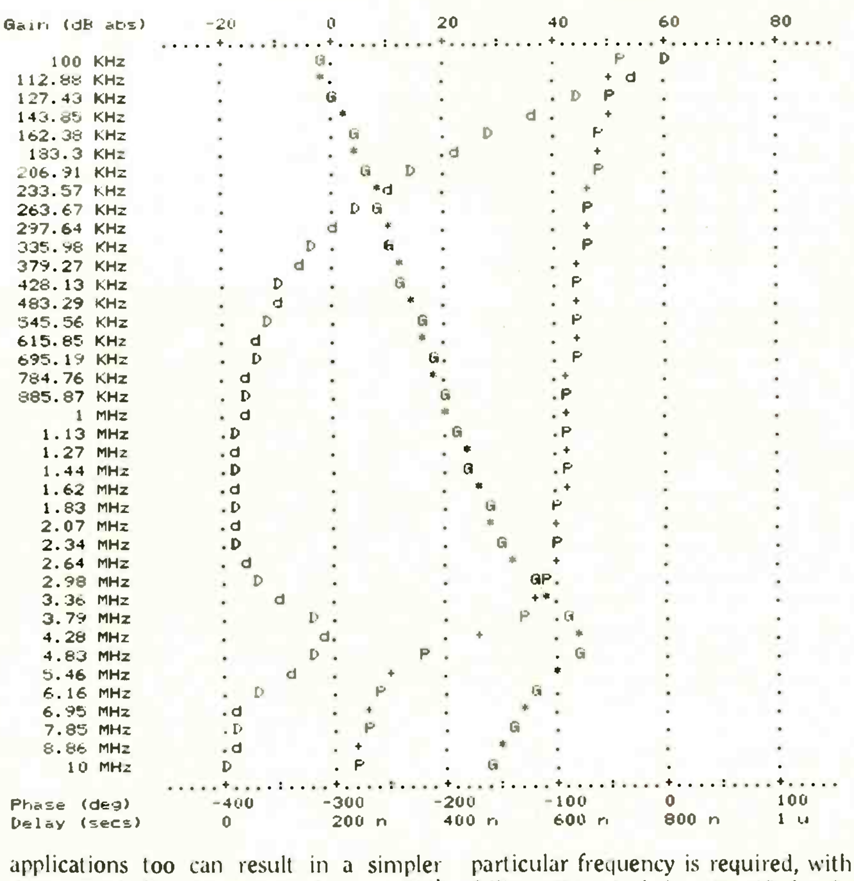
Frequency (Hz)	Gain (dB abs)	Phase (deg)	Delay (secs)
100.00K	-2.59	-43.16	801.26n
127.43K	532.86m	-50.20	627.82n
162.38K	3.41	-57.02	466.84n
206.91K	6.07	-63.30	331.88n
263.67K	8.56	-68.86	228.22n
335.98K	10.93	-73.66	153.93n
428.13K	13.23	-77.76	103.37n
545.56K	15.49	-81.28	70.22n
695.19K	17.75	-84.36	49.09n
885.87K	20.03	-87.17	36.01n
1.13M	22.40	-89.89	28.32n
1.44M	24.92	-92.74	24.51n
1.83M	27.72	-96.07	24.27n
2.34M	31.07	-100.61	30.03n
2.98M	35.62	-108.68	62.52n
3.79M	43.29	-135.14	181.28n
4.83M	43.32	-237.19	165.05n
6.16M	35.54	-264.67	36.63n
7.85M	30.87	-274.20	12.17n
10.00M	27.36	-280.92	7.50n

Number One Systems Limited Linear Circuit Analysis Program ANALYSER II (C)1986

Circuit Name: FIG3 14th October 1987

Simple transistor amplifier stage with peaked bandpass response around 5MHz

GAIN G,* PHASE P,+ Delay D,d ANY TWO #



be taken into account by the circuit analysis. The same applies for any impedance associated with the output load which the circuit drives.

The overall circuit block will almost certainly be too complex to analyse as a whole. Traditional methods of design break it down into several simpler stages, which are manageable. This means that the interaction between the blocks caused by non-ideal input and output impedances of each stage must be minimized, usually by rule-of-thumb methods which ensure that the input impedance of one stage is 'very large' (e.g. a factor of 10 000) compared to the output impedance of the previous stage, at all frequencies. The result is that the overall design cannot really be optimized.

GAIN BLOCK OR DISCRETE COMPONENT DESIGN

So this technique is not ideal, and has encouraged designers to opt for gain (amplifier) blocks, which can be realised as i.cs, in developing circuits. While more predictable, use of i.cs does not necessarily encourage the most cost-effective or even the highest performance design, as evidenced by the intensive use of discretes in Far-East produced radios and hi-fi equipment. Indeed, for many high-frequency applications the use of discrete components may be the only way to design successfully, and in other applications too can result in a simpler design with lower component count and greater inherent reliability.

In any circuit block, the designer will normally set out to achieve a specific transfer function, such as in the case of a filter design, where, say, a peak in gain at a particular frequency is required, with gain falling away to below specified values at either side of the peak. The basic circuit design can be chosen from standard textbook sources if required, leaving the designer to work out component values to meet the required performance.

D.C. CONDITIONS AND COMPONENT VALUES

Once the basic circuit design has been established, the really time-consuming process of analysis and refining can begin.

If a standard textbook design has been chosen, component values can be calculated from formulae given to provide a first approximation of the required performance. In a design from scratch, the designer will have to use his own experience to calculate or estimate values from first principles or rule-of-thumb methods. Any components that affect d.c. conditions must first be set to satisfy these before calculating the values of other components, since all may interact to affect a.c. performance.

BREADBOARDING TO REFINE PERFORMANCE

Now the fun really starts! The next step is to breadboard the circuit, and apply suitable input signals from a test source that simulates as nearly as possible the impedance and signal level of the real-life source. Output signals are measured across a load that again simulates the real one (or using the real load if available).

Readings may also be taken with open circuit output, and with varying loads, to assess impedance. Tedious enough if you have a phasemeter and a decent a.c. millivoltmeter, but with only an oscilloscope...

COMPUTER CIRCUIT-ANALYSIS TO THE RESCUE

Contrast this procedure with that required when using a computer-aided circuit design tool such as Analyser, produced by Number One Systems Ltd., which runs on popular computers such as IBM compatibles, Research Machines Nimbus and BBC.

The first stages of producing the basic circuit design are the same, and any required d.c. conditions in the circuit must be established. It will help, but it is not essential, to know a first approximation of the values of other passive components in the circuit. Active components are entered from a library of types whose specifications ($r_{bb'}$, $C_{b'c}$, $C_{b'e}$, C_{ce}, C_{bc}, C_{be}, $r_{b'e}$ for bipolar transistors; C_{gs}, C_{gd}, C_{ds} and g_m for fets; and R_i, G_{o1}, f_u, C_i and C_x for operational amplifiers) are held within the program, but which can be edited by the user to cope with different types. Bipolar transistors use the well-proven hybrid-pi model, but a simpler model with just $C_{b'e}$ is also available within Analyser (Fig.2).

NO NEED TO SPLIT UP COMPLEX CIRCUITS

Circuits will almost certainly not need to be broken up into smaller blocks, since Analyser can cope with circuits containing upto 60 nodes and 180 components, immediately removing a source of error and allowing the designer to deal with highly complex circuits.

The circuit is labelled up by numbering all the node points where components interconnect, including the input node, the output node and the common node. Components are entered into Analyser by specifying their identification number and type (e.g. R_3, QB_2, etc), the node numbers they connect to, and the component value (see Fig.3). In the case of bipolar transistors, the user specifies d.c. collector current I_c, and the gain h_{fe} and transition frequency f_T, of the transistor at this collector current. This method takes into account variations in performance of the device at differing collector currents.

ANALYSIS WITH TABULATED AND GRAPHIC RESULTS

When all the components are entered, Analyser gives a summary of the circuit so that correct entry of components can be checked. At this point, analysis of the circuit can begin. The user has a choice of voltage gain and phase, or input impedance or output impedance anaylsis over any specified number of linear or logarithmic frequency steps. Results can be calculated in real and imaginary (Cartesian) co-ordinates, or magnitude and angle (polar) forms. Values can be given as direct numeric or decibel (dB), absolute or relative to a specified reference value.

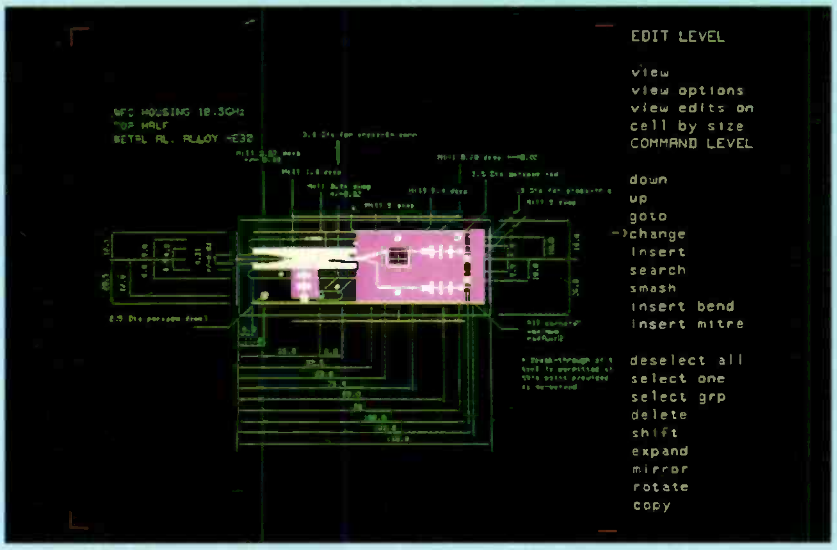
TeMCAD – MICROWAVE CIRCUIT LAYOUT

British Telecom has been exploring new circuit technologies which, unlike the traditional bulky and expensive waveguide, allow components to be built cheaply on circuit boards similar to the pcbs used at low frequencies. The requirements of high accuracy, fast turnround, and easily modifiable designs demanded a cad process.

Such a cad tool for microwave applications would have to deal with little circuit complexity compared to, say, l.s.i. design, but would need to deal with a wide range of the new circuit technologies such as microstrip and finline. It would therefore have to provide for instance microstrip track all of different widths, and curved taper sections for waveguide-to-finline transitions. Library designs would need to be much more complex than simple pick-and-place because component topology varies non-linearly with parameters such as operating frequency and substrate material properties. Software should run on a laboratory PC rather than require an expensive workstation but nevertheless be powerful enough to be tailored to individual company practice.

TeMCAD was written to meet these needs. Most of the flexibility is in the cell library, which can be modified and added to by the user to meet his specific requirements. Because designs stored in the library can include the electrical design equations, the software is capable of handling a wide range of circuit technologies and microwave components. Even coordinate data can be entered in the form of a calculation, bypassing the stage where an engineer keeps a pocket calculator alongside the computer. The editing commands also have, with microwave use in mind, the ability to radius or mitre bends, rotate through arbitrary angles, include taper sections, and incorporate experimental data into component designs.

The system is used by BT in the design of radio systems operating in frequency bands up to 100GHz. Further details can be obtained from BT's Business operations division, Martlesham Research Laboratories, Ipswich.



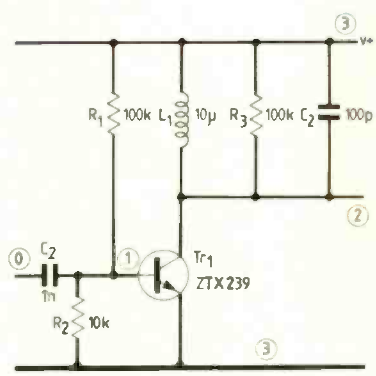


Fig.3. Simple transistor amplifier with tuned output circuit. It has a peaked band-pass response with F_0 around 5MHz (analysis example in the text) Note the numbering of circuit nodes from 0 to 3, and for a.c. purposes, both supply rails are treated as ground. Capacitance and resistance could be added to simulate a more practical circuit.

These calculated forms allow Analyser to preset results in any convenient way, for example to show dB/decade response roll-off.

Calculation of group delay (rate of change of phase with frequency) is also available. This parameter is very awkward to calculate manually, since it requires a second set of calculations at a slightly shifted frequency from the first set. It provides an important measure of the different delays in propagation of different frequencies in, for example, communications signal paths.

Analyser first tabulates the calculated results on screen, and then allows options to print the results, to display them graphically on screen, and to print the graph. This graph shows the gain and phase (or impedance) performance of the circuit at a glance, and shows up, within a few tens of seconds of starting the analysis, if changes to the circuit design need to be made.

CHANGING COMPONENTS WITHOUT SOLDERING

Component changes can be entered by simply editing the necessary component(s) within the component list. Re-evaluation of the circuit is a repeat of the first analysis, and is again completed within a few tens of seconds. This repetitive process to fine-tune a circuit to the required performance, or to show 'what if' effects, can be followed from the engineer's or student's desk without the need to wield a soldering iron or oscilloscope probe in anger at any stage! Moreover, it can be done very quickly.

Not that I am advocating abandoning these worthy tools – the circuit design (if it is to become a real design) will need to be tested at some point. But the use of Analyser will make it possible to test the circuit at a prototype p.c.b. stage rather than through a tedious breadboard development process. Because of Analyser's clear and logical menu-driven operation, the user will quickly achieve this degree of confidence, eliminating the traditional rat's-nest problems of breadboarding. For education, the need for the soldering iron and measuring equipment is greatly reduced, since circuit simulation is all that is required for many teaching purposes. This will save a considerable amount out of tightly-squeezed teaching budgets.

Of course, you may still want to check that Analyser's results do really mean what they say. Number One Systems tell me of a user at one particular University who entered a circuit from a text book to check up on Analyser, only to discover that the textbook gave the wrong circuit analysis formulae!

HELP FOR THE HIGH FREQUENCY DESIGNER

Analyser takes into account the effects of inter-electrode capacitances in bipolar and field-effect transistors, and input to input and ground capacitances in operational amplifiers. A parasitic capacitance of 0.2pF is added across resistors to allow for what is the case in practice. These hidden elements can affect circuit performance in ways that the designer may not realise without the aid of a tool such as Analyser, especially at higher frequencies.

A recent revision allows designers to analyse circuits that contain microwave striplines and transmission lines, to make Analyser an invaluable tool for the r.f. designer, whose job without such aids is a very difficult one.

FUN ON A LOW BUDGET

It is hoped that the use of cad tools such as Analyser will encourage designers to rediscover the joys of designing with discrete components, and enable them to produce more cost-effective and reliable designs, in a shorter space of time. For students, and teachers of electronics, Analyser should help dispel the mystique of a.c. circuit theory by allowing simple and obvious demonstrations of their behaviour, and of the effects of changing each element in the circuit. And that can only be for the good of the British electronics industry!

Further information on Analyser is available from Number One Systems Ltd., St. Ives, Cambs.

Martin George is a freelance consultant, interested in furthering the role of electronics and technical computing in British industry through the co-operation of industry and education.

Toleranced designs by computer circuit analysis

Most circuit analysis programs for personal computers have limited use when dealing with variations of component values. Two inexpensive programs described here can determine literal dependency and evaluated sensitivity of a circuit to produce a 'toleranced' design for a given specification, a vital step in guiding students toward the art of design.

ROGER WHEELER

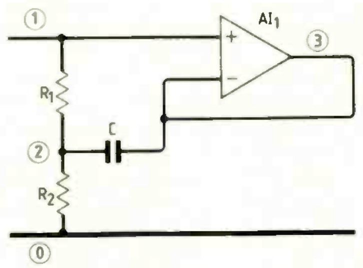
There are several software packages available for personal computers that will analyse linear analogue circuits. These compute the small-signal a.c. numerical response for an active or passive circuit. The output of such programs is usually a listing or a plot, of the desired performance, over a given range of frequencies. The circuit modelling is accurate enough to save hours of tedious measurement on practical circuits. Computer circuit analysis is a powerful tool for those working with and those learning about electronics.

Unfortunately the assistance provided by the computer has, until recently, provided the analysis of the design but not the design itself. Complex software on mainframes is being developed[1], to provide an optimized circuit for a given input data base related to required performance figures. When the PC has been developed to provide 'mainframe capability' this too will be able to produce a circuit design from a given specification.

In the meantime, the circuit designer armed with a PC must be interactive with software that analyses the 'self specified' circuit topology. A very significant step in the development of analysis has been the introduction of a suite of programs, Lana[2]. Lana can perform not only the numerical analysis, but also the literal analysis of circuit performance. Literal analysis provides the gain, phase or impedance, in terms of the circuit literals (component names). The example below indicates the program output for a lossy grounded inductor.

CIRCUIT

```
*        LANA        *
Literal Analysis Program Version 2.3
Grounded Inductor
Component                 Nodes
    R1                    1 2
    R2                    2 0
    C                     2 3
    AI1                   1 3 3
```



1. Literal analysis of this circuit immediately shows those components affecting performance. e.g. $Z_{in} = (R_1 + R_2) + j\omega R_1 R_2 C$.

Input Impedance Function Input Node 1
Numerator
(+R2+R1)s^0
(+R1R2C)s^1
Denominator
(+1)s^0
Hence
$Z_{in} = R_1+R_2+sR_1R_2C$
letting $s = j\omega$
$Z_{in} = R_1+R_2+j\omega R_1R_2C$

This clearly shows the dependence of the synthesized inductance on components R_1, R_2 and C.

Actual component values can be given and the program will complete the corresponding response over the frequency range of interest. Literal, followed by this numerical analysis, leads to very rapid evaluation of circuit performance.

Lana and another numerical analysis program Linac[3], both provide an additional facility of 'circuit sensitivity' which is not usually available in this type of program. Sensitivity[4,5], indicates the relative change in performance for a change in a component value. Thus the required tolerance of a component can be evaluated for a given deviation in desired performance. This feature of 'sensitivity' shifts the emphasis of these programs towards the design, rather than just the analysis of circuits.

Both programs permit all results to be plotted, and additionally allow the 'overlay' of disc stored results. Hence the 'spread' in performance parameters is easily assessed.

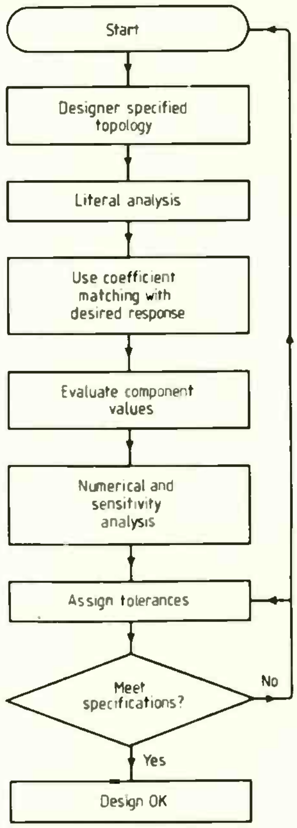
Linac and Lana are used by students at the Colchester Institute for laboratory work in electronics and circuit design units in the BTEC National and Higher National programmes.

Students rightly claim that the interaction of computer analysis and subsequent circuit evaluation is an aid to understanding that is both meaningful and interesting. The benefit for those teaching electronics is that aspects of circuit performance can be quickly assessed and demonstrated, without resort to mathematical justification beyond that required by the syllabus. Additionally students can build up a 'library' of analysed circuits, with which they are familiar, for inclusion in subsequent large scale systems.

As an example of the scope of literal and sensitivity analysis consider the following design example.

SPECIFICATION

Design a second-order bandpass filter with a midband gain of 34dB ±3dB, with a nominal centre frequency of 160Hz. The nominal Q is to be 10. This specification is based on a problem in Ref.6. Design strategy is as follows:



Designer-specified topology is as in Fig 2 below.

Input and resultant output from 'LANA' is shown below.

* LANA *

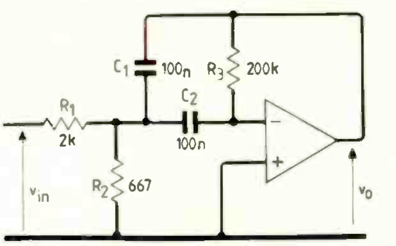
Literal Analysis Program Version 2.3

Copyright 1984
Essex Engineering Software

Bandpass filter.

Component	Nodes
R1	1 2
R2	2 0
R3	3 4
C1	2 4
C2	2 3
A11	0 3 4

Voltage Transfer Function
Input Node 1, Output Node 4
Numerator
()s^0
(+R2R3C2)s^1
Denominator
(−R2−R1)s^0
(−R1R2C1−R1R2C2)s^1
(−R1R2R3C1C2)s^2



2. Literal analysis of an active bandpass filter circuit gives a voltage transfer function which can be adjusted to the required value by altering components and evaluating the result.

Arranging this as a rational polynominal the voltage transfer function is easily obtained as:

$$H_{(S)} = \frac{(R_2R_3C_2)s}{(-R_1R_2R_3C_1C_2)s^2+(-R_1R_2C_1-R_1R_2C_2)s+(-R_2+R_1)}$$

Let $C_1 = C_2 = C$ and simplifying gives

$$H_{(S)} = \frac{\left(-\frac{1}{R_1C}\right)s}{s^2+\left(\frac{2}{R_3C}\right)s+\frac{R_1+R_2}{R_1R_2R_3C^2}}$$

The desired 2nd order response is as shown below

$$H_{(S)} = \frac{\left(\frac{\omega_0}{Q_0}\right)A_0s}{s^2+\left(\frac{\omega_0}{Q_0}\right)s+\omega_0^2}$$

where $Q_0 = \frac{f}{B\omega}$, ω_0=centre frequency, A_0 is the gain at ω_0

Equating coefficients in numerator and denominator
e.g. from denominator coefficient for s:

$$\frac{\omega_0}{Q_0} = \frac{2}{R_3C}$$

Similarly it is simple to show

$$R_1 = \frac{-Q_0}{A_0\omega_0C}; R_2 = \frac{1}{2\omega_0C\left(Q_0+\frac{A_0}{2Q_0}\right)} \text{ and } R_3 = \frac{2Q_0}{\omega_0C}$$

Note A is a negative quantity

Hence by setting $C=0.1\,F=C_1=C_2$
this yields $R_1 = 2000$
$R_2 = 666.7$
$R_3 = 200k$
Alternatively R_1 may be set to equal the driving impedance and C_1, C_2 evaluated.
A1 may be a 741 op-amp.
The designed circuit is as shown below.

SENSITIVITY

Linac and Lana both provide sensitivity analysis. This will indicate the relative change in circuit performance for a change in a given component value.

The output from Linac for the circuit under consideration is shown below:

Comp	N1	N2	Value		
R1	1	2	2000		
R2	2	0	666.67		
C1	2	4	1E−7		
C2	2	3	1E−7		
R3	3	4	2E5		
	+	−	0	GB	R o
A1	0	3	4	1	50

Voltage gain (i/p = 1 o/p = 4)

Frecuency	Gain	Phase	C2 Sens	
(Hz)	(dB)	(deg)	Mod	Ph
145	27.572	−118.58	4.7242	−2.3001
146	28.086	−120.5	4.8949	−2.5878
147	28.617	−122.65	5.063	−2.9229
148	29.164	−125.07	5.2214	−3.3134
149	29.725	−127.8	5.3601	−3.7683
150	30.296	−130.88	5.4643	−4.2963
151	30.873	−134.38	5.5132	−4.9044
152	31.447	−138.35	5.4789	−5.5954
153	32.006	−142.83	5.3257	−6.3634
154	32.536	−147.89	5.0124	−7.188
155	33.017	−153.53	4.4982	−8.0275

For small changes the sensitivity figures may be used to relate the effect of a change Δx/x% in a component, to the resulting relative change ΔA/A% in the amplitude response and the absolute change in degrees in the phase response. i.e. a modulus sensitivity value of 1 means that a 10% change in the component will give a 10% change in the amplitude response. While a phase sensitivity of 1 indicates that a 10% change in the component value will alter the phase response by 0.1 degree.

thus

$$\frac{\Delta A}{A} = S_x^A \cdot \frac{\Delta x}{x} \qquad \Delta\phi = S_x^\phi \cdot \frac{\Delta x}{x}$$

where S_x^A A is the modulus sensitivity and S_x^ϕ is the phase sensitivity. Thus a high sensitivity indicates that the circuit response is very dependent upon the specified component.

The specification of this circuit, requires that the gain does not change by more than 3dB due to variation in any component value. As an example, consider this change was attributable due to the selection tolerence of a single component, C_2.

To find the required percentage tolerance

$$\left(\frac{\Delta x}{x}\right).100$$

we see that

$$\left(\frac{\Delta x}{x}\right).100 = \left(\frac{\Delta A}{A}\right)\frac{100}{S_x^A}$$

The required maximum response deviation of 3dB corresponds to a percentage change of 41.25%

N.B $$\left(\frac{\Delta A}{A}\right).100 = \left(10^{\frac{n}{20}} - 1\right).100$$

where n is the deviation expressed in decibels.

S_x^A=5.5132 at 151Hz

thus the required tolerance is

$(\Delta x/x).100 = 41.25\%/5.5132$

$= 7.5\%$

thus a 5% change in C_2 will not change the gain of this circuit by more than 3dB. This is confirmed in Fig. 4 which shows the nominal response overlayed by the response with C_2 increased by 5%.

In general the tolerence (or other variations) must be considered for all circuit components. The sensitivity plots, overlayed, for this circuit are shown in Fig. 5. This clearly indicates that the circuit response is more sensitive to some components than others. Choosing all components to have a small tolerance may well be adequate, but Fig. 5 suggests that an approach based on assigned tolerances is possible.

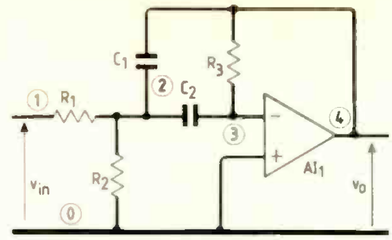
Summating the effect in performance for all component changes:

$$\sum_{i=1}^{n} t_i \frac{S_{x_i}^A}{100} \leq 10^{\frac{n}{20}} - 1 \qquad \ldots A$$

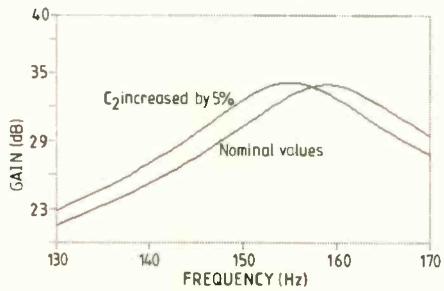
where t_i is the variation (in %) of component x_i and $S_{x_i}^A$ is the sensitivity of component x at a frequency f where the sum of all products of tolerance and sensitivity will yield a positive maximum. Note in this circuit the sensitivities peak at one frequency, in general this may not be the case. n is the maximum allowable deviation in gain, in dB.

Setting the tolerance in components as follows

R1	R2	R3	C1	C2
5%	2%	1%	2%	1%



3. The designed bandpass filter with components evaluated to meet the nominal specification can be subjected to sensitivity analysis to perform the tolerancing of the design.



4. Program printout from Linac showing the effect on performance of a single component (C_2) change.

evaluating the sum of products of tolerance and sensitivity, for this circuit, a maximum is seen to occur at 167Hz.

Substituting values into equation A yields

$0.3783 < 0.4125$

Hence this allocation of tolerances, even under worst case conditions, will not cause the gain to exceed the specification. Fig 6 shows the nominal response overlayed with the response with all values incremented as indicated above. Note that the error in amplitude is very close to the specification indicating that this is a 'sensitive' circuit. The designer would be advised to consider another circuit or the assignment of smaller tolerances, before committing this design to production.

CONCLUSION

It has been shown that using appropriate software it is possible to move towards interactive design, yielding circuits that provide appropriate responses with toleranced design matched to a given specification.

These steps are often accomplished by knowledge acquired by experience. However for engineers and technicians undergoing training such knowledge may not be underpinned by experience. For them, a formalised approach, as outlined above, has been found to be of considerable benefit.

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3. Linac. Essex engineering Software.
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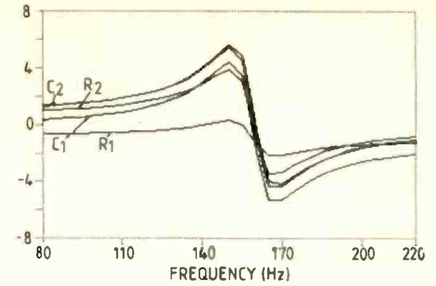
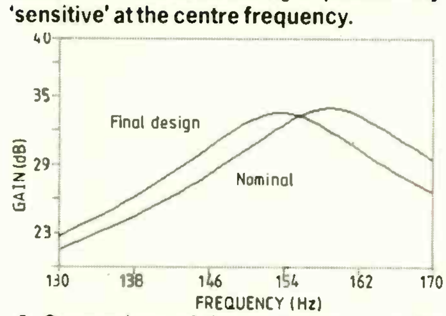


5. Program printout showing the relative component sensitivities. R_3 is particularly 'sensitive' at the centre frequency.



6. Comparison of the performance of the final design with the nominal response. In the final circuit all components are at their maximum excursions of tolerance. Note that the change in gain meets the specification of f_0.

CIRCUIT MODELLER – 5 YEARS ON

An updated version of Circuit Modeller, first described in *E&WW* August 1982, is available for Personal Computers using MS-DOS, and the Atari ST. In addition to the gain, phase, group delay, and bandwidth calculations on circuits, two new features are the 'screen plot' and the 'tune' commands. The screen plot is upright rather than sideways, and is much faster in use. The tune command enables a selected R, L or C to be tuned through a given range and the response displayed on a plot. New built-in models are the hybrid-pi for the transistor and the fet model, which take their parameters from libraries on disk. New hardware supported is a mouse for pop-up menus and for manipulating the cross-hairs on the plot. Also the 8087 is supported giving a 300% improvement in calculation time. Up to 80 node circuits are accommodated with up to 260 components. A library of transistors is supplied on disk with 50 different devices. Libraries of fets and op-amps are also supplied. Circuit Modeller is available from Harcourt Systems, Worthing, W. Sussex.

Noise in electronic systems

A perspective view of the subject of electrical noise and its origi~s

Professor D.A.BELL, F.Inst.P., F.I.E.E.

Noise, which in electronics and communication is the traditional name for random fluctuations or disturbances, is of fundamental importance because it sets an absolute limit to the performance of systems of communication, including measuring devices and transducers. In papers published in 1948, Shannon[1] established the foundations of modern communication theory and stated the fundamental limitations as follows:

"If the channel is noisy it is not in general possible to reconstruct the original message or the transmitted signal with *certainty* by any operation on the received signal E."

Note that he emphasized with *certainty*: an enormous amount of work has been expended on error-correcting codes which allow the reconstruction of the original message to a high degree of probability (low probability of error) but signal-to-noise ratio remains a fundamental parameter of all systems. The two forms of noise which are fundamental and simply defined are *thermal* and *shot* noise, though the development of solid-state devices has brought forward *avalanche* noise, the peculiarities of noise in Gunn effect devices and the still unexplained 1/f noise.

THERMAL NOISE

Since all electrical conduction depends on the movement of charged particles (displacement current is not a source of noise and for radiation resistance see *Wireless World*, August 1981) a basic formula is

$$\delta J = ne\delta u + eu\delta n \qquad (1)$$

where J is current *density*, n is the number of charged particles per unit volume, e is the charge of each particle and u the mean velocity of the n particles. The term due to variation in velocity is called thermal noise and this is closely associated with equipartition, the theory of which has been developed since the first half of the nineteenth century.

Given the general idea that all molecules of a gas have the same average kinetic energy, it is natural to ask what happens in a mixture of two gases of very different molecular weight, for example hydrogen and xenon of molecular weights 2 and 131, and J.J.Waterston deduced that equality of average kinetic energy would still apply between gas molecules of different weights. Waterston's paper was read before the Royal Society in 1845, but it contained some errors in the treatment of compound molecules like H_2O and it was not then printed, though at the instigation of Lord Rayleigh it was printed at the beginning of the *Philosophical Transactions of the Royal Society* in 1892. Waterston's collected papers were edited by J.B.S.Haldane[2] and published in 1928.

A step towards the idea of equipartition between the molecules of a fluid and immersed particles larger than a molecule had come with the observation of Brownian motion in 1828. Microscopic pollen grains suspended in water were found to be in constant motion and the question was whether this was due to the pollen being alive or to the thermal agitation of the water molecules. The latter planation was eventually accepted and as finally shown by Einstein in a series pers between 1905 and 1908 that any p icle immersed in a fluid must have the equipartition value of kinetic energy corresponding to the temperature of the fluid. This was taken up by the German physicist I ppler[3] in 1931, using a minute mirror sus ded on a quartz fibre as the particle and urrounding air as the fluid in which th agitation occurred. From photograph ords of the oscillation of the mirror, pler deduced a value of $1{\cdot}37.10^{-23}$ Joules degree centigrade for the Boltzmann con ant k of equipartition energy, whereas the present accepted value is $1{\cdot}38.10^{-23}$.

Two further general ideas w e illustrated by Kappler's experiment. Th first is the fluctuation-dissipation theorem that any source of dissipation must also be a source of fluctuation and vice versa, which is familiar in electrical systems in the form that noise is a function of resistance regardless of any reactances; the theorem was formally developed by Callen and Welton[4] in 1951.

In Kappler's experiments, the air provided damping of any movement of the mirror, yet bombardment of the mirror by air molecules caused the movement. From the latter it would be natural to suggest that fluctuation could be reduced by removing the air and Kappler repeated the experiment after reducing the air pressure nearly a million times: the effect was to change the frequency spectrum of the mirror's oscillation without changing the mean square amplitude which takes in all frequencies from zero to infinity. This serves as a remin~~er that in electrical systems it is important to distinguish between total noise at all frequencies and the more familiar idea of noise in a limited band of frequencies, e.g. in a communication channel. The fact that mean square amplitude was independent of air pressure illustrates the fact that the sharing of energy, equipartition, is a thermodynamic property of linear systems which is independent of mechanism but depends on the number of degrees of freedom of the system.

The theory of equipartition can be developed in the following steps:

1. assume the frequency theory of probability.
2. conservation of number of particles and of total energy then leads to a distribution of energy U of the form $e^{-U/kT}$.
3. if U is a quadratic function of the relevant co-ordinate, e.g. kinetic energy proportional to square of velocity, then it follows that the average energy is $\bar{U} = \frac{1}{2}kT$.

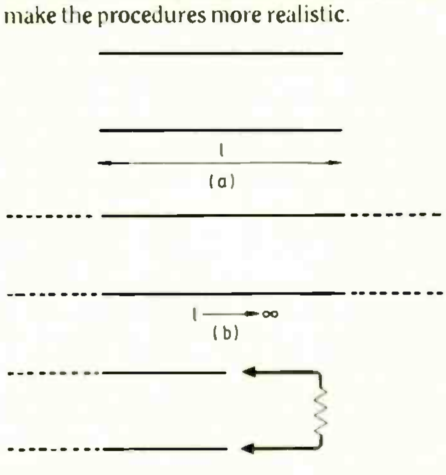
The first point is an axiomatic assumption, as is the conservation of number and of energy in the second point, and from there the development follows mathematically for a linear system. Since the noise energy now depends on degrees of freedom and not on mechanism it is possible to predict the noise in a macroscopic system such as an electrical circuit including both resistance and reactances.

However, 'degree of freedom' is a difficult concept: as a working definition it may be taken as the number of co-ordinates which must be specified in order to define the state of the system as viewed from the terminals which can be used for exchange of energy with other systems (including the observer). For example, it was initially feared that a transatlantic cable would show noise corresponding to all its internal degrees of freedom, but in fact it is only accessible through two terminals at an end and therefore shows only noise corresponding to a two-terminal circuit. (A mechanistic interpretation is that noise does arise in the middle but has been attenuated before it reaches an end.) A parallel RC circuit has one degree of freedom corresponding to the voltage across its terminals; but with an oscilla ory RLC circuit one needs to measure cur ent and voltage simultaneously, just as one would measure both position and velocity of a pendulum, because the value of either varies with the phase of the oscillation and this indicates two degrees of freedom.

Johnson[5] in 1928 confirmed experimentally the dependence of electrical noise on temperature, by heating a mainly resistive circuit; but he observed the variation with temperature of the noise through an audio-frequency amplifier of limited bandwidth, not the total noise at all frequencies from zero to infinity, so that it was not directly comparable with, say, Kappler's work and equipartition. In communications and most other applications of electronics we are accustomed to a specified bandwidth; and Nyquist[7] in 1928 deduced that the mean square noise voltage generated in a resistor was uniformly distributed over all frequencies.

But, before examining Nyquist's work, it is worth looking back to the similar problem of the distribution of radiant energy over the spectrum of black-body radiation, a problem which required the intervention of quantum theory. Lord Rayleigh[6] in 1900 proposed that if black-body radiation were contained in an enclosure with perfectly reflecting walls it must, in equilibrium, consists of a set of all standing waves which could be set up between the walls and that each standing-wave mode could be regarded as a degree of freedom having the equipartition value of energy; but this predicted that, as the density of modes increased with shortening wavelength, the density of energy would increase without limit, a predicted phenomenon which came to be known as the ultra-violet catastrophe. Planck therefore suggested that the atomic oscillators constituting the reflecting walls could not exchange radiation in arbitrary amounts, but only in quanta, the energy of which increased with frequency; and in consequence fewer modes were allowed as the wavelength decreased, the ultra-violet catastrophe was avoided and the predicted spectrum of black body radiation now agreed with experiment.

Returning to the electrical case, Nyquist proposed a model in one dimension (rather than Rayleigh's three dimensions) consisting of a lossless transmission line carrying standing waves. The diagram follows Nyquist's general method but incorporates some more recent modifications in detail, to make the procedures more realistic.



Modification of Nyquist's method of deriving the formula for thermal noise in a resistor.

First, consider a lossless transmission line of length l with both ends open-circuited as at (a) in the diagram. This will support standing-wave modes corresponding to integral numbers of half waves between the ends and hence $2l/\delta\lambda$ modes in a wavelength interval $\delta\lambda$; and wavelengths are converted to frequencies according to the formula $1/\lambda = f/c$ where c is the velocity of electromagnetic waves. Remembering that the open-circuit line behaves like an LC resonator with two degrees of freedom, so that it has equipartition energy of twice ½kT per mode, the energy in a limited frequency band δf in this line of length l is $2l\delta fkT/c$. Now divide by l so as to give energy per unit length of line and then let line length tend to infinity, as represented at (b) in the diagram.

Two further points must be taken into account: firstly the power flowing along a line is energy density times velocity and secondly, each standing wave is the resultant of two travelling waves, one in each direction along the line. Since an *infinite* line is equivalent to a resistance equal to the characteristic impedance of the line, let the infinite line be cut in the neighbourhood of the observer and one half discarded while the other half (still infinite, since infinity divided by two is still infinite) is terminated here by a matching resistor, as shown at (c) in the diagram. In thermal equilibrium the power flowing out of the line into the resistor must be equalled by the power flowing from the resistor into the line. In matched conditions the latter will be $V^2/4R$, while the power flowing in one direction along the line is δfkT and equating these two gives the familiar Nyquist formula for squared noise voltage generated by a resistor,

$$V^2_{\delta f} = 4RkT\delta f.$$

The corresponding formula for noise current and conductance is

$$I^2_{\delta f} = 4GkT\delta f.$$

Objections to Nyquist's derivation have included: how do we know that there is thermal noise in an electrical circuit – answered by Johnson's experiment of heating a circuit – and can one visualize a truly loss-free and infinite line? With the development of superconductors one can have a resistance-free line, but even if there is no dielectric loss there will be a minute radiation resistance; and in fact some coupling with the surroundings, however small, is necessary to establish equipartition and is inherent in the assumption that the line can be observed.

The difficulty of infinite length is minimized by taking the energy *per unit length* (which Nyquist did not do) and the asymptotic approach to infinite length is to increase the length until the line appears to be perfectly matched by a resistor. The Nyquist model therefore appears to be reasonable. Why did Nyquist not need to invoke quantum theory, as was necessary with black body radiation? In Nyquist's time the highest frequency used in electronic systems was such that hf was very small compared with kT, where h is Planck's constant and f the frequency. Under these conditions the Nyquist formula may be replaced by

$$P = kTB \qquad (2)$$

where P is the 'available power', i.e. the maximum power as delivered to a matched load, which for a source resistance R is $V^2/4R$, and B for bandwidth replaces δf.

With the development of microwave frequencies and cryogenic devices, raising f and reducing T, it was thought necessary to add a quantum correction and a second formula was introduced:

$$P = \left\{\frac{hf}{\exp(hf/kT) - 1} + \tfrac{1}{2}hf\right\}B \qquad (3)$$

This included a half quantum, ½hf, which could not be exchanged with any real system and therefore was usually called "vacuum fluctuation". But it was shown by Bogoliubov and Shirkov[8] as early as 1951 that the average power is correctly given by the following formula:

$$P = [hf\coth(hf/kT)]B \qquad (4)$$

Series expansion of the exponential in (3) and of the hyperbolic cotangent in (4) shows that they are equivalent as far as the second power of hf/kT and to this degree of approximation they both modify (2) by a multiplier of $1 + (hf/kT)^2/12$. Only where temperature is very low and frequency is in gigahertz could one expect to detect any difference between (3) and (4).

The Nyquist formula can be applied to the real or resistive part of any impedance and, to complete the circle from breaking down the noise into a contribution per unit bandwidth to finding the equipartition value of total noise (thermal) energy in an electric circuit, one can integrate from zero to infinity and find that the total voltage fluctuation has the value one would expect for the equipartition value of energy in the residual shunt capacitance which will be dominant at infinite frequency, $\tfrac{1}{2}CV^2 = \tfrac{1}{2}kT$:

$$V^2_{tot} = 4kT\int_0^\infty Re(Z)df = kT/C \qquad (5)$$

One can either use ordinary integration of the resistive part of a simple circuit such as R and C in parallel, or use contour integration of an arbitrary impedance, subject only to the condition that it reduces to a capacitance at infinite frequency. The latter method closely parallels some of the circuit integrals used by Bode[9]. One can alternatively work in terms of current fluctuation and admittance to arrive at a total mean square fluctuation of current defined by $\tfrac{1}{2}LI^2 = \tfrac{1}{2}kT$, where L is the residual series inductance at infinite frequency.

SHOT NOISE

The second fundamental kind of noise, the second term in equation (1), is shot noise, which is found when electrons pass through a device randomly and independently. The prototype of shot noise was found in thermionic diodes in the absence of space charge, with electrons emitted from the cathode randomly and independently and passed practically instantaneously to the anode. Thermionic devices known as 'noise diodes' were at one time used as noise standards, but special precautions were needed to ensure the absence of space charge and of residual gas; and they could not be used at very low frequencies because of variations in cathode emission (flicker effect) or at very high frequencies at which the transit time of the electrons was significant. Shot noise was also found in vacuum photocells of the type in which electrons were released from the cathode by the impact of photons and collected by the anode.

It was in connection with these devices that Rowland[10] developed two theorems which can be used for shot noise and which are significant because they refer to the response of the apparatus to a pulse, not to the hypothetical current derived by spectral analysis of the pulses, a current which is then modified by the frequency response of the apparatus. If y is the output indication of measuring apparatus responding to events occurring randomly at a rate α per second and s(t) is the response of the apparatus to one such event, then the average output $\bar{y}$, which we might identify as the d.c. component, is α times the response to one event:

$$\bar{y} = \alpha \int_0^\infty s(t)\,dt \qquad (6)$$

The mean square deviation, which we might identify with the noise as observed through an a.c. amplifier eliminating the d.c., is α times the infinite integral of the square of the response to an individual event:

$$\overline{(y-\bar{y})^2} = \overline{y^2} - (\bar{y})^2 = \alpha \int_0^\infty [s(t)]^2 dt \qquad (7)$$

Now if the apparatus consists of a source of shot noise feeding current through a resistor shunted by a capacitor, s(t) for the sudden arrival of one electron is an instantaneous rise of voltage followed by an exponential decay of capacitor charge and voltage. But it might be asked how a single, indivisible, charge of one electron could decay exponentially.

The answer is that there will already be many electrons present so that the arrival of one more will only cause a perturbation of the distribution of electrons in the circuit, a perturbation which will decay exponentially. The assumption of an exponential decay leads to agreement with another method of analysis and with experiment. Rowland's theorems present the noise as a time function, as did Kappler's mirror deflections records, so that the mean square value which they predict is, in our terms, the total noise, covering all frequencies.

An alternative method of calculating shot noise is to take the Fourier integral of a single electron transit, so as to obtain a spectrum, and assume that pulses occurring at random in time can be represented by spectral components in random phase which must be combined by summing squares of amplitudes. The result is that the mean square noise current per unit of bandwidth is

$$I^2 = 2Nq^2 \qquad (8a)$$

where N is the number of particles per unit time and q is the charge per particle. But charge × rate of arrival is equal to current, so on replacing q by e, if the particles are electrons, the shot noise current in bandwidth df is

$$I_{df}^2 = 2ie\,df \qquad (8b)$$

The spectrum of the observed noise *voltage* will depend on the frequency characteristic of the circuit through which this current is passed.

THERMAL NOISE IN VALVES AND SOLID-STATE DEVICES

One of the first problems was to understand why the shot noise which was found in a thermionic device which was free from space charge was greatly reduced if space charge was present. This effect was known as space charge smoothing of shot noise and was important because all amplifying devices, such as valves with three or more electrodes, worked in a space-charge regime. (The mean-square smoothing factor was usually denoted by Γ^2.) In 1938 the writer made the crude suggestion that the electron stream leaving the potential minimum (where most of the space charge was concentrated) could have a temperature, by analogy with the definable temperature of a flowing gas, and in a stream originating from thermionic emission and passing through a space-charge barrier, a figure of half the cathode temperature was suggested[11]. This was an over-simplification and a different approach by North[12] led to a factor of 0·644 times cathode temperature instead of a half. This is an asymptotic value which applies when the space charge is concentrated near the cathode; but in the transition between zero anode voltage and the asymptotic condition all the experimental results available in 1942 showed[13] that Γ^2 was a function of the ratio eV/kT of energy supplied by the anode voltage to thermal energy from the cathode. This is past history but it shows that thermal noise occurs in electron streams as well as in conductors.

In solid state devices shot noise is sometimes evident: it may be called 'injection noise' because one speaks of injection of electrons into a semiconductor instead of thermionic emission of electrons into a vacuum. But in general thermal noise predominates because the conduction electrons or holes collide with lattice atoms frequently enough to have a temperature related to the measurable temperature of the solid and may be said to be thermalized. So thermal noise can be minimized only by cooling the solid-state device to a low temperature, a method which would obviously be impossible with a device using thermionic emission, but which is particularly useful in earth stations for use with artificial satellites, because the background which the aerial 'sees' is outer space at a very low temperature. The limit on cooling of devices such as diodes, masers and parametric amplifiers is the cost of refrigeration; but there is also the SQUID which uses Josephson junctions between superconductors. Its name is an acronym for Superconducting Quantum Interference Device.

NOISE IN SOLID-STATE DIODES AND TRIODES

The simplest solid-state device is the junction diode, but the complication is that it is a diffusion device in which electrons move in one direction and holes in the reverse direction and there is some recombination on the way, so that there is recombination noise as well as thermal noise. For forward bias it was shown by Van der Ziel[14] that the noise appears to depend on the sum of the actual diode current i_D and twice the saturation reverse current i_s:

$$I_{df}^2 = 2kTG\,df(i_D + 2i_s)/(i_D + i_s) \qquad (9)$$

In the limit when i_D is much greater than i_s the factor 2 instead of 4 in equation (9) may be taken as corresponding with the fact that the diode conducts for only half the time; and when i_D tends to zero, i.e. the diode has neither bias nor signal input, equation (9) can be reduced to the Nyquist form:

$$I_{df}^2 = 4kT(di/dV)df \qquad (10)$$

where G has been replaced by di/dV, the conductance of the diode.

The diode is a special case of a non-linear conductor, but general formulae for thermal noise in a conductor on any degree of non-linearity, *provided it is in thermal equilibrium with its surroundings* were given by Gupta in a review paper[15], though if there is input of energy from any other source, e.g. electrical, arguments based on thermal equilibrium cease to be valid. A space-charge-limited solid-state device has a square-law relation between current and voltage, instead of the 3/2 law of a vacuum device, and for square-law devices, the thermal noise per unit bandwidth is doubled to 8kT times the differential resistance.

General non-linear devices may be treated by the salami method, in which the device is imagined to be cut into a stack of thin slices, each of which is treated as approximately linear and having a noise contribution which is therefore calculable by the Nyquist formula. The overall noise was originally found by summing squares of individual voltage contributions, but some modification is needed to take account of correlation between slices, as proposed by Thornber[16] and implemented by Van Vliet *et al.*[17]. A theoretical difficulty with the salami method is that one is inclined to say "Let the slice thickness tend to zero and the summation of contributions be replaced by an integral." This cannot be correct in the limit because both the mean free path of electrons and the structure of the crystal introduce discontinuities when viewed on a small enough scale. A stratagem which seems legitimate is to interpolate a continuous curve through the discontinuities and integrate along the curve.

In 1960 the writer showed[18] that the transit of a single electron in vacuo between parallel plates produced a current in the external circuit while the electron was in transit, not merely when it arrived at the second plate. The idea of studying the effect on the external circuit of an electron moving within a device was generalized for solid-state devices in 1966 by Shockley, Copeland and James[19] under the name of "field impedance method" with the important difference of dropping the assumption of continuity of electric current between the terminals. Because it relates current in the external circuit to movement of an electron at any point and in any direction in the device, the method is particularly suitable for calculating noise in Gunn effect devices, which depend on a domain of accelerated electrons moving between the terminals.

since some of the noise current circulates within the domain but yet has an effect at the overall terminals. Since the method employs field integrals it meets the same difficulty as the salami method, namely integration through a fundamentally discontinuous structure, and this is overcome by substituting an approximating continuous function as integrand.

HOT ELECTRONS AND AVALANCHE AMPLIFICATION

A feature of solid-state conduction in semiconductors is that with small electric fields the result of frequent scattering by atoms of the solid is that the electrons, or holes, acquire a random component of velocity which can be regarded as representing a temperature equal to the temperature of the solid in which conduction is occurring. But if a sufficiently large electric field is applied, the random energy of the scattered electrons will exceed the thermal energy of the atoms of the solid; and the electrons are then said to be 'hot', since they have a higher equivalent temperature than their surroundings. The effect of a sufficiently increased electric field is to cause liberation by impact of additional electrons from the atoms with which the primary electrons collide, leading to what is known as avalanche multiplication of the original current. (There are detailed factors which can make this process stable, in contrast to the destructive arc which may occur between metal electrodes in air.) A similar effect occurs in the vacuum types of photomultiplier which use secondary emission from intermediate anodes or from the wall of a narrow tube.

Now shot noise is proportional to the square of the charge carried per particle, so that if electrons arrive in groups of M, looking like single particles carrying M times the electron charge, the noise will be proportional to M^2. But the noise is further increased by the fact that M is only an average value, not a constant; and after taking account of the random variation in M the upper limit of increase in noise power is M^3 for large values of avalanche multiplication. The signal current is multiplied by M and signal power by M^2, so the signal-to-noise power ratio is deteriorated by a factor not greater than M, the ratio by which current is amplified by avalanche.

SPECIAL TYPES OF FET

At the present time, special interest attaches to transistors for use at frequencies of a few tens of GHz up to 100 GHz. One may hope for ballistic transport, which means that electrons shoot through the device without collision and scattering, thus eliminating thermal noise at the temperature of the semiconductor but leaving shot (or injection) noise. One can raise mobility, presumably raising the mean free path, (at the present time it is not practicable to make a fet with gate length much less than a quarter of a micrometre) by transfer of electrons between gallium-aluminium-arsenide and gallium arsenide to make a high-electron-mobility transistor. This is referred to by the initials h.e.m.t. and is identical in structure with a modfet, which is a field-effect transistor in which the doping is modulated, i.e. varied from one part to another. It has been stated by Duh *et al.*[20] that this type of fet is suitable for millimetre waves and has shown the lowest noise figure yet recorded up to 62 GHz, where it is 2·7 decibels.

1/f NOISE

The foregoing allows one to calculate the noise (thermal and shot) at frequencies above the lower limit at which the phenomenon of 1/f noise predominates. This is usually below 1 kHz and may be as low as tens of Hertz, though in point contacts 1/f noise has been found in the MHz range; and it arises only when a steady current flows, the 1/f noise power being proportional to the square of the steady current.

The feature which makes 1/f noise so difficult theoretically is the absence of any detectable lower limit to the inverse frequency law. In one of the earlier experiments Rollin and Templeton[21] recorded noise from resistors consisting of pyrolytic carbon films on magnetic tape running 800 to 80,000 times more slowly than normal and performed a frequency analysis of the output from the tape when running at normal speed. After applying a correction for the frequency characteristic of the tape recorder they found a close fit to a 1/f law from 5.10^{-4} to 8 Hz. The line to which the points fitted closely was represented by the formula $\delta R^2/R^2 = 10^{-13}df/f$ which expresses the noise as the square of a fluctuation in resistance. This is a natural form to adopt since the squared noise voltage is proportional to the square of voltage due to the steady current, $V^2 = i^2R^2$. This idea of fluctuation of resistance as the source of 1/f noise has been widely used but it has been challenged and must not be taken as evidence of the source of 1/f noise. Later work on silicon by Caloyannides[22] has extended the spectrum down to 10^{-6} Hertz and by piecing together the results of various experiments one can demonstrate a 1/f law over at least ten decades, which is ten thousand million to one in frequency.

It has been suggested that the law might not be 1/f but one upon the square root of $a^2 + f^2$, which would give 1/f for large f, but a flat spectrum for very low frequencies where f^2 is much smaller than a^2. But although this is mathematically more reasonable, there has never been any experimental evidence of a lower limit to a 1/f spectrum.

The problem is complicated by the occurrence of a 1/f law in a wide variety of non-electrical phenomena where it might be described qualitatively as a general rule that "the bigger the fewer". In electronics the first doubt was whether the extrapolation of 1/f to zero frequency posed a problem of infinite power similar to the ultra-violet catastrophe predicted by the application of classical equipartition theory to black body radiation, but it was pointed out by Flinn[23] that the effect was so small that the 1/f noise power in a resistor, over any conceivable frequency range and taking the age of the universe as the period of the lowest frequency, would be only a small fraction of the power input from the steady current which excited the noise.

Early theories that 1/f noise was associated with contacts through which the exciting current was fed to the device have been ruled out by the use of four-terminal experimental bodies, so that the contacts through which current is injected are not included in the circuit in which noise is measured. One of the conventional ideas, proposed by Van de Ziel[24] in 1950, was that the 1/f law was approximated by a collection of phenomena having spectra of the form $1/(a^2 - f^2)$, but with the values of a^2 and the weighting of individual components so spread that the combination of the flat parts of the spectra for small f and $1/f^2$ for large f would produce 1/f in an intermediate range of frequencies.

The objections to this are firstly that the predicted flat spectrum at small enough f has never been found experimentally and secondly that the range of values of a^2 must be *twice* the range of frequencies over which 1/f is to apply. It is difficult to envisage a mechanism which would both have a correctly weighted range of time-constants of twenty decades (taking the experimentally observed range of the 1/f law as ten decades) and be found in all the substances and systems in which the 1/f law has been found.

In 1969 Hooge[25] showed that most of the experimental results in silicon were consistent with the 1/f noise being inversely proportional to the number of electrons involved in the conduction, according to the formula

$$\frac{\delta \overline{V^2}}{V^2} = \frac{\alpha}{N} \cdot \frac{df}{f} \qquad (11)$$

and he suggested that δ was a universal constant having the approximate value 2.10^{-3}. Later results from other materials were not consistent with δ having a universal value, so formula (11) was modified by Hooge *et al.*[26] who proposed in 1979 that only scattering by the crystal lattice, not as surface or other irregularities, was relevant, thus arriving at equation (12):

$$\alpha = (\mu/\mu_{latt})^2\alpha_0 \qquad (12)$$

The total scattering was apportioned between the lattice and other scattering mechanisms by representing scattering as inversely proportional to mobility, the total value of which can be measured. The correction factor in (12) is necessarily less than unity, so it would account for values of α less than that found originally in silicon. Kleinpenning[27] has related 1/f noise to fluctuations in mobility. This would not be inconsistent with the relation to lattice scattering when this is expressed through its effect on mobility, nor with the overall expression as a resistance fluctuation. However, the mechanism which produces the 1/f shape of spectrum has still to be explained, especially as 1/f noise is found in so many different materials and phenomena.

Throughout the history of 1/f noise, now over 50 years, there has been controversy as to whether it arises in the bulk of the conductor or only at surfaces: unfortunately the answer seems to be both, so one might be forced to assume that there is more than one mechanism. The only rules for minimizing 1/f noise in practice are first, to use as large a body as possible so as to maximize the number of electrons participating in conduction; second, to avoid concentration of steady current in narrow paths because the noise is proportional to the square of current *density;* third, to minimize defects such as surface leakage, impurities or other defects in crystal structure; or fourth, to avoid 1/f noise entirely by using a modulation scheme to eliminate low frequencies. Other design considerations, such as miniaturization, may be opposed to some of these rules, but as long as 1/−f noise remains a mystery, the only conclusive rule is to avoid the use of very low frequencies as far as possible.

The substance of this article is available as a two-part lecture on video tape. Copies may be obtained from the Audio-Visual Centre, University of Hull, Hull HU6 7RX.

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R.E. YOUNG

With the death of Eric Young, telemetry engineering has lost one of its principal champions and contributors. Born 76 years ago, he had spent the last quarter of a century as a consultant dealing with a wide range of problems to be encountered in telemetry, automation and systems engineering. Prior to setting up his consultancy, Eric Young had spent ten years as the Chief Electronics Engineer of the Hawker Siddeley Group and Electronics Manager of Armstrong Whitworth Aircraft. Here, his team was responsible for the development of a wide range of telemetry systems and components ranging from the telemetry of the Bluebird racing car to airborne systems for aircraft and missiles. Prior to that, he had held previous appointments with the BBC Engineering Division and with the RAF Radar Group Headquarters.

He had a long and, in many ways, unique experience and discovered many novel ways of overcoming difficult problems in transducers, transmission of television over low-bandwidth cables and of the combined software-hardware approach to the remote monitoring of offshore oil platforms.

In many ways, Eric Young was best known for the work he pioneered on early man-machine communication systems, when such systems were unfashionable, in the early days for blind landing aircraft schemes and latterly with control systems, communication systems, telemetry systems, vehicle systems or management of complex systems. He was a prolific author, writing four books on his subject, and many associated papers and articles, as well as being the holder of a number of patents. In the latter years of his life, his attention was concentrated on the problems of the mentally handicapped and how to communicate with them. His published researches into this subject are both unusual and interesting, and should do much to change the attitudes of many individuals to this most difficult and unusual of communication problems.

Eric Young played a full role in the Institution of Electrical Engineers. He was a fine lecturer and legendary raconteur and he gave the Oliver Lodge Lecture to packed audiences in Birmingham and Manchester. He was in every sense of the word a large and interesting man in stature, in thought and in deed. It is hoped that much of what he started and pioneered can be put to practical use, for that in reality was the driving force behind everything he did.

H C A Hankins

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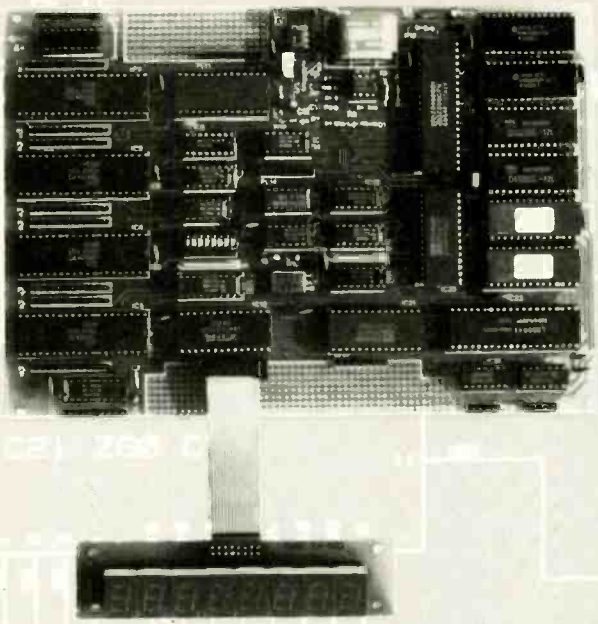

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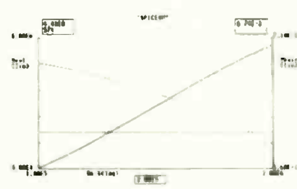

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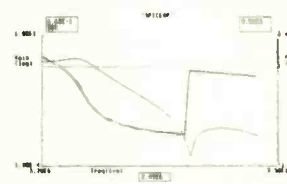

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Equivalent circuits

Removing d.c. circuitry and looking at small-signal operation simplifies analysis

JOULES WATT

My earlier discussion[1] about parameters turned out to be jumping the gun for a number of readers. If you remember, we considered the generators in the 'black boxes' often used to describe amplifier stages and other blocks in electronic circuits. When knowledgeable, we become complacent about such modelling. But, in effect, the blandness can be a pitfall.

The switch from the real circuit to an equivalent, but different-looking one, which often occurs during discussions about radio and electronics theory, always seems to result in one of those hiccups of understanding, judging from the rather horror-stricken student who said after a lecture, "But the lecturer suddenly short-circuited the supply lines to earth, then drew alternators all over the circuit!"

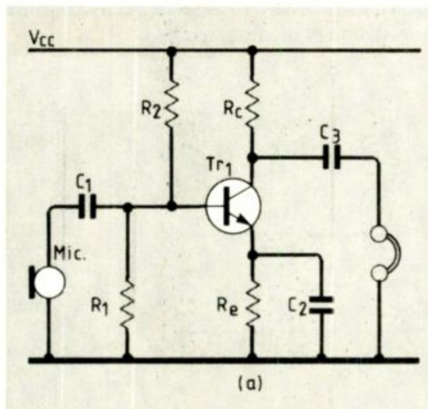
The hardware-schematic to equivalent-circuit jump appears too abstract for most people meeting it for the first time, but seems particularly simple and useful once you know it. This explains the glib way lecturers state it as 'obvious'.

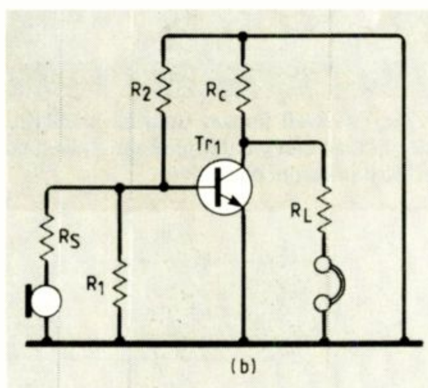
I remember studying "Cathode Ray's" discussion about That Other Valve Equivalent [2], where he introduced the constant-current generator (which turned out to be more suitable for pentodes) in place of the constant-voltage generators that turned up more often in those days. I soon learned that these generators were far from 'constant': they generated the varying signal voltages or currents [3].

MAJOR DIVISION

If you want to analyse or design an amplifier, say, then the overall requirement is either for a simple, single stage or for a multistage system or subsystem. Even in this last case, each stage of the system appears as an entity which you can usually pick out and analyse. Only in recent times have we found whole subsystems integrated into tiny boxes, in which perhaps the manufacturer has placed a dozen stages working together. This is, of course, the integrated-circuit approach, which enables designers to construct super-systems with many such circuits working together.

Therefore, it would seem that discrete-component designing has decreased and that analysing the single-stage equivalent circuit might have become obsolete. This is not so in practice, for a couple of reasons: discretes apparently still get used a great deal; and the integrated devices themselves have an equivalent circuit of the same type as





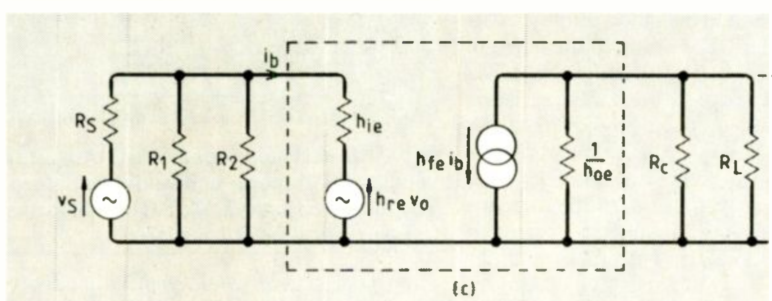


Fig.1. The simple amplifier stage shown at (a), gradually becomes reduced to the a.c. small signal equivalent shown in (c), via the step (b) not usually given in discussions.

a 'stage' and if you want to know how the inside of the chip works, or even design the stages therein, you still have the full equivalent-circuit approach to cope with. At least some people will need to be experts at such techniques if any more new i.cs are ever to come off the production lines.

The trick of the trade is to divide the circuit into two parts and analyse these separately by invoking *linearity*. Although none of our circuits are linear in their operation, we nevertheless behave as though they were. This enables us to talk about the 'Law of Superposition', which simply means, 'if you work out one solution and then another, the overall result is just the sum of the two'. This means that the two results remain independent and do not interact. In a linear communications system, the two signals pass through independently without cross-modulation, but of course, in a real system, we know that they do.

Mathematically, if the output of a system is, say, V_o and this is a function of inputs V_a and V_b and possibly also the temperature T, then,

$$V_o = f(V_a, V_b, T)$$

so that for a *linear* system,

$$v_o = \frac{\partial V_o}{\partial V_a} v_a + \frac{\partial V_o}{\partial V_b} v_b + \frac{\partial V_o}{\partial T} \delta T$$

where v_o is the total change in V_o, v_a is the increment in V_a and so on. We have seen similar expressions before [1].

Notice the three terms in this example simply add. They come from straight line segments along the function, or from what amounts to saying the same thing – the linear terms of a Taylor expansion of the function f. Hence the mathematical approximation gives the title to the physical assumption.

From the ability to make this useful simplification, you can assume that the d.c. bias arrangements which set the operating or Q point and so on, form one 'input' and the a.c. small signal forms the other. The circuit performance resulting from these can be analysed entirely separately, then added at the end to get the overall performance – assuming the aforesaid linearity and therefore superposition, applies.

As I already intimated, we knowingly realise that in practice altering the Q point soon alters the a.c. performance. Also, overdriving the circuit with large signals soon results in distortion, cross-modulation, blocking and even shifts in the operating point and bias currents.

Yet this major division of circuits into the d.c. part and how it operates, together with the a.c. equivalent with the possibility of its analysis, yields a most fruitful procedure.

A.C. EQUIVALENT CIRCUIT

As an example, a look at the old, rather obsolescent, single-transistor amplifier stage might revive a few memories. What the books call the 'mid-band' operating region means that the author wants to ignore the reactive effects, with their poles and zeros in the transfer function of the stage. A typical full circuit shown at Fig.1(a), becomes reduced to that in (c).

The way you think through this procedure goes something like this. "Mid-band – let the reactances of the couplers C_1 and C_3 be zero. Also let the large capacitor across V_{cc} to earth in the power supply also offer zero ohms – all the signal frequency". Figure 1(b) results from this thinking, hence the surprise of 'V_{cc} shorted to earth' when first met.

What you have to see is that with the d.c. drive removed, the active devices themselves must generate the required power – completely fictitiously of course. With so many equivalents available to simulate this generator action, your skill determines which one to choose in any particular case [3]. For good measure, the microphone (in this example) also becomes transformed into an alternator generating the signal v_s.

You might have notice that authors employ the h-parameter set as one of the best descriptors of the small-signal a.c. performance of the common-emitter stage in Fig.1. Using these, we finally arrive at the equivalent circuit shown in (c).

Obtaining this equivalent now enables you to take stock. Some books plod on through an analysis of the complete circuit to yield expressions for the voltage gain, the current gain, input resistance, output resistance and perhaps, according to the needs of the moment, one of the various power gains.

Practical engineers note that the resistors at best might be only within ± 5% of their nominal values. The transistor parameters might be even further scattered about the nominal data sheet figures. Further, modern transistors offer very small h_{re}. Most often $h_{oe} >> R_c$ and R_L. This means the simplification shown in Fig.2 usually gets drawn, ending up with the claim that it will give a working indication.

WHICH GAIN?

I discussed the next problem in an earlier article [3]. Whether you want the overall voltage gain, the transconductance gain or any of the others often depends on the transducers used and the duty sought. In this example, we might like to know how many milliamps pass through the headphones for a given sound pressure level at the microphone. The microphone may have its generated e.m.f. versus sound level published in the data sheet. Manufacturers usually note its impedance on the sheet.

We may have an idea of the sound level available from the headphones versus the signal current through them. Therefore the final milliamps out divided by the e.m.f. of

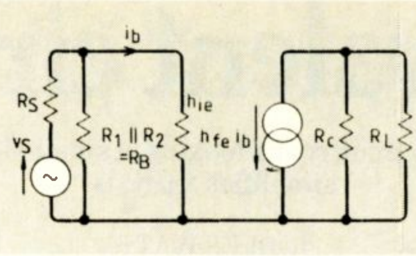


Fig.2. More often than not, Fig. (c) simplifies even further, by choosing appropriate approximations which make only a small difference to the final results.

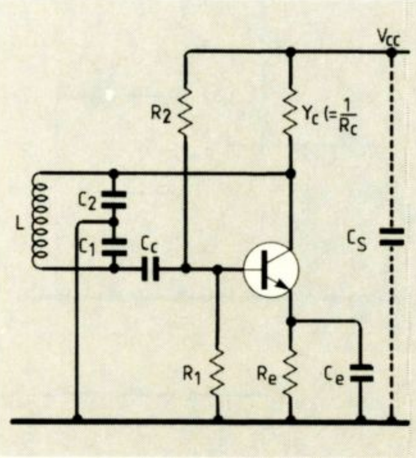


Fig.3. The well known Colpitts oscillator circuit also can yield its secrets by means of the equivalent circuit.

$$G_T = \frac{i_L}{v_s} = \frac{h_{fe}R_BR_c}{(R_sR_B + h_{ie}[R_s + R_B])(R_c + R_L)}$$

While deriving this, you should bear in mind the effect of the two current dividers. You will find one of these at the output where current divides between R_c and R_L. Only the current through R_L actuates the headphones. The other one occurs where the input signal current divides between R_B (which is R_1 and R_2 in parallel) and h_{ie}. Only the current through h_{ie} operates the transistor. From this discussion you see that we require $R_L << R_c$ and $h_{ie} << R_B$ respectively for maximum gain. If you put these approximations into the equation for G_T, you will find it simplifies right down to,

$$G_T = \frac{i_L}{v_s} = \frac{h_{fe}}{R_s + h_{ie}}$$

TO OSCILLATE OR NOT TO OSCILLATE

How do we know if a certain oscillator circuit will actually start up and continue going? You can go a long way to answer the question by using the same equivalent circuit approach as for the amplifier.

The amplifier operated in the mid-band region for simplicity. A quick think about sine-wave oscillators soon shows that we cannot make the same simplifications in their case, because reactances and reso-

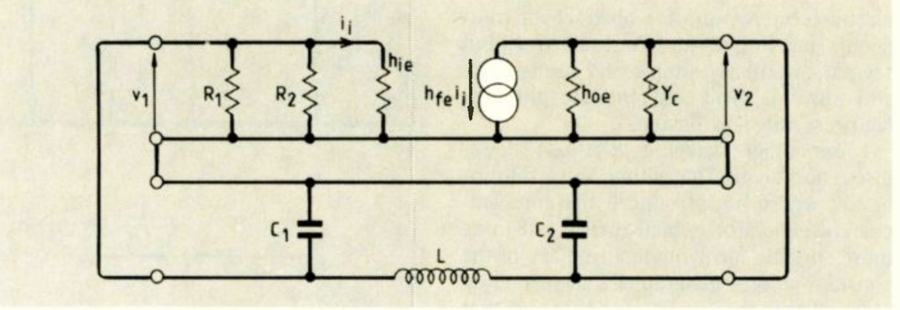


Fig.4. The first step replaces the transistor with its h-parameter equivalent as before. The feedback path via the L-C circuit forms another four terminal network.

the signal source would yield a good performance indicator. This is the transconductance gain,

$$G_T = \frac{i_L}{v_s}$$

To be strictly accurate, we should call this the 'outer transconductance gain', because you could define an 'inner transconductance gain' i_L/v_i if you knew v_i, which appears across the input terminals instead of the source e.m.f. v_s.

BACK OF THE ENVELOPE AGAIN

You might be running out of old envelopes if you read these columns, but nevertheless have yet another go on the back of one of them, "as an exercise for the student". Show that the mid-band transconductance gain of the circuit in Fig.1(a), using the simplified equivalent circuit in Fig.2 is,

nance are bound to come into the picture as a fundamental part of the frequency-control action. On the other hand, you know just where you want the output frequency to be, so you can make the reactance of the decoupling capacitors zero at that frequency.

In oscillator circuits, there is also a problem with the definition of small signals. Nearly all of them rely on limitations at the *large*-signal extremities to keep the amplitude constant. In fact, this causes slight (or perhaps a great deal) of distortion and therefore some harmonic content in the oscillator's output.

We assume at this point in the thinking that the small-signal performance, complete with h-parameters and so forth, will give us information about the *start-up* condition. More feedback than this minimum allows the oscillations to grow until the large-signal distortion sets in to limit the gain, and therefore prevent further amplitude growth. Many discussions on oscillators fail to point all this out, so causing more head scratching for students.

If you look at the oscillator I have chosen in Fig.3 "Colpitts" should spring to mind, because of the tapped tuning capacitor across L. The a.c. equivalent circuit immediately gives us Fig.4 where the transistor has its equivalent h-parameter network and the feedback LC circuit forms another four-terminal network. The networks join up in series at the input and the output of the transistor. A pair of networks in series like this indicates to us that the z-parameters I discussed[1] turn out to be the most appropriate for the analysis. Like all good rules, such orders should be broken now and then and, in this case, to get round having to convert all the h-parameters to z's, we proceed directly with a nodal analysis instead.

Figure 5 shows a final, simplified, oscillator equivalent circuit assuming that R_1 and $R_2 >> h_{ie}$ and $h_{oe} << Y_c$. You will notice this is ready for a nodal analysis with v_1 at node A and v_2 at B.

Dare I say it – yet another envelope and you should find the following two equations satisfy Kirchhoff's Current Law at each node,

$$0 = v_1\left(\frac{1}{h_{ie}} + j\omega C_1 + \frac{1}{j\omega L}\right) - \frac{v_2}{j\omega L}$$

at node A
and,

$$-h_{fe}i_i = v_2\left(Y_c + j\omega C_2 + \frac{1}{j\omega L}\right) - \frac{v_1}{j\omega L}$$

at node B.
Now we want to use these to eliminate one of the voltages, say v_2 and the current i_i. Current i_i is simple, because $i_i = v_1/h_{ie}$. You should discover the final result comes out as

$$-\frac{h_{fe}}{h_{ie}}v_1 = \frac{jv_1}{\omega L} +$$

$$\left(\frac{j\omega L}{h_{ie}} - \omega^2 LC_1 + 1\right)\left(Y_c + j\omega C_2 + \frac{1}{j\omega L}\right)v_1$$

Note that v_1 cannot be zero all the time, so it can be cancelled right through and you are not dividing by 0. The complex number equation now remaining contains all the information we need for two conditions, as you may remember from "j"[4]. These two relationships yield, on the one hand, the frequency of oscillation, and on the other the condition for the circuit to start up and maintain oscillations. You obtain the two expressions by equating the real parts and the imaginary parts of the above equation.

Doing this, you should get for the imaginary parts,

$$0 = \frac{1}{\omega L} + \frac{\omega L Y_c}{h_{ie}} +$$

$$\left(1 - \omega^2 LC_1\right)\left(\omega C_2 - \frac{1}{\omega L}\right)$$

which by dividing through by ω (also not equal to 0) tidies up to

$$\omega^2 = \frac{1}{L\left[\frac{C_1C_2}{C_1 + C_2}\right]} + \frac{Y_c}{C_1C_2h_{ie}}$$

We can write down the final result for the frequency of oscillation by noting that the factor involving C_1 and C_2 in the first term of the last equation is the effective capacitor, C_T, across L in the Colpitts oscillator. Therefore,

$$\omega^2 = \frac{1}{LC_T}\left(1 + \frac{LY_c}{(C_1 + C_2)h_{ie}}\right)$$

is our grand finale for the frequency of oscillation. We should expect to see the factor outside the bracket, but you might like to have a thought or two about the second term inside the brackets. Obviously (and it is obvious for a change), the frequency of oscillation depends on the transistor parameters (at least on h_{ie}) and certainly on the loading of the circuit (Y_c). Any resistive output circuit shunts and therefore changes the effective Y_c, so altering the frequency. You should note that this is so even with 'mid-band' non-reactive parameters. When near the high-frequency cut-off of the transistor, where the h-parameters contain imaginary parts and strays contribute, a great increase in reactive terms complicates the issue so much that analytical expressions become virtually unmanageable, although a cad program will enhance the number crunching if you know values of stray capacitances, and so on, to enter.

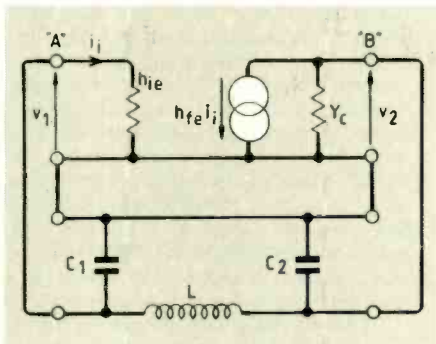


Fig.5. With the same simplifications as for the amplifier, this is the equivalent circuit finally analysed.

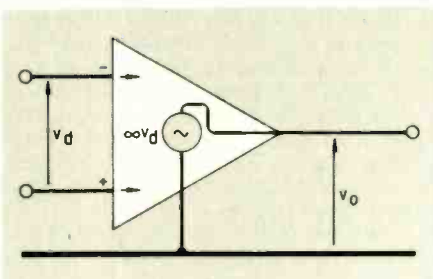


Fig.6. The op-amp, although a complex integrated circuit, has a very simple equivalent.

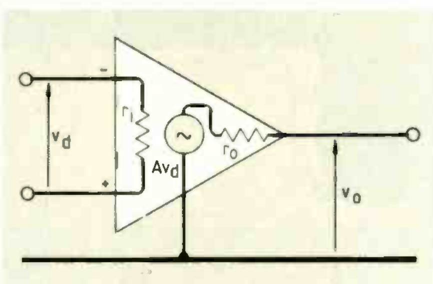


Fig.7. A real op-amp has a slightly more detailed small signal equivalent (and because of internal feedback, this applies to quite large signals also) which complicates the analysis.

The final move in this example involves equating the real parts of the above equation. You should obtain

$$-\frac{h_{fe}}{h_{ie}} = (1 - \omega^2 LC_1)Y_c + \frac{j\omega L}{h_{ie}}\left(j\omega C_2 - \frac{j}{\omega L}\right)$$

Rearranging a little, you obtain the condition that h_{fe} must be

$$h_{fe} \geq h_{ie}Y_c(\omega^2 LC_1 - 1) + \omega^2 LC_2 - 1$$

Neglect the very small second term in the equation for the frequency we derived above,

$$\therefore \quad \omega^2 = \frac{(C_1 + C_2)}{LC_1C_2}$$

Now you can insert this expression for ω^2 in the minimum h_{fe} equation, to end up with a much simplified expression for the maintenance condition,

$$h_{fe} \geq h_{ie}Y_c\frac{C_1}{C_2} + \frac{C_2}{C_1}$$

and we find it gratifying to notice the dimensions all check (pure ratio in this case), so we feel confident of a correct result.

THE SAME WITH LCS

The use of equivalent circuits applies in just the same way to linear integrated circuits such as operational amplifiers, so you cannot get away from the idea. The 'first approximation' to an op-amp usually describes it as having an infinite input impedance, a zero output impedance and an infinite open-loop gain. We recognise this as the ideal case – never to be obtained in practice, of course, but it gives us a good starting point. The equivalent circuit in Fig. 6 shows how simple it is, and even the humble 741 often becomes elevated to this plane of perfection.

The usual derivation of the closed-loop gains of the inverting and non-inverting amplifier circuits proceed with these simplifying assumptions.

Of course, actual amplifiers depart greatly from these impossible heights. The 741 has a finite input-terminal impedance, a finite output impedance and a large, but certainly not infinite, open-loop gain. It looks like the equivalent circuit in Fig. 7.

The effect of r_i and r_o with a finite A makes quite a difference to the full analysis, which you might like to try (another envelope...?) For example, consider an inverting amplifier. Figure 8 shows the circuit and the result of working out the voltage gain gives the rather horrific expression,

$$\frac{v_o}{v_i} = -\frac{\dfrac{R_2}{R_1}}{1 - \dfrac{1 + \dfrac{R_2}{R_1} + \dfrac{R_2}{r_i} + \dfrac{r_o}{R_1} + \dfrac{r_o}{r_i} + \dfrac{r_o}{R_2} + \dfrac{r_o}{R_L} + \dfrac{r_oR_2}{R_1R_L} + \dfrac{r_oR_2}{r_iR_L}}{A + \dfrac{r_o}{R_2}}}$$

You start off on the journey towards this expression by using Kirchhoff's current law for the summing node (point A on Fig.5) and then do the same thing for the output node (point B), finally eliminating the voltage v_t from the two expressions. Tidying up the result gives the above equation.

If $r_i \rightarrow \infty$, $r_o \rightarrow 0$ and $A \rightarrow \infty$ (what we really mean is if $r_i >> R_1$ and R_2, and if $r_o << R_1$ and R_2, together with A 'very large', that is if $A >> 1 + R_2/R_1$) then,

$$\frac{v_o}{v_i} = -\frac{R_2}{R_1}$$

which you may be relieved to see is the ordinary inverting amplifier closed-loop gain relation.

Summing up, we can say equivalent circuits simplify the analysis of stages in amplifiers and oscillators by treating them as linear circuits. By so doing, we can remove the bias or d.c. circuitry while considering the a.c. small-signal performance. The operative words are *small signal*, because the majority of circuits remain linear enough for the approximation only if the signal swings are small.

The discussion I have given only looked at the mid-band region. When you come to consider the full frequency response, things get quite complex (in both senses...), as I hinted in talking about the oscillator. The complex driving point and transfer functions, poles and zeros, bandwidth and stability – all come into the picture, so that the simplifications of the equivalent circuit now become even more appreciated by designers. Going into all the possibilities, however, is a whole new ball game for another time, as our colleagues across the Atlantic would say.

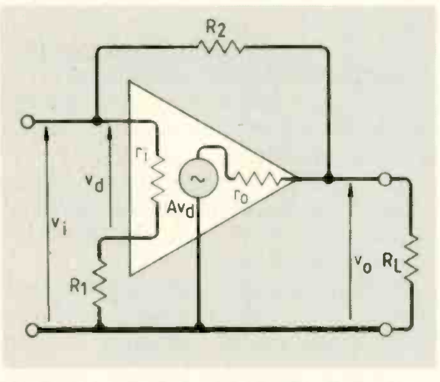


Fig.8. As noted in Fig.7, the 'less than perfect' op-amp has much more detail in its analysis, as the result of carrying it out for this circuit shows.

1. Joules Watt, Parameters *Electronics and Wireless World*, vol.93, No 1612, February 1987.
2. 'Cathode Ray'. That other valve equivalent *Wireless World*, April 1951.
3. Joules Watt, Voltage or current? *Electronics and Wireless World*, vol.93, No 1615, May 1987.
4. Joules Watt, j-real thoughts on the imaginary axis. *Electronic and Wireless World*, vol.93, No 1619, September 1987.

Real-time Unix/VMEbus operating system

In a footnote to Steve Heath's article on single-board computers and the VMEbus last month, we mentioned a new operating system which introduces what was thought to be the impossible – a real-time operating system for Unix. We now have details. The VMEexec project developed by Motorola in collaboration with several independent software vendors will provide the VMEbus user with a set of software interface standards for real-time and System V applications.

The essence of the project is embodied in the real-time executive interface definition (RTEID). This defines a core set of operating-system kernel services. According to Roger Fordham, Motorola microcomputer division manager of software product planning; "To support the range of increasingly demanding applications being developed by our customers, we believe that we have arrived at an elegant architecture with unprecedented performance and robustness." Significant technical assistance has been made by the Software Component Group, of Santa Clara, California, who have become joint sponsors with Motorola for the promotion of the system. It has been offered to the VME International Trade Association (VITA) as a proposed standard. Several companies associated with VME products have committed their support for RTEID, including Industrial Programming Inc. developers of MTOS-UX/68K, and Wind River Systems, suppliers of VxWorks. The combination of VxWorks and RTEID will provide a powerful development system that will load Unix modules directly to a target board.

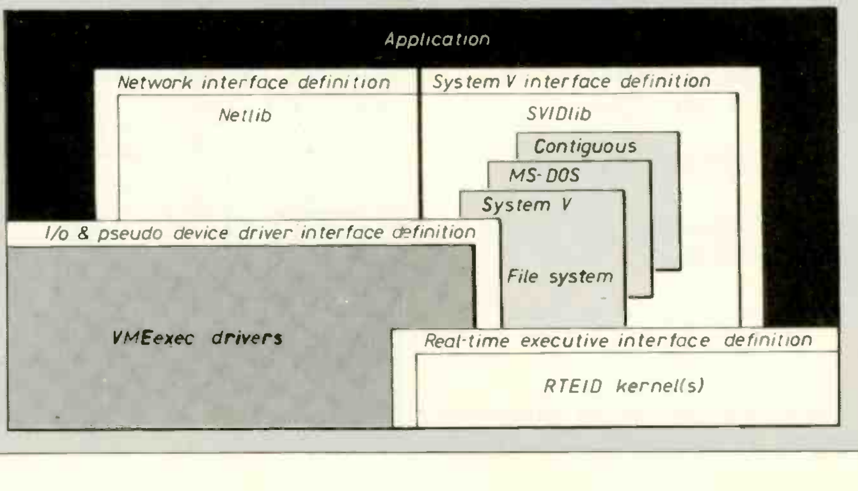
To provide the software developer with a more familiar programming interface, Motorola is developing a System V interface definition (SVID) software library, called SVIDlib, that will interface System V-like user-level processes to RTEID compliant kernel(s). Future extensions to the SVIDlib will support a comprehensive set of network services and will be called NETlib. The development of SVIDlib and NETlib interfaces will be concurrent with AT&T's development of the SVID itself. Motorola's enhanced System V/68 operating system will form the users' software development basis for code generation under the VMEexec program.

SYSTEM V/68 is Motorola's derivative of AT&T's Unix System V operating system, which is fully supported by Motorola's broad range of VMEmodule-based systems. In addition to the set of software development tools provided by Unix systems, Motorola is developing additional tools to aid in software generation and debugging.

In the initial release, remote debugging will be supported over the VMEbus backplane. In subsequent releases the remote debugging facility will be extended to operate over RS-232C, TCP/IP and Motorola's implementation of the Manufacturing Automation Protocol (MAP). Microtec's XRAY68K makes extensive use of a modified version of Greenhill's C-compiler and provides for the debugging of the highly optimized code generated by the Greenhill compiler. This gives state-of-the-art C-code generation and debugging capability for embedded real-time software as well as Unix application-level software.

To provide customers of Motorola's VERSAdos/RMS68K real-time operating system with continued support, Motorola will assure maintenance of VERSAdos. In fact, VERSAdos remains the right choice, says Motorola, for application development starting now. In parallel, to provide VERSAdos applications with improved functions and performances, Motorola is developing a comprehensive program for migration of VERSAdos software to RTEID and SVIDlib. At kernel level, request code for RMS68K services will need to be converted to the RTEID. In fact, a lot of RMS68K functions have a direct equivalent in the RTEID. For device drivers, Motorola will be programming all VMEmodule VERSAdos device drivers to work with RTEID. Complementary to this, a VERSAdos-to-RTEID device driver translation guide will be offered for VERSAdos system integrators.

Motorola VMEexec products to be released in Mid 1988 will include: software development on VME Delta systems under SYSTEM V/68; VERSAdos migration support; symbolic debugging for C-code and assembly language; target support for MC6801/020/030 non-m.m.u. VMEmodules; SVIDlib with System V File system support; and shared memory communications. Towards the end of 1988 the system will be expanded to include; software development on the VME Delta systems under SYSTEM V/68 and on PCs under DOS; more VERSAdos migration support; symbolic debugging for C, Fortran, Pascal and assembly language; target support for all Motorola VMEmodules; SVIDlib with MS-DOS and System V File system support; shared memory, RS-232, TCP/IP and MicroMAP communications.



BOOKS

Video Handbook, second edition, by Ru van Wesel. Heinemann, 455 pages, hard covers, £30. Comprehensive practical guide for the student, technician or small-studio tv operator. Text covers television studio operation and techniques, and the theory, construction and modification of equipment, with many circuit diagrams, line drawings and photographs. Full of information and ideas, and at times engagingly quirky – especially in the author's sudden historical digressions. The text has been amended where appropriate to match UK conditions and the anonymous translator has done an efficient job.

Plan your route: the new approach to map-reading, by Victor Selwyn. David & Charles, 196 pages, hard covers, £10.95. Of particular interest to readers of *E&WW* will be the section on new technology, which describes satellite navigation and position-finding systems, electronic compasses, vehicle tracking systems and digital mapping techniques, with appraisals of a number of commercial implementations. The remainder of the book deals with conventional route-finding methods in a military style, spelling them out in – perhaps – rather more detail than most readers would need. The author ran a map-reading and navigational school overseas for British forces.

Passport to World Band Radio, 1988 edition, edited by Lawrence Magne. International Broadcasting Services Ltd, P.O. Box 300, Penn's Park, PA18943, USA; 400 pages 178×254mm, soft covers, $14.95. Available in the UK from Interbooks, Stanley, Perth PH1 4QQ, Scotland. Up-to-date information about activity on the h.f. broadcasting bands is provided by 256 pages of channel-by-channel listings in an easy to follow graphical format. Data is compiled from monitoring observations as well as published schedules, and so includes fade-in and fade-out times, jamming incidence and so on. The tables identify broadcasts in nine major languages. Country-by-country listings are given in a separate section. Also included are feature articles and an extensive buyer's guide to current receiver models. A worthwhile companion to the World Radio TV Handbook. (Previous editions carried the title Radio Database International.)

Radio and Television Servicing, 1986-87 models, edited by R.N. Wainwright. Macdonald Orbis, 828 pages, hard covers, £29.50. Epitome of service sheets on a broad range of current models, both European and far eastern. The radio servicing section includes music centres, record players and tape recorders and other items under 14 brand names and, for the first time, a compact disc player – Ferguson's model CD01, to which no less than 50 pages are devoted. In this entry, as in others, diagrams and tables have had to be split over two or more pages, making them difficult to follow. With the growing complexity of today's consumer electronics, there must by now be a good case for changing to a larger page format. The index includes cross-references to electrically similar models covered in this or other recent volumes. In a separate booklet is a cumulative index of models covered since this publication first appeared in 1952.

Design of moving-coil head amplifiers

Douglas Self describes the problems of designing m.c. head amplifiers and illustrates them by means of a new design, originally intended for use with his precision preamplifier.

DOUGLAS SELF

In recent years, moving-coil cartridges have increased greatly in popularity. This is not the place to try and determine if their extra cost is justified by an audible improved performance; suffice it to say that a preamplifier now needs a capable moving-coil cartridge input if it is to be considered complete. The head-amplifier design presented here as an example was originally intended to be retrofitted to the precision preamplifier previously published in *Wireless World*[1], feeding the existing moving-magnet disc input. However it is adaptable to almost any preamplifier and cartridge as the gain range available is very wide; it should therefore be of interest to any engineer working in this field. Hereafter "moving coil" is abbreviated to m.c., and "moving-magnet" to m.m.

Traditionally, moving-coil cartridges were matched to moving-magnet inputs by special transformers, which give "free gain" – in a sense – and are capable of a good noise performance if the windings are carefully designed for very low series resistance. However, the inescapable problems of low-frequency distortion, high-frequency transient overshoots and the need for obsessive screening to avoid 50Hz mains pickup render them unattractive and expensive.

The requirements for a high-quality m.c. head-amplifier are as follows. The overwhelming need is for a good noise performance, as the signals generated by m.c. cartridges are, in general, very low. However, this sensitivity is also much more variable than that of m.m. cartridges, where one can take a nominal output of 5mVr.m.s. for 5cm/s at 1kHz as being virtually standard. In contrast, a survey of the available m.c. cartridges gave a range from 2.35mV (Dynavector DV10X IV) to 0.03mV (Audionote 102vdH), though these are both exceptional and the great majority fell between 0.2mV and 0.4mV. Figure 1 shows the output levels of a number of current m.c. cartridges plotted on a scale of dBu (i.e. referred to 775mV) and m.m. cartridges are included on the right for comparison. It is notable how these bunch together in a range of less than 7dB.

A representative m.c. cartridge used both as a basis for design, and for testing, is the Ortofon MC10 Super, which has an output of 0.3mV for 5cm/s, and an internal resistance of 3 ohms. There is general agreement that this is a good-sounding component.

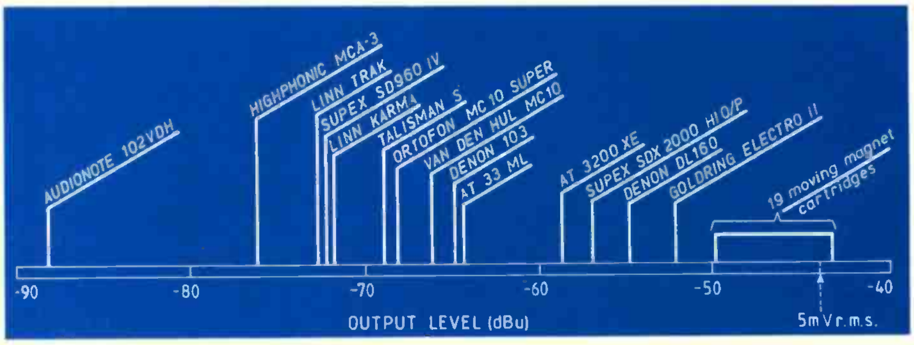


Fig. 1. Output levels of representative moving-coil cartridges plotted on a scale of decibels relative to 0.775V (1mW in 600 ohms), with the outputs of a number of moving-magnet cartridges as a comparison.

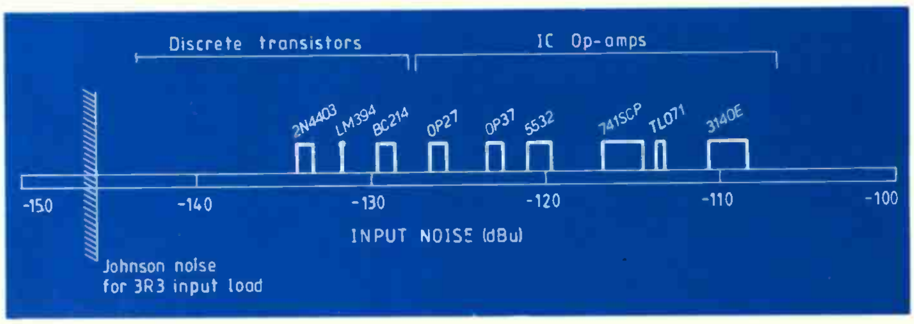


Fig. 2. Discrete transistors still, in the main, provide a better noise performance than op-amps at low source resistances, as shown here for five examples of each type.

As detailed above, there is a need for easily variable gain over a wide range. This can be quite adequately provided in switched steps, avoiding the problems of uncertain stereo balance on dual potentiometers. From the above output figures, a gain range of 6dB to 46dB appears necessary to cater for all possible cartridges. It would seem, at the low-gain end, that the amplifier is virtually redundant, and so a minimum gain of 20dB was chosen.

Moving-coil cartridges are very tolerant of the loading they see at an amplifier's input, as a result of their own very low internal impedance. For example, Ortofon, who might be reckoned to know a thing or two about m.c. cartridges, simply state that the recommended load for most of their wide range of cartridges is "greater than 10 ohms". Nonetheless, since experimenting with cartridge loading is a harmless enough pastime, provision for changing the input loading resistor over a wide range has been made in this design.

The preamplifier should have the ability to drive a normal m.m. cartridge input at sufficient level to ensure that the head amplifier does not limit the disc headroom. Any figure here over about 300mVr.m.s. should be satisfactory. A less obvious point is that the input impedance, apart from the nominal 47k resistive component, usually includes a fair amount of capacitance, either to adjust cartridge frequency response or to exclude r.f. This can cause head-amplifier instability unless it is dealt with.

Finally, a head amplifier should meet the usual requirements for frequency response, crosstalk, and linearity. Capacitive crosstalk is usually not a problem, due to the very low impedances involved, but for the same reason, linearity can present problems despite the low signal levels.

DESIGN PROBLEMS

The theoretical noise characteristics of amplifiers have been dealt with very competently in other articles[2], and there is no need to repeat the various mathematical derivations here. The designer's options are usually limited to choosing a suitable input device, operating it at roughly the right current, (not usually critical due to the flat bottoms of the noise curves) and then making sure that the surrounding circuitry doesn't mess things up too much. M.c. head amplifiers are almost always built around discrete devices, with or without the addition of an accompanying op-amp (for an exception see Ref. 3.). Figure 2 shows the reason why: when source resistances are low (say below 1k) even advanced op-amps are easily out-performed by discrete devices, due to the inevitable compromises in i.c. fabrication. The values of equivalent input noise (e.i.n.) in Fig.2 were taken from five samples of each device, using a source resistance of 3R3, and the general circuit configuration in Fig.3. The rather non-standard measurement bandwidth is due to the use of the internal filters on a Sound Technology measuring system; adding a third-order 20 kHz active filter at the ST input would be very difficult, as the levels of noise being measured are so low. To convert to 20 kHz upper bandwidth limit, subtract 1.5dB. One of the prerequisites for good performance in this role is a low value for R_b, and this has led to a fine miscellany of devices being applied to a job they were never intended for: medium power devices, print-hammer drivers, (a lot of transistors seem to have been designed as print-hammer drivers) and so on.

Apart from careful device selection, the other classical way of reducing noise with low source impedances is to use multiple devices. The assumption here is that m.c. amplifier noise will swamp the miniscule Johnson noise inherent in the source (this is usually all too true) and therefore, if two input devices have their outputs summed, the signals will simply add, giving a 6dB gain, while the two uncorrelated device noise contributions will partially cancel, giving only 3dB.

Thus, there is a theoretical gain of 3dB in noise performance every time the number of input devices is doubled. There are, of course, clear economic limits to the amount of doubling you can go in for; eight parallel devices is the most that I have seen. It also seems difficult in practice to get the full theoretical benefit.

M.c. head-amplifiers in use today can be roughly divided into three common topologies, as shown in Fig.4. That shown in 4(a) relies on a single device with low R_b, and the combination of limited open-loop gain and the heavy loading of the low-impedance of the feedback network on the final transistor means that both linearity and maximum output level tend to be uninspiring. Given the technical resources that electronics can deploy, there seems no need to ask the paying customers to put up with any measurable distortion at all. An amplifier of this type is analysed in Ref.4.

Figure 4(b) shows the classic multiple-parallel-transistor configuration; the amplifier block A is traditionally one or two discrete devices, that usually have difficulty in driving the low-impedance feedback network. Effort is usually expended in ensuring proper current-sharing between the input devices.

This can be done by adding small emitter resistors to swamp V_{be} variations, but these will effectively appear in series with the source resistance, and compromise the noise performance unless they are individually decoupled with a row of very large electrolytics. Alternatively, each transistor can be given its own d.c. feedback loop to set up its collector current, but this tends to be even more prodigal of components. Having said this, experiment proved that the problem of current-sharing was not as serious as conventional wisdom holds; this is explained below. For examples of circuitry see Ref.5.

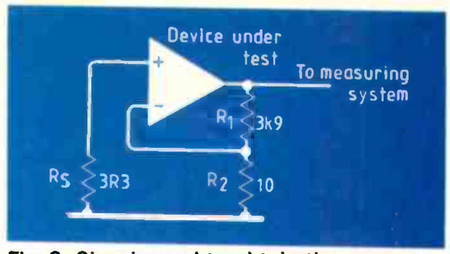


Fig. 3. Circuit used to obtain the measurements shown in Fig.2.

Figure 4(c) shows the series-pair scheme. This simple arrangement allows two input devices to give the normal 3dB noise improvement without current-sharing problems as substantially the same collector current goes through each device. The collector signal currents are summed in R_c, which must be reasonably low in value to absorb any current imbalance. This configuration has its adherents but it also has its difficulties, such as indifferent linearity.

It was therefore originally decided to base the design presented here on a single well-chosen device, with the spadework of providing open-loop gain and output drive capability left to an op-amp. This leads to the configuration in Fig.4(d), which gives excellent linearity, and less than 0.002% t.h.d. at

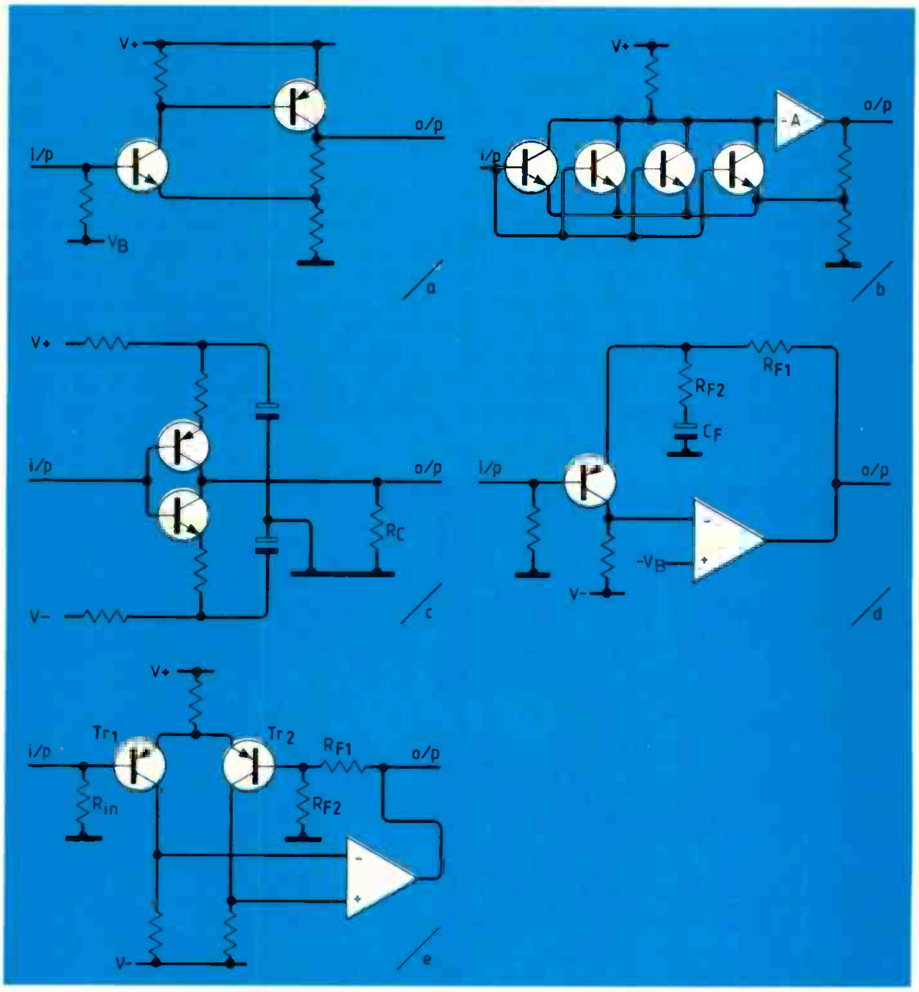


Fig. 4. Some head-amplifier configurations. A fairly low open-loop gain in the circuit at (a) results in poor linearity. At (b), the gain is provided by multiple transistors, which theoretically gives an improvement of 3dB in noise performance for twice the number of transistors, but can also present current-sharing problems. The arrangement at (c) provides the 3dB improvement without current sharing: linearity is not of the highest order. Circuit (d) uses one input device, the gain being provided by an ip-amp: the necessity for Cf presents problems, which are overcome in the (e) configuration at the expense of a lowered noise performance.

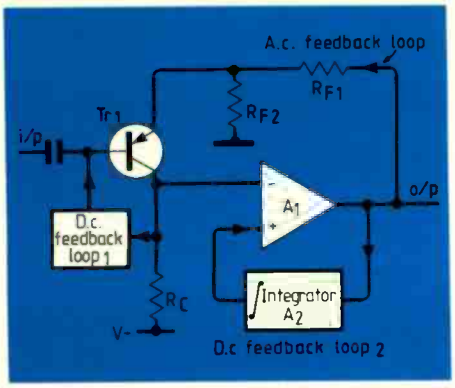


Fig. 5. The layout adopted for the final design.

full output may be confidently expected. The first problem to be dealt with is the very low value of R_{f2}; this must be as low as possible (say 10ohms) as it is effectively in series with the input source resistance and will degrade the noise performance accordingly. This means that C_f must be very large, of the order of 2200µF, to preserve the l.f. response. A 3R3 resistor in the R_{f2} position demands 4700µF to give −3dB at 10Hz; this is not elegant. The capacitance C_f cannot be dispensed with, since there is a d.c. level of +0.6V on the emitter of the input device, leading to a wholly impossible offset at the output of the op-amp.

One solution to this is the use of a differential pair, as in Fig.4(e). This cancels out the V_{be} of the input transistor Tr_1, at the cost of some degradation in the noise performance of the circuit, and hopefully the d.c. offset is so much smaller that, if C_f is omitted and the offset is amplified by the full a.c. gain, it will not seriously reduce the output voltage swing. In effect, the second transistor Tr_2 is an emitter follower transferring the feedback signal to the emitter of Tr_1, and such a circuit element introduces a small but inescapable amount of extra noise. In this case, with the component values shown, the degradation is about 2.8dB.

A possibly more serious objection to this circuit is that the offset at the output is non-negligible, about 1 volt, much of which is due to the base bias current flowing through R_{in}. A d.c.-blocking capacitor on the output is essential, and if it is an electrolytic there may be some doubt as to which way round to put it, as the exact level of input pair balance is unpredictable.

After practical trials, it was decided that a 3dB noise penalty was too great, and that a way had to be found to use a single-ended input.

A NEW APPROACH

The new method evolved is shown in the block diagram Fig.5. There is no C_f in the feedback loop, and indeed no overall d.c. feedback at all. The two halves of the circuit, the input transistor and the op-amp, each have their own d.c. feedback systems. The transistor relies on simple shunt negative feedback via d.c. loop 1, while the op-amp has its output held precisely to a d.c. level of 0V by the integrator A_2. This senses the mean output level, and sets up a voltage on the non-inverting input of A_1 that is very close to the level set on Tr_1 collector, such that the output stays firmly at zero; its time-constant is made large enough to ensure that an ample amount of open-loop gain exists at the lowest audio frequencies. Failure to do this results in a rapid rise of distortion as the frequency is lowered. Any changes in the direct voltage on Tr_1 collector are completely uncoupled from the output. However, a.c. feedback passes through R_{f1} as usual and ensures that the linearity of the compound arrangement is near-perfect, as is often the case with transistor op-amp hybrid circuits. Due to the high open-loop gain of A the a.c. level on Tr_1 collector is very small and so a.c. feedback through d.c. loop 1 does not significantly affect the input impedance of the amplifier, which is about 8 kΩ.

The device chosen for the input transistor was the 2N4403, a type that has been acknowledged as superior for low-noise applications for some years. The R_b is quoted as about 40 ohms[5]. More modern purpose-designed devices such as the 2SB737 will improve the noise performance by up to 1 dB, but the extra cost is significant.

A single device used in the circuit of Fig.6 gives an e.i.n. of −138dB with a 4mA collector current, which is certainly not bad, but it was consistently found that putting devices in parallel without any current-sharing precautions whatever always resulted in a significant improvement in noise performance. On average, adding a second transistor reduced noise by 1.2dB, and adding a third reduces it by another 0.5dB. Beyond this the law of diminishing returns sets in and, since further multiplication was judged unprofitable, a triple-device input was settled on. The current-sharing under these conditions was checked by measuring the voltage across 100 ohm resistors inserted in the collector paths. Using 3.4mA as the total current for the array it was found after much device-swapping that the worst case of imbalance was 0.97mA in one transistor and 1.26mA in another. No attempt was made to ensure that all the devices came from the same batch. It therefore appears that, for this device at least, matching is good enough to make simple paralleling worthwhile, and it was therefore decided to use three devices in parallel in the final circuit.

There now remains the problem of setting the gain. Usually it would be simple enough to alter R_{f1} or R_{f2}, but here it is not quite so simple. The resistance R_{f2} is not amenable to alteration, as it must be kept to the lowest practicable value of 3.3 ohms, and R_{f1} must be kept up to a reasonable value so that it can be driven to a full voltage swing by an op-amp output. This means a minimum of

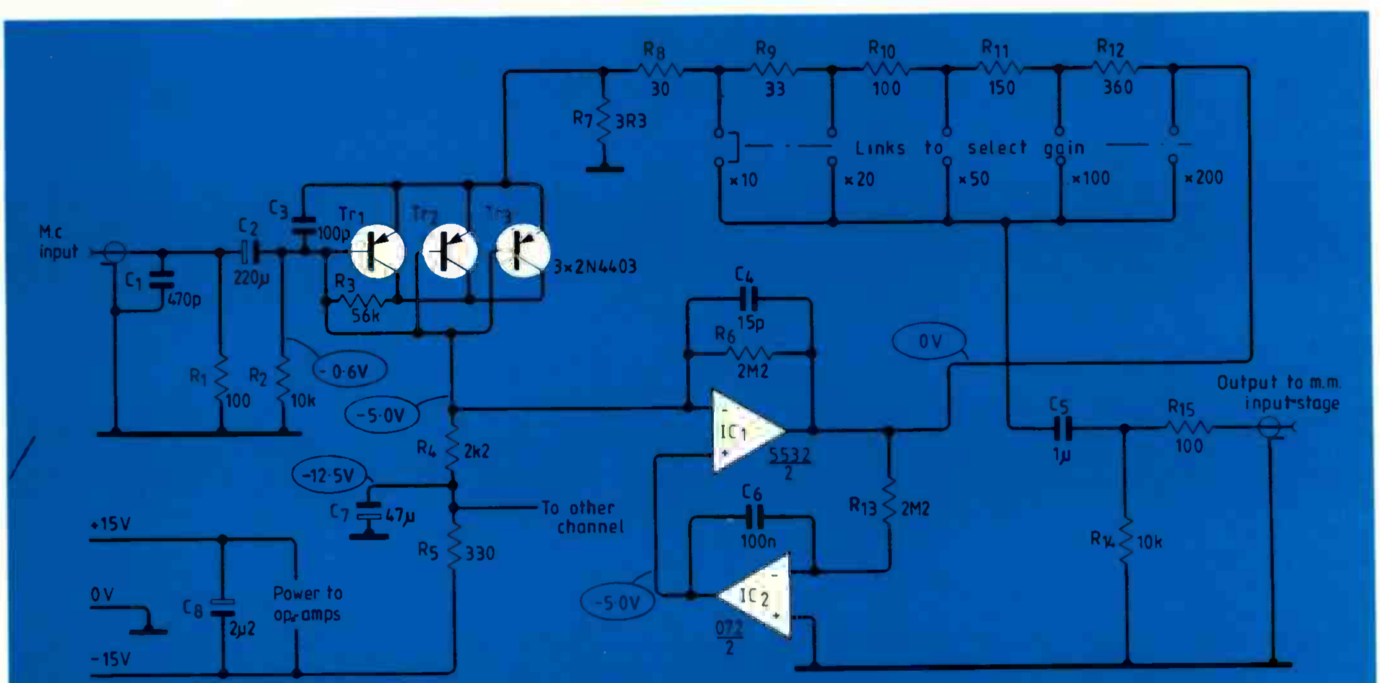


Fig. 6. Complete circuit diagram of the moving-coil head amplifier, intended to drive the moving-magnet input of a preamplifier.

500 ohms if the op-amp is to be of an easily obtainable type such as the 5534. (It is paradoxical that amplifiers whose output is measured in millivolts are required to chuck around so much current).

These two values fix a minimum closed-loop gain of about 44dB, which is far too high for all but the most insensitive cartridges. The only solution is to use a ladder output attenuator to reduce the overall gain; this would be anathema in a conventional signal path, because of the loss of headroom involved, but since an output of 300mVr.m.s. would be enough to overload virtually all m.m. inputs, we can afford to be prodigal with it. If the gain of the head amplifier is set to be a convenient 200× (+46dB) then attenuation to reduce overall gain to a more useful +20dB still allows a maximum output of 480mVr.m.s.; this comfortably exceeds the input capability of the intended host preamplifier, though one previous design would accept it all and come back for more[7]. Smaller degrees of attenuation to provide intermediate gains allow greater outputs, and these are summarized in the specification. The Ortofon MC10 was used with +26dB of gain, to give similar output levels to m.m. cartridges driving the precision preamplifier RIAA stage direct.

The last constraint is the need to provide a low output impedance to the succeeding m.m. input stage, so that it can give a good noise performance; it is likely to have been optimized to give of its best with a source impedance of 500 ohms or less. This implies that the ladder attenuator will need low resistor values, imposing yet more loading on the unfortunate op-amp, so this problem has been side-stepped by making the ladder an integral part of the a.c. feedback loop, as shown in Fig.6. This is only practicable because it is known that the load resistance presented by the next stage will be too high at 47 kΩ to cause any significant gain variations.

THE FINAL CIRCUIT

This is shown in Fig.6, and most closely follows the configuration of Fig.4(d), with the exception that the input devices have suddenly multiplied themselves by three. Capacitor C_1 is soldered on the back of the m.c. input phono sockets and is intended for r.f. filtering rather than modification of the cartridge response. If the need for more capacitive or resistive loading is felt, then extra components may be freely connected in parallel with R_1. If R_1 is raised in value, then load resistances of up to 5 kΩ are possible, as the impedance looking into C_2 is about 8kΩ. Capacitor C_2 is large to give the input devices the full benefit of the low source impedance, and its value should not be altered. Resistors R_2,R_3 make up d.c. loop 1, setting the d.c. operating conditions of $Tr_{1,2,3}$, while R_4 is the collector load, decoupled from the supply rail by C_9 and R_5, which are shared between the two channels. Op-amp IC_1 provides the main a.c. open-loop gain, and is stabilized at h.f. by C_4: R_6 has no real effect on normal operation, but is included to give IC_1 a modicum of negative feedback and hence tidy behaviour at power-up, when this would otherwise be lacking due to the charging time of C_2. the other op-amp, IC_2, is the integrator that makes up d.c. loop 2, its time-constant carefully chosen to provide plenty of open-loop gain from IC_1 at low frequencies, and to avoid a peaking in the l.f. response that can occur due to the second time-constant of C_2.

The ladder resistors R_8–R_{12} make up the combined feedback-network and output-divider, overall gain being selected by a push-on link in the prototype. A rotary switch could be used instead, but this will produce loud clicks when moved with the volume up, since the emitter current of Tr_1-Tr_3 flows through R_7, and a small current therefore flows down the divider chain. The output resistor R_{15} ensures stability when driving long screened cables, and C_5 is included to eliminate any trace of d.c. offset from the output because the stage might find itself driving a horribly vulnerable 'esoteric' input stage with direct coupling and possibly substantial gain at d.c. Anything is possible these days.

COMPARING PERFORMANCE PARAMETERS

These are given in the specification, and I think there will be few opportunities to quibble. On the vital question of noise it would be instructive to compare it with other preamplifiers – not easy because the noise performance of m.c. head amplifiers is specified in so many different ways it is virtually impossible to reduce them all to a similar form, particularly without knowing the spectral distribution of the noise. Noise performances are specified with and without CCIR-ARM weighting, over different bandwidths, and with different source impedances. This article has dealt throughout with unweighted noise referred to the input, over a 400Hz-30kHz bandwidth, and with RIAA equalisation *not* taken into account. Without getting bogged down in invidious comparisons, I can only say that it is my belief that the design given here is quieter than most current designs, being within 6dB of the theoretical minimum.

When using this design with the precision preamplifier, it was noted with some surprise that it was so quiet that the m.m. RIAA stage actually caused the noise performance to deteriorate by about 3dB. Since the RIAA stage is itself very quiet (s/n ratio -81dB referred to 5mVr.m.s. input it is considered that the design goals were met.

PRACTICE

P.c.b. layouts require some care if the full performance is to be realised. Firstly, the grounding should be carefully planned, as it must be realised that with such low impedances as R_7 (3R3) playing a vital role, the resistance of tracks can be significant. It is suggested that a single star ground point be chosen on the p.c.b., and critical paths (input ground,R_1,R_7) all connected to this, to prevent signal currents causing voltage drops where they are least wanted. It is vital to avoid making loops in the input path that will pick up 50Hz magnetic fields.

It is essential to place the decoupling capacitor C_8 next to IC_1 to prevent insidious h.f. oscillation which makes its presence known only by severely impaired linearity. When interfacing the head amplifier to an existing design, note that about 8mA flows down the ground connection.

SPECIFICATION

Careful earthing is needed if the noise and crosstalk performance quoted is to be obtained.

Gain	Gain(dB)	Max output (r.m.s.)
10×	+20dB	480mV
20×	+26dB	960mV
50×	+34dB	2.4V
100×	+40dB	4.6V
200×	+46dB	10V

Input overload level. 48mVr.m.s.
Equivalent input noise. −139.5 dBu, unweighted, no RIAA.
T.h.d. Less than 0.002% at 7Vr.m.s. output, (maximum gain)at 1kHz. Less than 0.004% 30Hz−20kHz.
Frrequency response. +0, −2dB 20Hz−20kHz.
Crosstalk. Less than −90dB 1kHz−20kHz (layout dependent).
Power requirements.
20 mA at +/−15V, for both channels.

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2. Walker, H.P. "Low-noise audio amplifiers" *Wireless World*, May 1972.
3. Duncan, B. "AMP-01" *HiFi News*, October 1984, pp67-73.
4. Nordholt & Van Vierzen "Ultra Low Noise Preamp For Moving-Coil Phono Cartridges." *JAES*, April 1980, pp219-223.
5. J. Barleycorn (a.k.a. S. Curtis) HiFi For Pleasure. August 1978, pp105-6.
6. A. Foord "Introduction to low-noise amplifier design", *Wireless World*, April 1981, p71.
7. Self, D. "High-quality preamplifier", *Wireless World*, February 1979, p40.

BOOKS

Dictionary of Electronics by S.W. Amos, second edition. Butterworth Scientific, 324 pages, hard cover, £25. Covers the subject from A-battery and accumulator to zener and z parameter, with extensive cross-references and numerous line illustrations. About 300 new definitions have been added to this edition and 200 existing entries have been revised. But the price seems rather high for a non-specialist title.

Industrial Control Handbook by E.A. Parr. Volume 2 (of 3): techniques. Blackwell Scientific Publications, 453 pages, hard cover, £45. Practical approach to industrial practice for the student or working engineer. Main subject headings include d.c. amplifiers, rotating machines and power electronics, computers in control, hydraulics, pneumatics and process control valves, recording and display devices, maintenance, fault-finding and safety. Volume 1 dealt with transducers and volume 3 will cover the underlying theory and applications.

FEEDBACK

Plastic film capacitors – a premature obituary

I read with interest Keith Thomas's article in the July issue on Europe's capacitor market. The comments expressed indicate that multilayer ceramic capacitors will dominate the capacitor market at the expense of film capacitors in the coming year. However, there are other opinions which differ and these are supported by facts.

Far from plastic-film capacitors being displaced by ceramic capacitors the reverse has occurred over the last six years with some types. Until the late 1970s multilayer ceramic capacitors had virtually 100% of the market for radial-leaded capacitors with 5mm and 2.5mm lead spacing. The introduction of metallized plastic-film capacitors with these lead spacings enabled plastic-film capacitors to capture about half the market previously held by ceramic capacitors. This penetration was more marked in those areas such as telecommunications, which required high reliability and greater capacitance stability than offered by X7R and Z5U ceramic-dielectric capacitors.

The American and European capacitor industries have differed for many years and this can be traced back to the 1930s, when polystyrene-film and zinc-metallized paper capacitors were developed in Germany to reduce dependence on strategic materials such as mica and aluminium. Since then Europe has had a lead in plastic-film capacitors. This lead was aided by the introduction of polyester (polyethylene terephthalate), polycarbonate and polypropylene plastic films which were all invented in Europe. The USA, where mica capacitors are still much in evidence, developed the multilayer ceramic capacitor.

Multilayer ceramic and plastic-film capacitors have different properties and both will co-exist for the foreseeable future. At the present time ceramic capacitors have 100% of the chip or SMD market for surface mounting capacitors up to 0.1 μF. Plastic-film chip capacitors have been recently developed and will supplant their ceramic rivals in some areas where capacitor reliability and stability are major requirements. It is thus premature to write the obituary of plastic film capacitors as yet.

R.H.Hanson,
Waycom Ltd

Coupling as a way of life

I was happy to see that Mr Ivall has returned to electronic journalism but not so happy with his treatment, or more accurately that attributed to Mr Donaldson, in his interesting article relating to coupling coefficients in *EWW*, June 1987.

In *Electronic Engineering*, circa 1945, I gave the design details for a number of types of tuned transformers together with equivalent circuits and the conditions for the onset of double humping. It was really a war-time, state-of-the-art article and shortly afterwards I updated it to include designs based on insertion loss characteristics. In dealing with inductively coupled circuits it is useful to consider 'k' as having a value of between plus and minus one depending on the direction of connection and the degree of coupling.

Referring to the implantable receiver, presumably power efficiency is important and this implies that the inductor, L_2, has a high Q. Figure 2 shows a test circuit that presents an inductance in series with a parallel combination of a 13Ω resistance and an inductance and this can hardly be recommended as an elegant method of measurement. Would it not be better to use a direct measurement of the magnetic field or, since there are lots of volts and amps flying around, the voltage across a low series resistance of say 0.5Ω could be measured.

It is well known that for any network using purely reactive components and operating between resistive loads, at the frequency at which zero insertion loss obtains, the impedances presented to the driving source and the output load must be purely resistive and of such values as to provide matched conditions. Thus an oscillator using the input impedance of such a network for frequency discrimination will oscillate at this frequency when the maintaining amplifier in the oscillator has zero phase shift.

When the resistance R_2 is zero the network presents zero impedance at frequencies corresponding with $\omega^2LC(1\pm k)=1$, as stated. An inspection of the equivalent 'T' networks given in my article makes this obvious. This is not a desirable state of affairs, as Sod's Law says the system will operate at the unwanted frequency or perhaps both frequencies. The current flowing in the secondary circuit is independent of the coupling coefficient at either of these frequencies for a loss-less transformer. In practice the dissipation in the components will make this current somewhat dependent on coupling.

In ultra-reliable equipment is it good practice to use an op-amp to drive a pulse waveform into the large input capacitances of the Vmos transistors? Perhaps the op-amp used is exceptional.

F G Clifford
Cape Town
S.Africa

The Ether

I thank K. Wootten (Letters, August) for diplomatically overlooking the absurd statement in my May letter – "The energy of any system of central forces depends only on their relative position." Their total energy is the sum of the kinetic energy, the energy due to momentum, and their potential energy, the energy due to position.

I agree with Wootten that the concept of magnetism as an effect caused by an ether wind is only useful "in understanding and predicting physical phe-

FEEDBACK

nomena." One prediction is based on an analogy with a polorised sound wave in the form of a beam. A transverse atmospheric wind would deflect the beam. A magnetic ether wind should deflect a laser beam.

An alternative understanding of the Zeeman effect and its anomalous counterpart is possible. A fan freely suspended between two fixed fans (simulated poles) simulates a paramagnetic molecule by appearing to be attracted by the nearest fixed fan when the blades of all three fans rotate in the same direction. The free fan simulates a diamagnetic molecule when turned through 180 degrees, appearing to be repelled by both fixed fans.

Zeeman discovered his effect using a flame coloured by sodium salts. His effect is very uncommon. The anomalous effect is common. We could imagine that the molecules of the sodium gas are paramagnetic and fly to the nearest magnetic pole, and the molecules of the vast majority of gases being diamagnetic actively resist the passage of the magnetic ether wind, and are blown aside by the force of the wind. The diamagnetic gases would act as if repelled by both magnetic poles and move away at right angles to the direction of the magnetic ether wind.

In other words, the Zeeman and anomalous effects are Newtonian Doppler effects, caused by a combination of the motion of the source of the light wave and the motion of the wave's medium. If we knew the velocity of the light wave's medium measured by Maxwell's magnetic ether wind velocity vector H, we could calculate the velocity vector of the gas molecules and reduce two apparently dissimilar effects into two related causes.

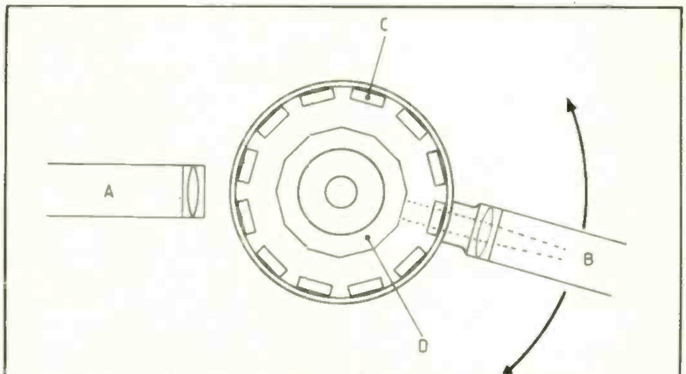
However, H. Aspden's letter (August) is not concerned with conjecture but with scientific facts deduced from accurate measurements made with instruments designed to measure the earth's velocity, both in magnitude and direction, with respect to standing ether waves synonymous with Newton's absolute space. The experiments of Silvertooth and Marinov are variations of the 1977 experiments of Muller described in his paper 'The Cosmic Background Radiation and the New Aether Drift', (Scientific American, 238, May 1978), the subject of E. Eastwood's article in the *Wireless World*, August 1981, which in turn was the subject of my June 1985 letter. These experiments are obviously crucial experiments. An *experimentus crucis* may be defined at an experiment which a theory predicts is impossible.

M. G. Wellard
Kenley
Surrey

Mechanical tv

Further to Tim Voore's excellent article on the pre-War Scophony mechanically-scanned television receiver, your readers may be interested to learn a little more about the heart of this receiver – the mirror drums.

In 1935 I was apprenticed in the optical test room of Adam Hilger Ltd, the company who had surfaced the mirrors for Michelson and Morley.



Equipment for the testing of glass and stainless steel polygons used in the Scophony television receiver. Each facet in turn was compared with the standard blocks. A is the measuring autocollimator; B, the check-zero autocollimator, C, plane parallel glass blocks adjusted to the facet angle; and D, stacks of glass or s.s. polygons on mandrel. The photograph on page 1212 shows the complete equipment.

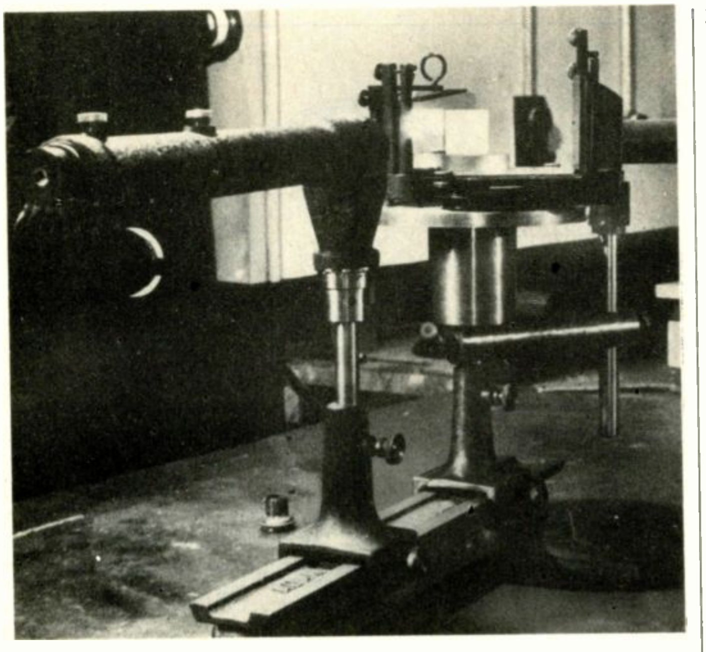
When the requirement from Scophony arose, it fell to Harry Yates, my predecessor, to carry out the lapping and polishing of the facets of the polygons, and to me to arrange for the testing. (Meantime, Ted Wilson, our former boss in the test room, had departed to join Scophony.) Our then Managing Director, Frank Twyman, F.R.S. took a personal interest in the whole process, and designed the test gear on which we tested many stacks of glass and stainless steel plyogons.

I was at the time an enthusiastic amateur photographer, quite apart from using spectrography in the course of duty, and one negative has survived these fifty years – of the test equipment that we used.

The set-up illustrated was for checking one of the early 20° angle gauges for the 18-faced polygons, using the submultiple reflection method, whereby the angular error is multiplied by the ratio of the angle under test to 180°. When testing polygon stacks, the set-up shown was replaced by a brass ring about 9in bearing as many precision-polished glass blocks as the polygon, held down by a slow-setting cement. These were adjusted by me to as near as may be to the perfect polygon. No-one is perfect, so the final document was a list of the residual errors (in seconds of arc), which in itself could be regarded as a perfect polygon within the limits of measurement.

There are three sources of degradation of the projected image that can be imparted by the crossed mirror drums:

– the angle which each facet



makes to a common base plan (which we called the basing error)
– the angle between facets
– the flatness of the facet, which would produce defocussing of the beam.

As the two polygons (frame and line) were crossed in orientation, these errors would produce different degrees and forms of image degradation. We had nothing to do with the specifications, ours only to decide whether it could be done and to quote a price.

In the absence of written records, my memory says that the basing error for all polygons was 30 seconds of arc, the angle between facets (seen as a departure from a perfect polygon) was 15 seconds, and the flatness of each individual facet had to be within the Rayleigh limit of ¼ wavelength.

Individual polygons, glass or stainless steel, were clamped in stacks, symmetrically disposed on a massive steel mandrel. There were machined by standard engineering to a ground finish, ready for the optical technician to achieve the near-impossible, which he used to do six days a week. The only one which gave us a real headache came near to the end of the series, when they requested a 49-faced stainless steel polygon. Imagine the problem of producing a polygon whose interface angle was 7.4489796 degrees, to an accuracy of 10 seconds of arc! Still, we managed it. With the aid of a sine bar and some Johannsen blocks, Harry Yates made a gauge and with the aid of specially coated mirrors, we checked it by the sub-multiple technique, availing of the in-built x49 error factor.

Post-War, the future was clearly with domestic television, and a system which relied on such precision *and* labour-intensive components would start at a disadvantage. Its only future was cinema television, where people without the resources to buy their own television would flock to the nearest cinema to see the latest television.

The rest is history. However, while it lasted, it was a good time, and I am pleased and not a little proud to have been part of it.

A. S. Henderson
Ystrad Meurig

Maxwell's e.m. theory revisited

I was impressed by this article and congratulations to the author. I spent four weeks during last year trying to explain the background and deduction of the usual form of Maxwell's Equations. The main problem seems to arise at the change-over point from physical laws to mathematical representations which require operators that are not used in basic circuit theory or telecommunications. Consider the 3rd equation which is based on Faraday's Law of Electromagnetic Induction. The principle can be demonstrated by a simple experiment and most students are prepared to accept that an induced e.m.f. equals the rate of change of magnetic flux. However they forget the definition from electrostatics of electric potential which uses the electric field intensity **E**. Thus **E** and **B** (magnetic flux density) can be directly related. The four equations are deduced from fundamental laws. It would appear that this point can never be overstated.

I believe that graduate engineers should have a good grounding in Maxwell's Equations. Otherwise they cannot hope to understand areas such as propagation in dielectrics and conductors. Sometimes engineers with considerable experience claim that this type of information is not needed. In my experience this is true for technicians but graduates should have a comprehensive over-view of their subject. I appreciate that the various aspects and use of the equations are confusing on the first occasion for the average student. If at first you do not succeed try, try again.

Brian Patrick McArdle
Newbridge, Ireland

'Empty' waves, 'Empty' space

The article "Relativity – a critique" in the October issue of EWW[1] challenges Professor P.C.W. Davies' views on the twin paradox and reminds us of the ever-present background ether.

According to Stephen Grieve, what Davies says about the relativistic meaning of space – "a space *per se* consisting of nothing"... with observational physics".

Such terminology reminds me of the scathing views Professor Davies expressed in the journal *Nature* when reviewing my book about the ether[2]. To him, what I wrote about the need for a real ether medium was wrapped up in his caption "The Physics of Fairyland".

I have just returned from an international conference on quantum physics at which faster-than-lightspeed interactions were discussed in a forum of informed opinion now speaking openly about the ether. It seems that there is a climate of change ahead. One of the issues raised was the evidence pointing to the existence of 'empty' light waves, waves which somehow do not convey photons but yet play a determining role in wave mechanical interactions.

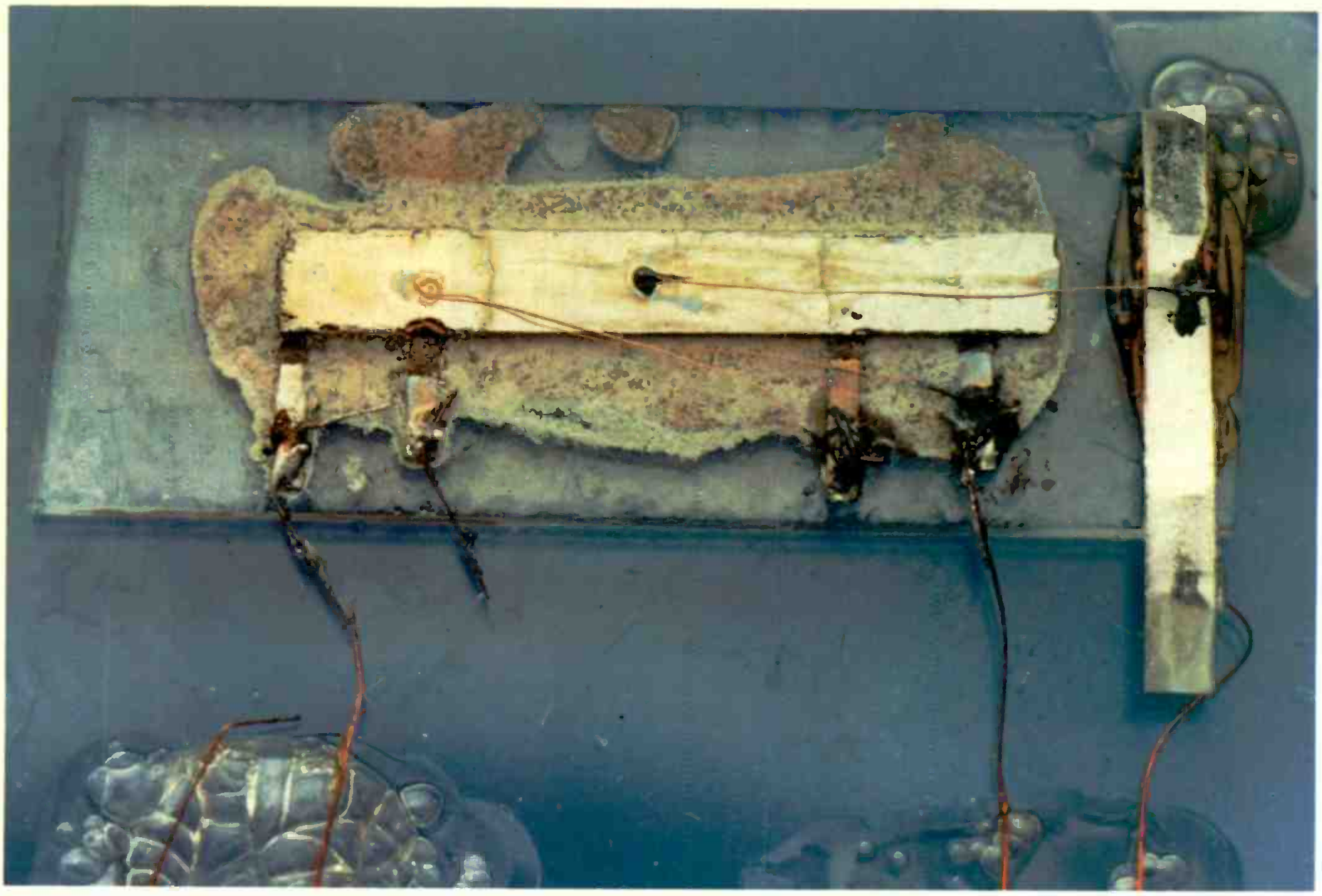
Given the fact that when a propagating polarized EM wave is reflected back on itself by a mirror its electric field (but not its magnetic field) undergoes a 180° phase reversal at the mirror surface, thereby setting up standing waves, what happens to its phase for a 90° mirror reflection? Can we agree that the EM wave reflected through a right-angle proceeds with the electric field phase-shifted through 90° to put the electric and magnetic fields in phase quadrature, contrary to Maxwell's equations and 'empty' in the sense that energy need not then be forced to propagate with the wave?

As a UK professor colleague at the conference remarked, this would mean that an 'empty' wave at its next 90° reflection would revert to a 'Maxwell' wave. To me, such events which involve energy exchanges demand the involvement of an ether medium, because it becomes an essential basis on which to make sense of the paradoxical experimental results being encountered in the testing of quantum mechanics. The relativistic Lorentz invariance is recognized as the real problem facing the interpretation of experimental data bearing upon quantum mechanics.

H. Aspden
Department of Electrical Engineering
University of Southampton

References
1. Stephen Grieves, *Electronics and Wireless World*, 93, p.1026 (October 1987).
2. H. Aspden, 'Modern Aether Science', (Sabberton, Southampton), 1972.

The author of the article referred to by Professor Aspden, Stephen Grieve, has pointed out an error in the preparation of the piece. On p.1029, in the first column, three lines from the bottom of the text, the line should read ". . would imply its absoluteness: must have no objective reality . . .". Apologies for the error – Ed.



Do you know anyone who was born on September 12, 1958? Tell them they were born on the day the electronics revolution began. It was on that day that the first integrated circuit was completed. But do not say silicon chip, for it happened to be made of germanium.

Pioneers

12. Jack St Clair Kilby (born 1923): inventor of the integrated circuit.

W.A. ATHERTON

Jack Kilby's name is not well known, not even amongst electronics engineers. There are no famous television dramas of his invention. No multi national companies bear his name. A hundred years ago he would have been feted, famous and worth a fortune. Instead this quiet, unobtrusive 'nice guy' is simply happy to work on.

Jack Kilby conceived the idea of the integrated circuit soon after he joined Texas Instruments, a youthful semiconductor manufacturer that was achieving considerable success in the late 1950s.

For eleven years he had worked at a company in Milwaukee called Centralab, a division of Globe Union, having joined them after graduating from the University of Illinois with a degree in electrical engineering. His work had taken him into the field of transistor manufacture and had introduced him to the increasingly desperate search for a solution to the major problem then facing electronics – the tyranny of numbers.

Towards the end of the 1940s, as electronic systems grew in importance and size, the number of components within them threatened to impose a limit on their size and complexity. As systems became larger more power was consumed. The weight increased and costs increased. But more components and more soldered joints meant that the reliability fell. It looked as though a limit was in sight.

Above: one of Kilby's first integrated circuits, a germanium phase-shift oscillator completed on September 12, 1958. For its circuit diagram, turn the page. Below: Jack Kilby. Both photographs by courtesy of Texas Instruments.

After the war came the Cold War and then the space race. Both brought demands for cheaper, smaller and more reliable electronic systems.

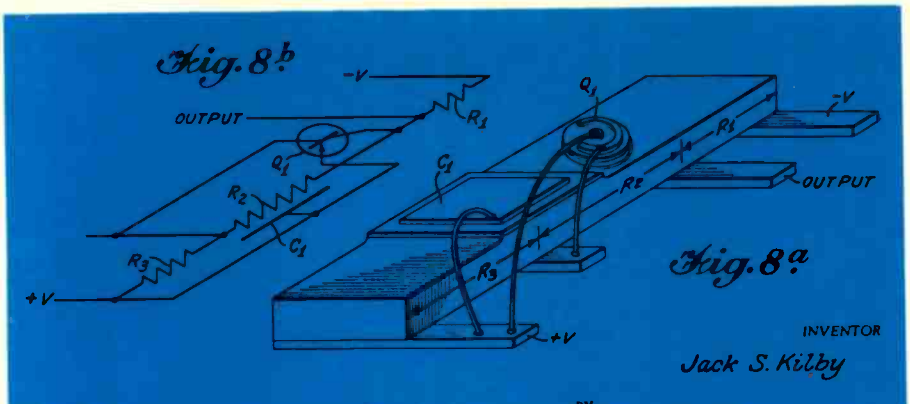
During the war, the US had examined silk-screen printing of conductive inks to print passive components on to ceramic bases for an army proximity fuse. Later, Centralab turned the technology to peaceful uses by printing components for hearing aids and radio and television parts. It was there that Jack Kilby learned to put, simultaneously, several passive components on a single substrate. It was an important lesson for the man who would one day revolutionize electronics.

THE TRANSISTOR ARRIVES

The first revolution, though, arrived when Bell Laboratories announced the invention of the transistor. When seminars were offered to licensees to explain how to make the new devices, Centralab sent Kilby along. It was 1952. On his return he started to make transistors.

The same year, G.W.A. Dummer of the then Royal Radar Establishment at Malvern, foresaw "electronic equipment in a solid block with no connecting wires". Within the block, he predicted, would be insulating, conducting, rectifying and amplifying materials connected directly. The next year Harwick Johnson of RCA in America filed the first patent for an integrated circuit, a phase-shift oscillator. As yet no-one could make it.

After six years with transistors at Centralab, Kilby was feeling the limitations of being on the fringe of developments. Others were



Circuit diagram of the phase-shift oscillator. From US patent 3,138,743.

succeeding with expensive diffused transistors which were better than the easier-to-make alloyed variety. Texas Instruments had announced the first commercial silicon transistors and now led the world in silicon technology.

To Kilby, it seemed that the time had come to move on. "I felt that changes were coming so rapidly that it would not be possible for very small groups with limited funding to be competitive".

In May 1958, after several interviews, he joined Texas Instruments. There, as elsewhere, the race was on to meet the demand for miniature electronics. TI's mission was the 'micromodule', in which all components were to be made the same size and shape and have wiring built in. For assembly they would simply be snapped together.

Kilby started his own project, but the cost analysis made gloomy reading. Reassignment to micromodules loomed and that did not appeal to him.

In July the factory closed for the summer holiday. Kilby had been there barely two months and had no leave due. He was left almost alone in the lab. A fairy-tale could not have set a better scene.

The costings at TI had surprised him. "In my discouraged mood, I began to feel that the only thing a semiconductor house could make in a cost-effective way was a semiconductor."

Then realization dawned. It was obvious that you could make diodes and transistors with a semiconductor. It was equally true, but not obvious, that you could make resistors and capacitors. If all components could be made of the same material then they could be made in a single block *in situ*, and connected up to form a circuit. This seminal idea was written up in his laboratory notebook on July 24, 1958.

"PRETTY DAMN CUMBERSOME..."

Not everyone would propose making resistors and capacitors from expensive silicon when standard materials such as carbon and ceramics were cheaper and better. But when the others returned from holiday, Kilby had a design for a flip-flop ready to present to his boss Willis Adcock. It would use silicon transistors, bulk-silicon resistors and silicon (pn junction) capacitors.

Adcock recalled, "My attitude was, you know, it's something.... It was pretty damn cumbersome..."

Cumbersome or not, Adcock gave the go-ahead for a discrete circuit to be built entirely of semiconductors to see whether it would work. It did, on August 28. Each component was made from a separate piece of silicon.

The next step was to make an all-semiconductor circuit in a single block – an integrated circuit of a phase-shift oscillator.

Some existing half-inch square wafers of germanium contained about 25 transistors complete with contacts in place. These were cut into bars, metal tabs were alloyed to the back as additional contacts, and black wax was used to mask a transistor and a distributed RC network.

On September 12, 1958 the first three were completed. Power was applied to one – and the world's smallest oscillator, the first integrated circuit, sprang into life oscillating at about 1.3MHz. The modern era of electronics had begun.

A week later, on the 19th, a flip-flop was built. Oxide layer capacitors followed in November and diffused resistors in December. The standard flat package was chosen "to emphasize that this technique was new and basically different from those which had been proposed previously", wrote Kilby.

A patent was filed on February 6, 1959 and the 'solid circuit' was announced at a conference in New York on March 6. The micromodule was left to die.

A FIREBALL

Criticism of the idea was soon forthcoming. Semiconductor resistors and capacitors would be pretty awful. Manufacture would be a nightmare. Yields would be very low and design would be expensive.

Such criticisms were hard to counter because, as Kilby put it, "They were true". In time though, as the inventor himself said, they simply became irrelevant.

Whilst large companies studied the objections, smaller ones got on with the job. Robert N. Noyce at Fairchild Semiconductor (now at Intel) filed a patent on July 30, 1959. It was largely he who designed the major manufacturing technique by applying the planar process to i.c. manufacture. (He had developed the process at Fairchild with G.E. Moore.) Kurt Lehovec of Sprague filed for a patent in which active devices were to be separated by multiple pn junctions.

At the age of 35, Kilby had started a fireball of ideas which still burns.

THE POCKET CALCULATOR

One day in 1964 Kilby was summoned to meet the president of Texas Instruments, Patrick Haggerty. Haggerty had already made some bold decisions during his career. Now he made another by asking Kilby to build something which would show the world what the i.c. revolution was going to mean. He asked him to make a small, cheap electronic calculator.

The smallest electronic calculators were then as big as a hefty typewriter and cost ten times Haggerty's target price of $100. In about three years the project was largely completed, but the Pocketronic calculator was not marketed until 1971. Kilby's name was on the patent. If you have a Texas Instruments calculator you may still find the patent number on it: 3,819,921.

Another of his projects was the TI thermal printer for which the firm gave him the Haggerty Award on April 16 this year. His name is on the basic patent for the semiconductor array used in the print head. It brought TI business worth nearly $1000 million.

In 1970 Jack Kilby left Texas Instruments to become a private consultant, with a part-time consultancy to TI. He is also a Distinguished Professor at the Texas A&M University.

He has worked on solar energy conversion and, more recently, on optical and biological computing.

He leads a quiet life and tends to shun publicity. His wife died in 1981 after 33 years of marriage but he has two grown-up daughters and four grand-daughters.

Photography and woodworking are among his hobbies, and he is a prolific reader of electronics magazines and papers, newspapers, news magazines and patents. Some of it just might turn out useful, is his philosophy.

Like most great inventors he has a string of patents (over 50) and awards and prizes to his name. He is even in the US Patent Office National Inventors' Hall of Fame, a distinction bestowed on only 50 or so people.

But despite having triggered the silicon chip revolution and helped launch the pocket calculator, Jack Kilby still retains a fondness for the elegance of his old slide rule. "There's nothing going on that isn't right there on the table", he says. "It has a sort of an honesty about it."

References

1. J.S. Kilby, Invention of the integrated circuit, *IEEE Trans on Electron Devices* ED-23, July 1976, 648.
2. T.R. Reid, The Texas Edison, *Texas Monthly* July 1982, 103.

Next in this series of pioneers of electrical communication will be Heinrich Hertz, discoverer of electromagnetic waves.

Dr Tony Atherton works at the Independent Broadcasting Authority's engineering training college in Devon. His book "From Compass to Computer, A History of Electrical and Electronic Engineering", was published by Macmillan in 1984.

RESEARCH NOTES

Silicon in a better light

Last month's Research Notes drew attention to work at AT&T Bell Laboratories into hybrid silicon-germanium materials capable of emitting light. These materials offer the promise of properties akin to those of gallium arsenide, but without the difficulties of integration. A disadvantage is that they require special manufacturing techniques to avoid the strains in the crystal lattice. These result from differences in the inter-atomic distances in natural crystals of the two elements.

As it happens, similar problems – and considerable benefits – stem from attempts to deposit gallium arsenide on silicon. University of Illinois researchers have recently reported the first successful continuous-wave, room-temperature laser fabricated from GaAs-on-silicon. It isn't the first time that such hybrid III-V-IV materials have been used for semiconductors, but a successful laser is considered by many to be a significant landmark. As with silicon-germanium materials there is an incompatibility of lattice dimensions between the constituents of III-V-IV composites. This makes the material prone to dislocations which can spread through the crystal structure and alter its electronic properties. It is less a problem in devices such as field-effect transistors which depend on majority carriers; it is an acute problem, however, in minority-carrier devices such as lasers. Carrier recombination can seriously affect laser performance.

Lasers are also peculiarly critical devices because of their natural function of generating light and heat, both of which are damaging to semiconductor lattices: dislocations grow to the point at which a laser diode simply becomes opaque. Until now, the heat problem in particular has limited gallium arsenide-silicon lasers to intermittent, pulsed operation.

Even now, the Illinois researchers, together with their collaborators at TI and Xerox, do not claim to have overcome the problem completely. Degradation still takes place over a few hours' operation, a fact that leads some authorities to believe that a commercial device is still a decade away.

An obvious question is: why bother? Especially when there are perfectly good reliable laser diodes built only from III-V materials. The answer is that any laser fabricated on a silicon substrate would open up the field for monolithic integrated optoelectronics of a sort that would revolutionize low-cost data transmission. The potential pickings are great.

Thermal picture synthesizer

A solid-state thermal picture synthesizer has been developed at the Sowerby Research Centre of British Aerospace. Several units have been made and one is in use at British Aerospace Army Weapons Divisions Missile Guidance Control Test Centre at Stevenage. There it is used to produce dynamic images of infra-red targets. It checks the responses, in simulated flight, of missiles equipped with infra-red seeker heads when they are operating in infra-red environments typical of real-life combat conditions.

The thermal picture synthesizer consists of a matrix of thermally-emitting thin-film resistors deposited on a thermal insulation layer built up on a silicon substrate. The substrate contains a corresponding matrix of integrated-circuit diodes used in the control of the resistor matrix. The image area of the device is 35mm square and contains 10,000 resistors arranged in a 100 × 100 matrix. Each resistor representing an infra-red pixel can be electronically addressed and activated independently of its neighbours. A resistor's temperature can be increased by a maximum of 25°C above the nominal baseline operating temperature of the device.

The degree of heat emitted by a resistor depends upon the current flowing through it and this can be programmed to be one of 200 values, so providing a graduated range of temperature colours for the generation of high-resolution infra-red images. The substrate also functions as a heat sink. It forms the base of a chamber containing a fluorinated hydro-carbon liquid and is cooled by the latent heat of vaporization of the liquid as it boils. This arrangement ensures that the thermal response of the resistors is sufficiently rapid for dynamic infra-red images to be reproduced in real time by the thermal picture synthesizer at frame rates of up to 50 per second.

The necessary electronic drive and control circuits, and a buffer data store are assembled to form an integrated thermal picture display unit. An external computer is used to provide the appropriate synthetically-generated thermal scene information as a digital data stream. This information is fed into the display unit's buffer store.

The thermal picture synthesizer was devised and developed, and is manufactured largely in-house by British Aerospace. The large single-slice silicon substrates initially provided by Plessey Semiconductors are completed by British Aerospace at its integrated-circuit manufacturing facility in Stevenage.

Towards electronic paper

For those of us who are hamfisted with keyboards and for whom the prospect of a machine that will recognise handwriting seems remote, a development at the National Physics laboratory may bring a ray of hope. For all practical purposes it *does* recognise handwriting, but not by optical means. That is still considered a somewhat distant prospect for people unpractised in italic script.

The NPL's system, which they call 'electronic paper', consists of a 313cm^2 sheet of transparent resistive material that will track the coordinates of a pen drawn across it. Resolution is 0.025mm. Behind the transparent writing surface is an a.c. plasma display, capable of 35 picture elements/cm; this mimics the track made by the pen, thus giving the user sensory feedback akin to that of writing on ordinary paper.

The next stage of the operation is the digitization of the writing and its conversion into a neat typed form. This requires a considerable amount of built-in intelligence, though considerably less than would be necessary if the handwriting were to be analysed *subsequent* to its execution. The secret ingredient is that of being able to follow the writer's pen strokes and not merely to observe the finished work.

To achieve a high (98%) level of accuracy, the system uses a database assembled by Movement Analysis, Cambridge. This embodies the results of numerous investigations of the handwriting styles of hundreds of UK, US, French and West German nationals. Additional studies at various UK universities have also investigated recognition rules for dealing with non-roman languages and for recognising such items as mathematical and chemical symbols.

Recognition algorithms are currently being developed that will eventually cope with cursive writing. This involves extensive use of artificial intelligence and a multi-layer recognition hierarchy with feedback loops between levels.

Once the handwriting – in whatever form – has been recognised and replaced with typescript, the system then provides comprehensive editing facilities with several novel features. Text, in fact, can be corrected in much the same way as one might do on a sheet of paper, by crossing out unwanted words. The computer doesn't even need to be told that it needs to provide an editing function.

As yet the concept of electronic paper is still in its infancy. The potential benefits are nevertheless enormous. Apart from being a great boon to us inky hacks or one-fingered typists, it has the ability to input data that cannot easily be communicated by keys. It is possible, for example, to draw a box and then write in it, without resorting to a mouse or light pen. NPL say that the benefits of an interface that will fully exploit the pointing ability of a human being are likely to be enormous. The future of electronic paper now rests mainly with the software development. All the hardware – much of it Japanese – is currently available and getting cheaper by the day.

RESEARCH NOTES

Quiet! I can't hear myself think

Those of us who work with words, either written or spoken, would agree that our ability to read or write or memorize information is seriously reduced when someone is talking nearby. Journalist colleagues frequently comment that it's possible to do twice as much work at home as in an open-plan office! Although this might seem a blinding glimpse of the obvious, it isn't simply a matter of interference in the sense of a data stream becoming corrupted with noise. Many researchers have shown, for example, that the degree of disruption of one's thought processes is very dependent on the type of noise.

Of all the sounds that impinge on our ears, human speech is by far the most intrusive. What's more, as any librarian will confirm, the degree of disturbance is to a large extent independent of level; even a whisper can be distracting when we're trying to concentrate hard. Conversely, sounds that are devoid of information and which occupy no special niche in the spectrum, such as white noise, are scarcely distracting at all. White noise has, in fact, been used very successfully to mask other sounds in the case of people who can't sleep because of noisy neighbours or tinnitus (noises in the ear).

But why should speech be so especially intrusive? Is it just because it conveys meaning that somehow grabs the attention of the mind? Apparently not, according to a research group working at the Department of Applied Psychology at the University of Wales Institute of Science and Technology in Cardiff. In a recently published paper, Dr Dylan Jones and Dr Chris. Miles describe experiments showing that speech is processed in a slightly different way from other information.

Interestingly enough, it isn't just the information content of background chatter that distracts us from our work. Speech produced by running a tape recording backwards is just as disruptive when the work we are trying to do involves the use of memory. Even more intriguing is the finding that sung words have the same effect as spoken words; both are infinitely more disruptive than non-vocal music. Could this be why pop music invariably has a vocalist, even when the words are sometimes distorted beyond recognition? Perhaps the real purpose they serve is to distract us from competing activities?

Be that as it may, there are several big questions left to answer. Why should speech grab our attention, even if played backwards or in a foreign language? And why should it interfere with a non-aural activity such as reading or memorization?

Jones and Miles say that there must obviously be some mechanism in the brain that asks in effect: does this noise *sound* like speech? This discriminating mechanism, they believe, is largely phonological and does not take the meaning into account. As to why such speech-like sounds interfere with reading, the evidence suggests that printed words are converted in the brain into a code that has a sound-like basis. This internally generated 'sound' is then interfered with directly by any acoustically generated words that enter the brain from the ear. Experimental results show that the interference is maximal when the printed words have a similar sound to the acoustically perceived words. It is also greater when a person is trying to commit the printed words to memory. Where memory *doesn't* play a very significant role, as in proof reading text, the effect of background speech is less, though in this case its effect does depend to some extent on whether it is intelligible.

The whole story is clearly much more complicated than the simple picture outlined above and the Cardiff Group suggest that the reason why speech has such an intrusive quality is that it evolved as a sort of 'early warning system'. For survival it was necessary to have a sense that always remained on the alert. Thus a mother will be woken by the sound of her crying child but not necessarily by a louder noise of no real importance.

The practical significance of this work is immense. If activities involving reading and memory are so severely compromised even by low-level speech, then open-plan offices are clearly going to be inefficient. So too are areas like airport control towers where operators sit in close proximity to each other. Jones and Miles say that the most important of all their findings is that the degree of interference is independent of level. They argue therefore that architects' decibel tables should all be thrown out of the window when it comes to planning work spaces – that is if people are going to be allowed to talk.

Erasable optical discs

Philips Research Laboratories at Eindoven in Holland are working towards an erasable optical disc, according to the recent report (*Physics Bulletin*, Vol.38, No 9). The disc is coated with either gallium antimonide or indium antimonide, doped with some unspecified impurity.

This thin crystalline layer is then written on by means of a high-power laser that almost instantaneously heats it to just above its melting point. The crystalline material, when it solidifies, changes into an amorphous form which has a different reflectivity to that of the crystalline semiconductor.

If a pulsed laser is used to write digital data onto the disc, then it will produce a series of spots which can be read out in much the same way as a conventional non-erasable optical disc. The semiconductor discs are said to be playable on existing equipment with only minimal modification.

Erasure is achieved by heating the disc to a temperature just below the melting point of the semiconductor material. At this temperature is reverts to its crystalline form and is ready for further use. Philips say that their erasable optical medium can be recorded on and erased about a thousand times without degradation.

Clearly, such a medium offers the prospect of huge amounts of re-usable data storage, far greater than that of any current medium. But whether the cost of the discs and the high power laser peripherals make it economic remains to be seen.

How to grow transistors

A team of researchers at GTE Laboratories in Waltham, Massachussetts has succeeded in growing transistors without recourse to the normal etching or deposition processes. This development, reported in *Science News* Vol.132, No 2, starts off with a mixture of molten silicon and tantalum metal. In this state, both ingredients form a homogeneous mixture. If the mixture is cooled, however, it separates into three phases: pure silicon, pure tantalum and microscopic threads of the compound tantalum disilicide. These threads run throughout the length of what otherwise resembles the normal crystal structure of silicon.

To manufacture this composite material in useful form, the GTE researchers lower a rod of silicon into the mixture just before it begins to solidify. This rod acts as a seed upon which the composite material will grow. Throughout it, the tantalum disilicide threads – about 1mm diameter – appear on average every 6mm.

By slicing the cylindrical crystal into wafers and attaching electrodes to the different parts of the crystal structure, the GTE team are able to fabricate field-effect transistors capable of handling considerable powers. This property stems from the fact that the transistor structure extends through the whole thickness of the wafer, 1mm in this case.

If this process sounds more like an April Fool than reality, it's perhaps worth adding that the GTE researchers are themselves somewhat mystified by it all. They say that it works best when the original mixture contains 98% silicon and 2% tantalum. If the mixture differs significantly from the figure then no useful results are obtained at all.

As yet, no information is available on device parameters for this year's crop of transistors, though they are said to be particularly photo-sensitive. Perhaps they grow best in the Sun?

'Research notes' is compiled by John Wilson

Relational analysis

A method of system analysis which depends on the fundamental laws which determine system behaviour, in contrast with classical dimensional analysis which uses units to invoke the laws

J. A. CORBYN

The conventional conception of dimensional analysis is based on the use of fundamental units for mass, length, time and other quantities. The generally used methods of dimensional analysis have their origins in the work of Fourier and Vaschy. Macagno[1] has traced the history of the classical conception of dimensional analysis. Rayleigh[2], Buckingham[3] and Bridgman[4] have been principally responsible for developing the subject in its present form. Modifications to using mass, length and time as a fundamental basis for dimensional analysis have been used, although these modifications have consisted of a replacement of these units by alternative units rather than a restructuring of dimensional analysis without reference to units.

As an alternative to the development of dimensional analysis based on units, Pankhurst[5] has given a development of Buckingham's π theorem based on consideration of the laws, universal constants and definitions of physical quantities relevant to a system. Happ[6] has given a flowgraph representation of dimensional analysis and Schuring[7] has given methods and applications of dimensional analysis which are based on the fundamental laws involved rather than the systems of units.

Difficulties inherent in the classical method of dimensional analysis derive from the use of units employed for measurement rather than the scientific laws and relationships relevant to the system being analysed. These difficulties include the generation of non-dimensional groups which are not significant but which appear in the analysis as a result of definitions of units invoking scientific laws which are irrelevant in the system under study.

It is proposed to designate the method of investigating a system by enumeration of the laws and quantities involved the *relational* method of analysis, in distinction to classical dimensional analysis where the assignment of dimension may depend on unseen assumptions of laws used in the definitions of the units employed. Classical dimensional analysis is culturally connected with the independent development of units for mass, length, time, thermal and electrical quantities during the last century, whereas it is now possible to create systems of units which employ the laws of physics to define standard rather than arbitrary objects or phenomena.

The method of dimensional analysis here described as relational analysis has application both to the practical development of models of physical systems and to the theoretical structure of physics and related areas of mechanics, electrical technology, geophysics and applied science. To demonstrate the significance of the choice of systems of units in classical dimensional analysis, an alternative development of traditional units is given which makes full use of available physical laws, the use of which is usually effected by the specification of relevant dimensional constants as parameters.

THE RELATIONAL METHOD OF ANALYSIS

A system for applying the relational method may be constructed by preparing a table where each row corresponds to a law or relationship between the variables in the system. The variables may be classified into primary variables which characterize the system and secondary variables which are introduced into the analysis through the application of the relevant laws or relationships.

In Table I there are l laws $L_1, L_2 \ldots L_l$. There are p primary variables: these specify the system in that a functional relationship existing between them describes the operation of the system. $P_1, S_2 \ldots S_s$ are the secondary variables.

Table 1. Organization of the solution of a system involving a relationship between p primary variables $P_1, P_2 \ldots P_p$ using laws $L_1, L_2 \ldots L_l$. $S_1, S_2 \ldots S_s$ are the secondary variables introduced into the system through the application of the l laws.

laws	secondary variables		Primary variables	
	S_1	$S_2 \ldots\ldots S_s$	P_1	$P_2 \ldots\ldots P_p$
L_1				
L_2				
. . .				
L_l				

Each row of Table I can be used to eliminate one of the secondary variables from the system, since the relationship expressed in each row carries the information that there is a specific combination of primary and secondary variables which needs to be satisfied in any solution. Elimination of s secondary variables using the l relationships will lead to l-s rows in a table derived from Table 1. This will then be the number of relational groups characterizing the system being analysed. It is necessary that the rows of Table 1 be independent and that any secondary variables appear in more than one row. The proposition can be made:

if a functional relationship exists between a set of p primary variables which describe the state of a physical or mathematical system and there are l laws or relationships between the p primary variables and s secondary variables, then the state of the system can be expressed as a relationship between l-s alternative variables. Each of the alternative variables is a product of one or more of the primary variables and each of the laws or relationships is in the form of a product of primary and secondary variables. The products of variables includes variables raised to any index .... (1)

This development of a theorem similar to the Pi theorem is related to the approach of Pankhurst[5] although Pankhurst treats dimensional relationships arising from the inclusion of universal constants in the system as separate from laws affecting the system.

Example of analysis of linear LCR circuit. Consider the example of an electrical circuit containing capacitance, resistance and inductance. It is required to model circuit performance as a relationship between resistance R, capacitance C, self inductance L, voltage V and time t. Table II shows the relational analysis. Rows 1 to 4 in this table represent the laws and relationships which determine circuit behaviour. Rows 5 and 6 show linear combinations of these rows which eliminate the secondary variables charge and current from the system of relationships. Charge, Q, and current, I, are secondary variables because they do not appear in the definition of the system but are introduced through the relevant relationships. The relational groups corresponding to this electrical circuit can then be written as:

$$\left(\frac{t}{RC}\right)\left(\frac{Rt}{L}\right) \qquad (2)$$

The first of these is the time constant of a resistive and capacitative circuit combination and the second that of a resistive and inductive combination. The two groups are those usually used in specifying circuits of this type. Proposition (1) gives the number of relational groups as two, as there are four relationships and two secondary variables, hence $4-2=2$ relational groups.

Example of deflection of an elastic beam. This example has been discussed by Siano[8]

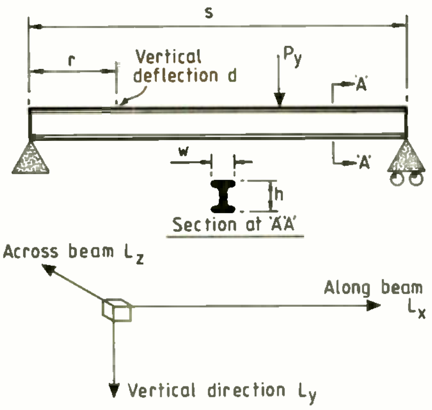


Fig. 1. Deflection of an elastic beam by vertical loading.

who shows that conventional dimensional analysis does not produce useful results in the analysis off this system. Figure 1 shows a non-uniform beam subjected to vertical loading and it is required to determine the relationship between the loadings, deflections and other relevant system parameters.

The dimensions in the three cartesian directions are treated as different types of quantity: to simplify the analysis representative quantities for length in the three directions are defined as L_x, L_y, L_z and the system measurements are all in proportion to them. Similar recognition of the directional nature of forces involved and elastic constants are made. The major approximation in the theory of elastic beams is that plane sections remain plane and that the deflection, d, at any point along the beam conforms to the relationship:

$$\frac{\partial^2 d}{\partial x^2}=\frac{\epsilon_x}{y} \qquad (3)$$

where ϵ_x is the strain in the x direction at distance y from the neutral axis.

This relationship is derived from the usual approximations in the theory of bending that the radius of curvature, of the deflected beam is given by:

$$\frac{1}{R}\approx\frac{\partial^2 d}{\partial y^2} \qquad (4)$$

The measurements for L_x, L_y, L_z strictly refer to dimensions of the beam before deflection: for this reason the vertical deflection d of the beam has been treated as a separate entity. The law of moments has been included in the list of relevant laws and relationships; it is essential to do this as that law is a necessary part of any full mathematical analysis of the system.

Table II. Relational analysis of electrical circuit containing capacitive, resistive and inductive elements. There are five primary variables, four relationships and two secondary variables. Rows 5 and 6 have been generated by the linear combination of rows 1 to 4 to form two relational groups which do not contain the secondary variables.

relationship	secondary variable		primary variable					notes
	I	Q	L	C	R	t	V	
(1) $Q=CV$		–1		1			1	relationship between voltage and charge.
(2) $V=IR$	1				1		–1	Ohm's Law
(3) $I=\frac{dQ}{dt}$	1	–1				1		definition of current
(4) $V=L\frac{dI}{dt}$	–1		–1			1	1	voltage-current relationship
(5) (3)–(1)–(2)				–1	–1	1		
(6) (2)+(4)			–1		1	1		

Table III shows the analysis. The computer software described in Appendix I or manual analysis generates the following relational groups:

$$\left(\frac{S^3P_y}{h^3E_x\omega d}\right)\left(\frac{r}{s}\right) \qquad (5)$$

These relational groups correspond to the results that are obtainable by mathematical analysis.

Example of a system with non-integral exponents. Non-linear relationships in electrical circuit analysis and fluid mechanics can in some circumstances be represented by power laws with non-integral exponents. The addition of a non-linear resistor to the system shown in Table II requires the inclusion of the additional relationship

$$V=KI^{\beta}$$

in the analysis.

If the analysis is performed with this additional relationship the relational groups that result are:-

$$\left(\frac{t}{RC}\right)\left(\frac{Rt}{L}\right)\left(\frac{V^{\beta-1}K}{R^{\beta}}\right) \qquad (7)$$

Modelling of this system then requires that all these three groups have the same value for system and model. Corbyn[9] has presented a conventional dimensional analysis of this problem.

The relational method of analysis presented permits the inclusion of parameters which are, conventionally, non-dimensional – for example the inclusion of strain in the analysis of a beam presented above. The method of analysis further enables the user to include functional relationships between parameters, which can be done by replacing equation (6) in the circuit example with the appropriate relationship.

Application of the method, computer software. Appendix I shows a computer program segment for performing relational analysis. This segment is part of a larger system for which the user enters the information shown in Table I. Provision is made for the user to modify this tabulated information and thereby generate various relational

Table III. Relational analysis of system for loading and deflecting a beam. Rows i and j are linear combinations of the other rows and represent the relational groups.

		Secondary variables						Primary variables						
	Relationship	L_z	L_y	L_x	σ_x	ϵ_x	P_x	r	d	w	h	s	P_y	E_x
a	Definition of strain ϵx, E_x				1	–1								–1
b	$\frac{\partial^2 d}{\partial x^2}=\frac{\epsilon_x}{y}$ Relationship between deflection and strain		–1	2		1			–1					
c	Law of moments		1	–1			1						–1	
d	Definition of σx	1	1		1		–1							
e	Definition of span			1								–1		
f	Definition of depth of beam		1								–1			
g	Definition of width of beam	1								–1				
h	Location of point of deflection			1				–1						
i	a+b–c–d–3e+3f+g								–1	–1	–3	3	1	–1
j	h–e							–1				1		

groups according to which laws or relationships are relevant. The application of relationships such as force = mass × acceleration are not relevant: this is easily done by the removal of such relationships from the list of laws.

The input to the computer system for relational analysis requires the user to specify the law or relationship involved as the product of the relevant quantities. The output is given as the relevant non-dimensional groups. The system is arranged to operate in an interactive mode, which has the effect of enabling the user to investigate the relational groups which arise according to the inclusion or exclusion of particular laws or relationships.

BUCKINGHAMS'S π THEOREM

Buckingham's π theorem relates the number of non-dimensional groups defining a problem to the number of variables involved and the number of significant dimensions. If the least number of fundamental units defining a problem is n and the number of variables to be related is p then Buckingham's theorem gives the number of non-dimensional groups as p-n.

One of the difficulties in applying Buckingham's theorem with current dimensional analysis practice, is in the decision as to what is a significant dimension. The relationship method obviates this difficulty by clearly stating the relationship between the quantities involved in the problem; the user of the analysis then deciding which relationships are relevant and which are not.

Buckingham's theorem can be derived in the following manner.

1. The number of separate variables between which a relationship is required is p. These may be termed the primary variables.
2. The number of additional quantities involved in the analysis of the problem is s. These may be termed the secondary variables.
3. The number of laws or relationships involved in the solution is l.
4. For each of the n fundamental units in the problem there is a law or relationship which will define the primary or secondary variables in these terms.
5. The number of groups needed to define the functional relationship between the parameters is $l - s$.
6. Each of the p original separate variables is definable in terms of the s secondary variables, which themselves include the n fundamental units, so that if d is the number of derived variables which are non-fundamental secondary variables
$$s = n + d \qquad (8)$$
7. The l laws or relationships comprise those associated with the definition of the p fundamental variables plus those associated with the d derived variables which themselves can be defined in terms of the d definitions of these derived variables in terms of the fundamental units. Hence
$$l = p + d \qquad (9)$$
8. Subtraction of (8) from (9) gives
$$l - s = p - n \qquad (10)$$
which is Buckingham's theorem

DEVELOPMENT OF UNIT SYSTEMS BY ELIMINATION OF DIMENSIONAL CONSTANTS

The present system of units comprises fundamental units for mass, length and time with units for force, electric current, electrical potential and other quantities derived through application of scientific laws. Units developed using the laws of electromagnetics are different to those developed using the laws of electrostatics: this is partly because the original electrical units developed by Weber and Gauss (1839 – 1845) were in use before Maxwell developed his equations (published 1885) which establish the relationship between these unit systems as the velocity of light.

Bridgman[4], Young[10] and others have discussed the elimination of dimensional constants from the laws of physics by the definition of units in such a way that the information which defines a unit is developed from one of the laws of physics. This method has long been used for defining units of force – the constant in Newton's second law is taken as unity.

Consider the following scheme of developent.

1. Selection of the second as the fundamental unit of time.
2. Definition of the velocity of light as unit velocity. This makes electrostatic and electromagnetic definitions of units the same.
3. Definition of unit length as the distance travelled by light in unit time.
4. Unit mass is defined as that mass which experiences unit acceleration towards a equal mass placed at unit distance, due to gravitational forces.
5. Definition of the permeability and permitivity of free space as unity.

Table IV shows the development of this scheme. A consequence of this is that all dimensions in the traditional sense are now defined in terms of time. The main dimensional constants of physics at the macro scale become unity.

The relationship, in any system of units

$$c = \frac{1}{\sqrt{\mu_0 R_0}} \qquad (11)$$

has been used in table IV to relate alternative developments.

The application of table IV to traditional dimensional analysis shows that the least number of non-dimensional groups that could emerge is one less than the number of primary variables. This is because the unit system implicitly assumes that the system being analysed conforms to Newton's law of gravitation, Newton's second law, the equations of electromagnetism and the equations of electrostatics, and that velocities are all relative to the velocity of light.

The conventional methods of dimensional analysis employing mass, length, time and other appropriate units work because the fundamental laws and relationships are implicit in the definition of relevant units and parameters. The usual method of incorporating the laws of physics at a macro scale into traditional dimensional analysis is by introducing the relevant physical constants as primary variables. In the relational method here described any laws or relationships of physics that are required must be explicitly defined.

```
Work arrays are SR(LN), HS(LN,SN),
HP(LN,PN)

5080 FOR I=1 TO LN:SR(I):NEXT I
5090 FOR JG =1 TO SN
5100 IG=0
5110 IG=IG+1:IF IG>LN GOTO 5310
5130 IF SR(IG)=1 GOTO 5110
5140 IF MS(IG,JG)=0 GOTO 5110
5150 REM Unused law with non-zero
     coefficient detected
5160 SR(IG)=1:X=MS(IG,JG)
5170 FOR J=1 TO SN:HS(IG,J)=MS(IG,J)/X
     :NEXT J
5180 FOR J=1 TO PN:HP(IG,J)=MP(IG,J)/X
     :NEXT J
5190 FOR I=1 TO LN
5200 IF MS(I,JG)=0 GOTO 5280
5210 T=MS(I,JG)
5250 FOR J=1 TO SN
5254 MS(I,J)=MS(I,J)-T*HS(IG,J)
5256 NEXT J
5260 FOR J=1 TO PN
5262 MP(I,J)=MP(I,J)-T*HP(IG,J)
5266 NEXT J
5270 MS(I,JG)=0
5280 NEXT I
5290 MS(IG,JG)=0
5300 GOTO 5110
5310 NEXT JG

After operation of the segment matrix
MP(I,J) carries the relational groups
describing the system in those rows
for which SR(I) is non - zero.
```

Fig. 2. Relational analysis program segment in Basic.

ARRAY MS(I,J)		ARRAY MP(I,J)				
0	-1	0	1	0	0	1
1	0	0	0	1	0	-1
1	-1	0	0	0	1	0
-1	0	-1	0	0	1	1

Arrays describing electrical system of section 2 before operation of program segment.

ARRAY MS(I,J)		ARRAY MP(I,J)				
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	-1	-1	1	0
0	0	-1	0	1	1	0

Arrays describing electrical system after operation of program segment.

Fig. 3. Application of the program segment to determination of relational groups in the electrical system shown in Table II. Expressions (2) show the relational groups.

CONCLUSION

An alternative to classical dimensional analysis may be constructed which involves specification of the scientific laws and relationships involved rather than the implicit assumption of such laws through the selection of definitions and unit systems appropriate to the system being analysed. Using this method, systems involving 'dimensionless' variables, vector representations, non-integral exponents in scientific laws and the planned non-inclusion of certain relationships may be analysed. The advantage of the method described is in the clarification of the system and the application of computers to analysis.

Table IV. The development of a system of units and physical laws at a macro scale without dimensional constants or primary standards. The above system is based on the second.

quantity	definition and defining equation	general formulae	numerical relationship to S.I. units	dimension
charge, q	unit electrical charge at unit distance from a similar electrical charge repels it with unit force in vacuo. $f=\frac{q_1q_2}{k_0r^2}$ where $k_0 = 8.854185\times10^{-12}$ F/m	$C^3S\sqrt{\frac{k_0}{G}}$	3.479993×10^{25} coulomb	T
magnetic pole, m	unit magnetic pole at unit distance from a similar pole repels it with unit force in vacuo. $f=\frac{m_1m_2}{\mu_0r^2}$ $\mu_0=1$ in e.m.u./c.g.s. units	$C^3S\sqrt{\frac{\mu_0}{G}}$	1.04327×10^{35} e.m.u.	T
magnetic flux density	unit magnetic flux density is that flux density in which unit magnetic pole experiences unit force.	$\frac{C}{S}\sqrt{\frac{\mu_0}{G}}$	1.160801×10^{10} tesla	T^{-1}
current	rate of flow of electrical charge.	$C^3\sqrt{\frac{k_0}{G}}$	3.47999×10^{25} amperes	1
magnetic flux density (current definition)	magnetic flux density due to current element length ds, strength i at a distance r measured normal to direction of current is $\frac{\mu_0 ids}{r^2}$	$\frac{C^2}{S}\sqrt{\frac{k_0}{G}}\mu_0$ or $\frac{C}{S}\sqrt{\frac{\mu_0}{G}}$	1.16080×10^{10} tesla	T^{-1}
time, t	fundamental unit taken to be one second	S	1	T
velocity, v	unit velocity is the velocity of light in vacuo	C	2.997925×10^8 m/s	1
length, l	distance travelled at unit velocity in unit time	SC	2.997925×10^8 m	T
acceleration, a	rate of increase of velocity	$\frac{C}{S}$	2.997925×10^8 m/s^2	T^{-1}
mass, m	unit mass at unit distance from a equal mass accelerates towards it with unit acceleration due to gravitational attraction. $ma=\frac{Gm^2}{r^2}\therefore m=\frac{ar^2}{G}=\frac{(2.997925\times10^8)^3}{6.670\times10^{-11}}$ $=4.03958\times10^{35}$kg	$\frac{C^3S}{G}$	4.03958×10^{35}kg	T
force, f	unit mass subjected to unit force accelerates at unit rate. f = ma $f=4.03958\times10^{35}\times2.997925\times10^8$ Newtons	$\frac{C^4}{G}$	1.211036×10^{44}N	1
work, w	unit force moving unit distance in its line of action	$\frac{C^5S}{G}$	3.630596×10^{52}J	T
magnetic flux	flux density times area	$C^3S\sqrt{\frac{\mu_0}{G}}$	1.043276×10^{26} weber	T
voltage induced by a change in magnetic flux	rate of change of magnetic flux	$C^3\sqrt{\frac{\mu_0}{G}}$	1.043726×10^{26} volts	1
voltage defined in terms of charge	the potential difference between two points is the work done in taking unit charge from one point to the other. The alternative general formulae for unit voltage arises from the relationship between C, k_0 and μ_0.	$C^2\frac{1}{\sqrt{k_0G}}$ or $C^3\sqrt{\frac{\mu_0}{G}}$	1.043276×10^{26} volts	1

Relational analysis can be associated with a theorem similar in scope and application to Buckingham's π theorem. The development of comprehensive unit systems involving the laws of physics to generate definitions of units can be used to demonstrate the difficulties inherent in classical dimensional analysis.

APPENDIX I PROGRAM SEGMENT FOR RELATIONAL ANALYSIS

A program segment for performing relational analysis in the Basic language is shown in Fig. 2. Figure (3) shows the application of the program to the electrical circuit analysed in section 2.

LN is number of laws relating the quantities in the system, l of Section 3.

SN is number of secondary quantities in the system, s of Section 3.

PN is number of primary quantities in the system, p of Section 3.

MS(I,J) is the matrix of coefficients giving the index MS(I,J) of law I for secondary quantity J. Modified by segment.

MP(I,J) is the matrix of coefficients giving the index MP(I,J) of law I for secondary quantity J. Modified by segment.

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Closing the loop

Using an intuitive approach, closed-loop digital control of a linear system is easy to understand without in-depth knowledge of theory.

HOWARD HUTCHINGS

Closed-loop control is an important microcomputer application and a specialist area. Connecting a microcomputer to an external device is an effective way of acquiring an understanding of computer control.

A study of dynamic systems ought to include exposure to differential equations, followed by familiarity with Laplace and z transforms. I do not intend to pursue these topics in this hierarchical way since only one student in ten is likely to benefit from this approach.

This article demonstrates how to interface a linear system – a d.c. motor – to a digital computer. To keep the discussion lively, mathematical explanations are auxiliary to the main text and mathematical methods are only used when essential.

Provided that the system to be controlled is selected carefully, Basic is a reasonably effective and attractive programming language. It permits rapid implementation of control algorithms, and is easier to learn and use than assembly language.

OPEN-LOOP CONTROL

The primitive concept of sending bit patterns to the outside world can produce remarkably sophisticated electronic projects with a minimum of hardware, principally because most of the problem is solved using software, Fig.1. Program 1 is a simple piece of Basic software for sending keyboard input to the motor controller through the v.i.a. port.

Bidirectional control of the motor is possible using a split-rail supply and power amplifier, Fig.2. For convenience I used a complete ZN425 digital-to-analogue converter instead of a binary-weighted adder. A signal of denary 128 applied to the d-to-a converter through the computer's parallel output port represents 0V at the motor terminals. Buffering between the d-to-a converter and power amplifier provides voltage gain and offset adjustment.

In the following example, interfacing is done through a 6522 v.i.a. To count shaft revolutions, an encoder disc mounted on the motor shaft interrupts infra-red light from an optical switch containing a led and phototransistor.

Maintaining a software-controlled shaft-revolution counter reduces cost. It also permits the problem to be solved using the v.i.a. timer/counter facilities, which is instructive and not too time consuming.

MEASURING ROTATIONAL SPEED

Hardware for measuring rotational speed is simply a pair of Nand gates providing the necessary signal conditioning, Fig.3. Gates with Schmitt-trigger inputs (74132) improve the pulse shape feeding the computer.

To restrict external electronics to a minimum, both timers within the v.i.a. are needed, one to produce a known-width gating pulse and the other to count the number of pulses during the gating period.

Timer T_2 of the v.i.a. has two operational modes controlled by bit 5 of the v.i.a. auxiliary-control register, a.c.r. Setting this bit high causes timer T_2 to decrement each

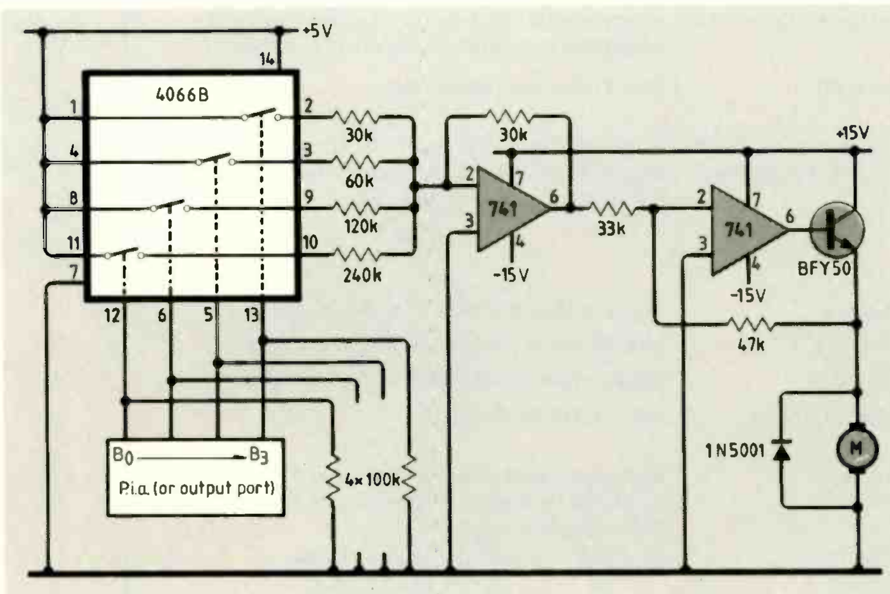


Fig. 1. Hardware for computer speed control of a d.c. motor is simple – most of the work is done by software. Diagram courtesy of Loveday, Practical interface circuits for micros, published by Pitman.

Program 1. Using keyboard input to control motor speed.

```
10 REM Keyboard control of motor speed
20 A = 40960: REM Start address of v.i.a.
30 POKE A + 2, 15
40 INPUT X
50 IF X<0 OR X>15 THEN END
60 POKE A,X
70 GOTO 40
80 END
```

Program 2. Motor speed and digital revolution counting.

```
10 REM Motor speed control with rev/min
counting
20 A = 40960: REM Port B of v.i.a.
30 POKE A+2,128: POKE A+3,255: POKE
A+11,244
40 INPUT X
50 IF X<0 OR X>15 THEN END
60 POKE A+1,X
70 POKE A+8,255: POKE A+9,255
80 POKE A+4,96: POKE A+5,234
90 IF PEEK (A+13) AND 64 THEN 100
   ELSE 90
100 C=65535 -
   (PEEK(A+8)+256★PEEK (A+9))
110 PRINT "Rev/min=";10★C
120 GOTO 70
130 END
```

Program 3. Closed-loop control.

```
10 REM Closed-loop control —60ms count
20 A = 40960
30 POKE A+2,128: POKE A+3,255: POKE
A+11,244
40 INPUT"Select speed by pressing keys in
the range 0 to 255";X
45 S = 4★(128-X)
46 S = ABS(S)
50 IF X<0 OR X>15 THEN END
60 POKE A+1,X
70 POKE A+8,255: POKE A+9,255
80 POKE A+4,96: POKE A+5,234
90 IF PEEK (A+13) AND 64 THEN 100
   ELSE 90
100 C=65535 -
   (PEEK(A+8)+256★PEEK(A+9))
110 PRINT "Rev/min =";10★C
115 PRINT "Set point =";S
116 IF X<128 THEN 190
120 IF S = 10★C THEN 60
130 IF S>10★C THEN 170
140 IF S<10★C THEN 170
150 X = X+1
160 GOTO 60
170 X = X-1
180 GOTO 60
190 IF S = 10★C THEN 60
200 IF S>10★C THEN 170
210 IF S<10★C THEN 150
220 END
```

MATHEMATICAL MODEL

Mathematical modelling is a judicious mixture of skill and experience. From experience, I know that the motor's dynamic characteristics can be modelled as a first-order lag of the form,

$$G(s)=\frac{a}{s+a}$$

The d-to-a converter is modelled by a zero-order hold, so that open-loop response can be expressed as,

$$\frac{Y(s)}{X(s)}=\left[\frac{1-e^{-sT}}{s}\right]G(s)$$

which may be written in terms of z transforms as,

$$\frac{Y(z)}{X(z)}=(1-z^{-1})\mathcal{Z}\left[\frac{ka}{s(s+a)}\right]$$

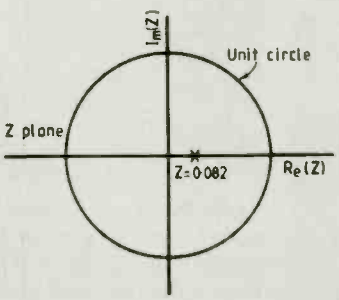
$$=\frac{z-1}{z}\left[\frac{z(1-e^{aT})k}{(z-1)(z-e^{-aT})}\right]=\frac{k(1-e^{-aT})}{z-e^{-aT}}$$

where $\mathcal{Z}$ means look up the z transform of the sampled-data Laplace transform and k is open-loop gain obtained experimentally (k=4).

To use this transfer function effectively it is necessary to evaluate the signal-processing time T and the time constant of the system. These were obtained experimentally, the values being 100ms and 40ms respectively. Substituting these numerical values into the transfer function gives,

$$\frac{Y(z)}{X(z)}=\frac{3.762}{z-0.082}$$

The system pole is located at z=0.082 as shown in the open-loop pole diagram below.



By intrepreting z and z^{-1} as a unit time advance and delay respectively, the transfer function can be decomposed into a recurrence relationship,

$y(n+1)=zy(z)$

$y(n-1)=z^{-1}y(z)$

$y(z)(z-0.082)=3.672x(z)$

so that

$y(n)=0.082y(n-1)+3.672x(n-1)$.

To use the recurrence relationship effectively, a systematic approach is required. Response of the open-loop system to a step input is shown below, truncated to the first five terms.

It is easy to keep track of the recurrence formula by adopting 'backward arrow' notation so that any carried-over results can be monitored as they ripple through the formula.

Sample number	Previous input	Current input	Previous output	Current output
0	0	1	0	0
1	1	1	0	3.672
2	1	1	3.672	3.973
3	1	1	3.973	3.997
4	1	1	3.997	3.999

EFFECT OF THE CONTROLLER

When an error between the nominated set point and the monitored output exists, the action of the program is to effect an incremental control on the bit pattern present at the output port. For a positive error, the controlling action is of the form,

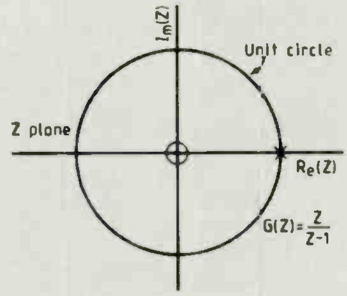
current output = previous output + 1

or

$y(n)=y(n-1)+x(n)$.

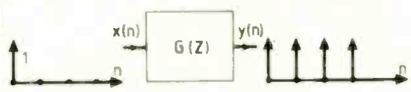
Expressed in terms of z transforms, this gives the transfer function of the controller,

$$\frac{Y(z)}{X(z)}=\frac{z}{z-1}$$



which is the digital equivalent of an analogue integrator.

In this diagram of the integrator pole-zero model, the pole is located on the circumference of the unit circle so the integrator is conditionally stable.

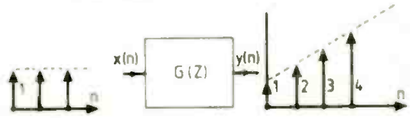


Impulse response of a backward integrator to a sampled data sequence.

n	x(n)	y(n−1)	y(n)
0	1	0	1
1	1	1	2
2	1	2	3
3	1	3	4
4	1	4	5

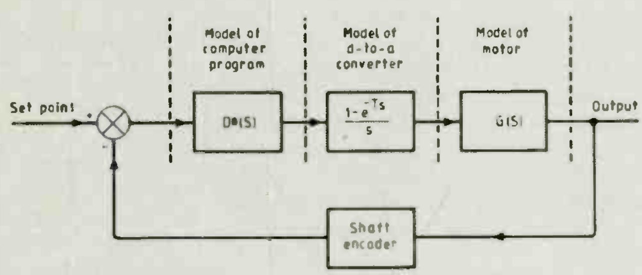
n	x(n)	y(n−1)	y(n)
0	1	0	1
1	0	1	1
2	0	1	1
3	0	1	1
4	0	1	1

This information relates to step response of a backward integrator to a sampled data sequence.



The computer program containing the recurrence relationship is modelled by the z transform D(z). Both the d-to-a converter and motor are modelled by the zero-order hold cascaded with G(s).

This is the system diagram.



The closed-loop transfer function is,

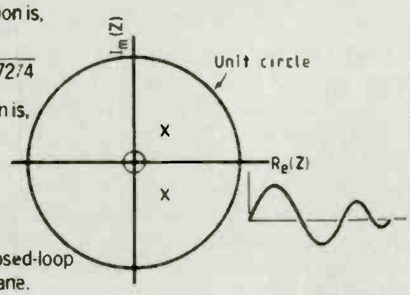
$$\frac{C(z)}{R(z)}=\frac{3.672z}{(z-1)(z-0.082)+z3.6727 4}$$

and the characteristic equation is,

$z^2-z(0.164)+0.082=0$

Pole locations are,

$z=0.082\pm j0.274$.



This diagram shows the closed-loop pole-zero positions on the z plane.

Since the poles are located within the unit circle, the system will be stable. Transient response of the closed-loop system may be obtained by expressing the z-transfer function as a recurrence relationship.

Proceeding as before,

$$C(z)[z^2-z0.164+0.082]=3.672\,z\,R(z)$$

$$C(n+2)-0.164\,C(n+1)+0.082\,C(n) = 3.672\,R(n+1)$$

$$C(n)=0.164C(n-1)-0.082C(n-2)+3.672R(n-1).$$

Impulse response is,

Sample number n	Current input R(n−1)	R(n)	Current ouput C(n−2)	C(n−1)	C(n)
0	0	1	0	0	0
1	1	0	0	0	3.672
2	0	0	0	3.672	0.602
3	0	0	3.672	0.602	−0.202
4	0	0	0.602	−0.202	0.082

time that control-line PB_6 goes low.

Loading of timer T_2 with 65535 is done by Poking 255 into low-order latch A+8 and high-order counter A+9 respectively. Timer T_1 produces an output on line PB_7 in monostable mode. In this mode, PB_7 goes low for a period determined by the contents of registers A+4 and A+5, which constitute timer T_1.

Consider counting pulses from the opto-electronic switch for 60ms. Since number N loaded into the computer is measured in microseconds, the counter is loaded with 60 000. This number is represented in the computer as two bytes. For the most-significant value in A+5, the byte is INT(N/256) and for the least-significant value in A+4, the byte is N-256[INT(N/256)].

In the previous software example, timer T_1 is loaded with 60 000 by writing POKE A+4,96: POKE A+5,234. When timer T_1 times out, a flag is raised in interrupt-flag register A+13. This flag is tested by the logical And function.

Finally, the number of pulses counted is the difference between 65535 and the current content of timer T_1.

SPEED MEASUREMENT USING ENCODER DISC

Consider an encoder disc with 100 lines on a motor shaft rotating at 120rev/min. Each second, 200 lines interrupt the opto-electronic switch slot (120×100/60).

By allowing the count to be maintained for 60ms, the counter will record a count of 12, i.e. $60\times10^{-3}\times200$, which represents one tenth of the true speed. To convert to true speed, the recorded count is multiplied by ten, or alternatively, the ratio and proportion,

$$\frac{60\text{ms}}{60\text{s}} = \frac{c/100}{\text{rev/min}}$$

is used. Here the true number of revolutions per minute is 10c. Program 2 illustrates motor control with revolution counting.

Resolution could be improved by increasing the count period up to about 65ms using the timer in the 6522 v.i.a. or by increasing the number of lines on the encoder disc. One problem is that the longer the time spent counting, the shorter the time available for controlling. While pulses are being counted,

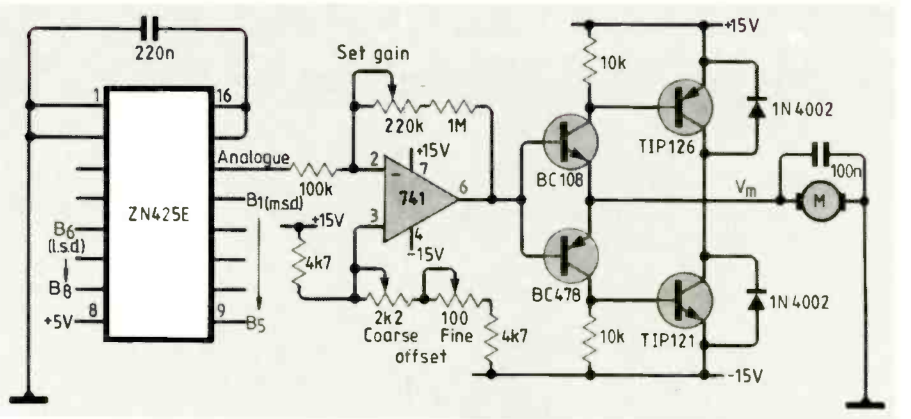


Fig.2. Bidirectional speed control of a d.c. motor with split supply rail and monolithic d-to-a converter. An encoder disc on the motor shaft provides digital information representing rotational speed for software processing.

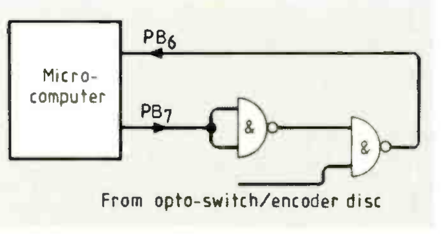


Fig.3. Pulses from the opto-electronic switch on the encoder disc are gated through to input PB_6 for counting when output PB_7 is low. Width of the PB_7 pulse is accurately fixed so motor speed can be determined by counting the number of pulses within the gating period.

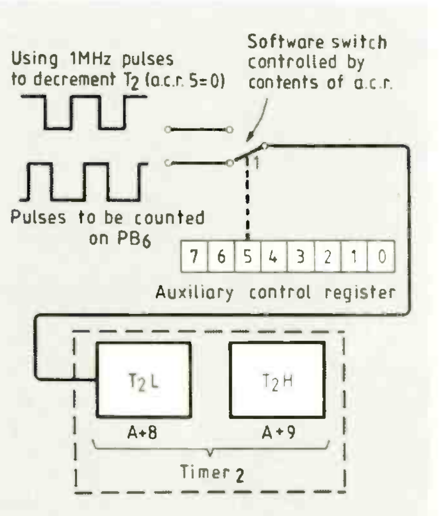
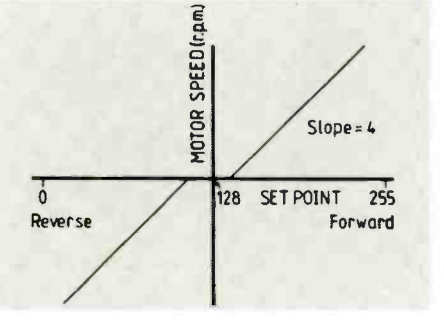


Fig.4. The v.i.a's second timer has two modes controlled by bit 5 of the auxiliary control register. When this bit is high, the timer is decremented each time that input PB_6 goes low.



◄Fig.5. Relationship between set-point keyboard input and motor speed.

the motor effectively runs under open-loop conditions so there must clearly be a compromise between stability and resolution.

CLOSED-LOOP MOTOR CONTROL

Having established a digital feedback system exists, the loop can be closed to allow the computer to control the motor's speed. Keyboard input determines the set point, which is processed in line 45 of the routine for closed-loop control, Program 3.

Open-loop motor-amplifier characteristics are shown in Fig.5. If motor load increases, tending to slow it down, drive is increased to the motor by incrementing the bit pattern on the output port, which is done in program line 150. Conversely if the motor tends to speed up, line 170 serves to decrement the port. When the error is zero, nothing is done.

Because the d-to-a converter is chiefly intended for unipolar operation, an output voltage of zero requires a digital input of 128, which is half way up the converter's input range of 0–255. To increase speed in the reverse direction therefore requires decrementing port value X and incrementing it to decrease speed – which is back to front. Program line 116 takes care of this.

Having constructed the system and successfully executed the algorithm, it is satisfying to produce a mathematical model of the controlled system to give this intuitive design a more rigorous basis (see p.1223).

Try a few experiments. Deliberately introduce time delay into the system to reduce the sampling rate and note when the system becomes unstable. If the incremental algorithm is too gentle for your needs, why not try bang-bang control? Increase the complexity of the motor by adding mass and damping to the motor shaft. Is the system still well behaved?

If you need more information, try reading Digital Control Systems by Benjamin Kuo (pub. Holt, Rienhart and Winston).

Howard Hutchings is a lecturer at Humberside College of Higher Education. He is also a part time tutor with the Open University

Advanced engine management systems

The trend towards total engine management is creating a need for ever more powerful microcontrollers. Pat Jordan of Motorola surveys the uses of microelectronics in fuel injection and transmission control.

PATRICK D. JORDAN

Fuel injection systems, like many developments in automotive applications, were pioneered on racing engines and were originally totally mechanical (apart from the fuel pump). Indeed many systems on cars today are mechanical: one example is the Bosch system fitted to the Ford Escort XR3i.

Jaguar's V12 on the other hand has for many years been fitted with electronic fuel injection, supplied by Lucas. This was originally an analogue system but later it became microprocessor-controlled, based on the Motorola 6801. Likewise BMW have fitted electronic fuel injection for many years; early systems were based on the RCA 1802 microprocessor.

In many cases, fuel injection systems were fitted only where more power was required. But with the continual tightening of emissions legislation, fuel injection is becoming more common on today's cars although it is still largely confined to those in the higher capacity range. US makers continue to lead the field owing to their much tighter emissions regulations and larger engines.

Fuel injection systems fall into two categories, single point and multi-point. Single point (or throttle body) fuel injection, as the name suggests, involves only one injector in the main body of the inlet manifold in a similar position to the carburettor. It has an obvious cost advantage. Multi-point fuel injection, however, gives much more accu-

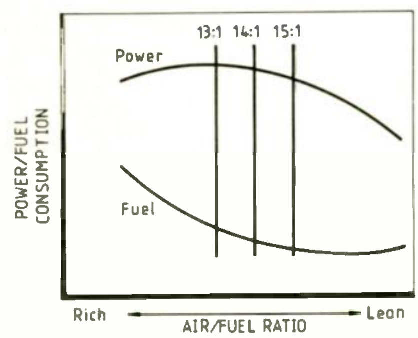


Fig.1. For minimum emission of carbon monoxide and unburnt hydrocarbons, an engine must work at the stoichiometric air-to-fuel ratio of 14:1. This means striking a compromise between maximum power and minimum fuel consumption.

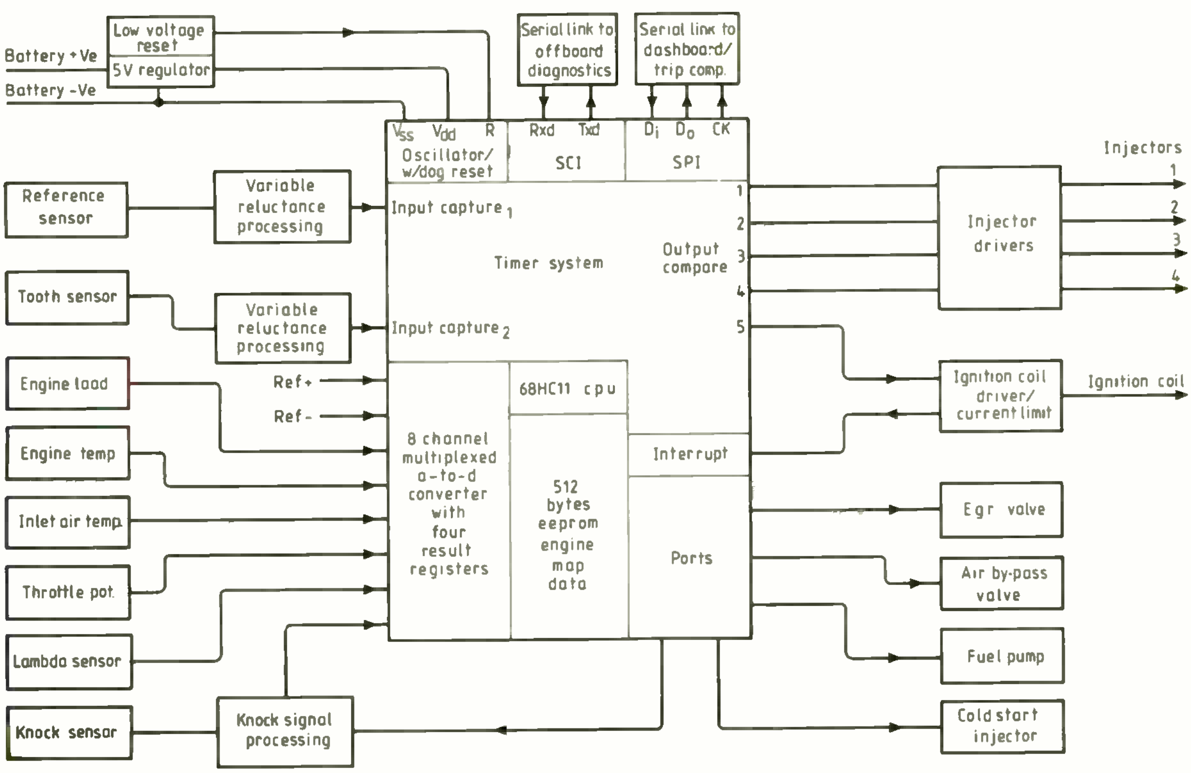


Fig.2. Motorola's powerful 68HC11 controller can handle both multi-point fuel injection and ignition control.

rate control over the amount of fuel injected. For each cylinder there is one injector which injects into the inlet manifold immediately prior to the inlet valve while the valve is open.

Electronic fuel injection is a constant fuel pressure system; therefore the quantity of fuel injected is detemined purely by the time the injector is open. But in practice, controlling the injector is not quite that simple.

PRINCIPLE OF FUELLING

Electronic fuel injection (e.f.i.) works by determining the mass of air drawn into the engine and injecting the appropriate amount of fuel to produce a combustible mixture. The optimum ratio of air to fuel is known as the stoichiometric ratio and it has a value of 14:1. This means that for every 1kg of fuel we require 14kg by weight of air; or in terms of volume we require approximately 9800 litres of air to one litre of fuel.

If a stoichiometric mixture is achieved, *complete* combustion should occur and all unburnt hydrocarbons and carbon monixide should be eliminated. The problem, however, is that spark ignition engines operate at maximum efficiency with the slightly richer mixture of 13:1 and run most economically with a mixture of 15:1 (Fig.1). A rich mixture increases fuel consumption and exhaust gas emissions, a weak mixture causes loss of power and engine overheating; and so a compromise must be achieved.

The main drawback of the carburettor is that it can be calibrated to produce a stoichiometric mixture at only one given air density. Air density, however, varies with temperature and altitude, factors which an e.f.i. system can take into account. If the volumetric efficiency of an engine remained constant, the task of the e.f.i. system would be very simple in that a fixed quantity of fuel could be injected irrespective of engine speed. The volumetric efficiency does, however, rise with engine speed and taper off at high revs.

In many respects the fuelling system is very similar to the ignition system in terms of the inputs and control required*. As before, the primary inputs are engine speed and engine load (air mass); however, the method of detection is generally different. Engine speed can be derived from a sensor in the same way as for the ignition system, but it is most commonly taken from the ignition coil negative terminal.

Air mass is measured by two common methods: by a silicon strain gauge pressure transducer (as for the ignition system), or by an air mass flow meter which may be the mechanical flap type or the hot-wire air mass flow meter. As with the ignition system, these two primary inputs are used to address a matrix of injector on-time versus engine speed and load; the injector is fired accordingly.

E.F.I. CONTROL UNIT

The description of how the e.f.i. system works (see panel) demonstrates the number of variables involved in such a system and the complex task of the control unit in monitoring all these inputs and scheduling the appropriate amount of fuel. The processor required to control this must have a greater processing power and/or more hardware features than are required for an ignition system.

The controller's first task is to determine engine speed from the crank shaft sensor or coil negative pulses. This can be done via the interrupt pin of the processor but it takes a fast processor with low interrupt latency (time required to stack machine status and respond to the interrupt) to measure high speeds accurately.

A much better solution is to make use of a timer with 'input capture' facility. This will automatically latch the contents of a free running timer when an edge occurs on an external pin and, if desired, will interrupt the processor. This ensures that the captured value for engine period is accurate to within one clock period of the timer. Because of the reciprocal relationship of period to speed, a 16 bit division may then need to be performed (depending on how the software is implemented) and it may be an advantage to have this available as a single instruction.

As well as engine speed, the air mass must be known and, this requires an a-to-d converter to produce a usable digital representation. Converters are required for all other analogue inputs, such as engine temperature, air temperature, oxygen sensor and throttle potentiometer.

In a similar manner to the ignition system, the e.f.i. unit uses the primary inputs of engine speed and air mass to address a look-up table (in rom or eeprom) and determines the optimum amount of fuel (injector on-time) required under these conditions to produce a stoichiometric mixture. This look-up table is the result of months of tests on several engines under every combination of conditions.

All other inputs to the control unit are generally some form of modification of these two primary inputs, but they may interact with each other and so demand processing power from the micro. The closed-loop system, by means of the lambda (oxygen) sensor, puts an additional burden on the micro to monitor an analogue input, which is effectively a representation of efficiency, and compensates accordingly. Having determined what the appropriate amount of fuel should be for that cylinder, the processor must then schedule the firing of the injector at the correct time and for the correct duration.

Clearly, if the processor has to time in software or to monitor a timer until the required firing point is reached, then the time is lost when it should be calculating the required fuel for the next firing cylinder. For this reason the 'output compare' facility of the timer is essential. This enables the processor to program latches in advance with the desired firing point and the duration (or off-point). While the processor goes about its business, the compare latches will automatically turn the injector on and off.

Two examples of microcontrollers well suited to this kind of system are Motorola's

*An article by Pat Jordan describing the principles of microprocessor-controlled ignition systems appeared in Electronics & Wireless World in the September issue, page 876.

HOW AN ELECTRONIC FUEL INJECTION SYSTEM WORKS

The fuel pump (see diagram on right) pumps fuel from the tank into the pressurized injector system. A constant pressure (around 200kPa or 30p.s.i.) is maintained by the pressure relief valve which releases excess fuel back into the tank.

The electronic control module obtains information on engine speed from the ignition coil negative terminal. Information on air mass is derived from a silicon strain gauge pressure transducer which measures the depression in the inlet manifold. The pressure sensor for fuelling systems generally measures absolute pressure (referenced to a vacuum) so that changes in air pressure due to altitude can be taken into account. Other inputs which have an effect on the amount of fuel required are engine temperature and air temperature which are measured by means of thermistors in the coolant and in the inlet manifold respectively.

To assist in starting, a cold start injector is mounted just downstream of the throttle butterfly and this injects extra fuel when the engine is cold and the starter is operated. This is required to compensate for fuel which condenses on the walls of the manifold when the engine is cold. It has a timeout (usually around eight seconds) to avoid flooding the engine.

In addition to the extra fuel required when the engine is cold, extra air is needed to overcome the increased frictional losses of the engine and to maintain a high idle speed. This is achieved by means of the auxiliary air-pass valve which allows air to bypass the throttle and thereby increase the idle speed. Additional information on the engine demands is derived from the throttle switch. Many different types of throttle switch exist but most commonly they consist of some form of switch and potentiometer, from which is derived information about when the throttle is closed and when acceleration is demanded. On overrun (deceleration with foot off the throttle), the e.f.i. system cuts off the fuel supply to reduce consumption.

When the engine is idling (throttle closed and engine below, say, 1000 rev/min), fine adjustments are made to stabilize the idle speed. The exhaust gas recirculation valve can be opened to recirculate some of the unburnt gases, thereby reducing emissions; this reduces power but is of little concern when idling. The rate of change of voltage from the potentiometer indicates to the e.f.i. system when acceleration is demanded, and extra fuel is injected to compensate for the engine's inability to react rapidly to sudden increases in the amount of air intake (similar to the accelerator pump on the conventional carburettor). Further, the throttle switch indicates when the throttle is fully open and maximum power is required.

If the e.f.i. system then schedules the correct amount of fuel for the given conditions, a stoichometric mixture should be obtained and emissions should be minimized. This can then be monitored by means of the oxygen sensor mounted in the exhaust pipe. Excess oxygen indicates incomplete combustion (hence high emissions) and the quantity of injected fuel can be altered to compensate.

MC68HC05B6 and MC68HC11A8. Both devices feature rom, ram, non-volatile eeprom, eight channel multiplexed a-to-d and a complex serial communications interface and timer structure. The MC68HC05B6 has two capture inputs and two output-compare registers. The MC68HC11 has three capture inputs and five output compares (one could be used for each injector on a four cylinder engine). The 68CH05 instruction set has some very powerful instructions in the form of bit manipulation and conditional branches on bits of registers or ports (e.g. BRSET 7, PORTA), as well as a multiply instruction. The 68HC11 instruction set has all the HC05 bit manipulation but also allows multiple bits to be set or cleared by specifying a mask. It also contains two eight bit accumulators which can be concatenated to one 16 bit accumulator. There are many 16 bit instructions such as 16 bit integer and fractional multiply and divide. Furthermore it contains two 16 bit index registers which can be used for indirect addressing anywhere in its 64K memory map (when used in expanded mode, 8K internal rom).

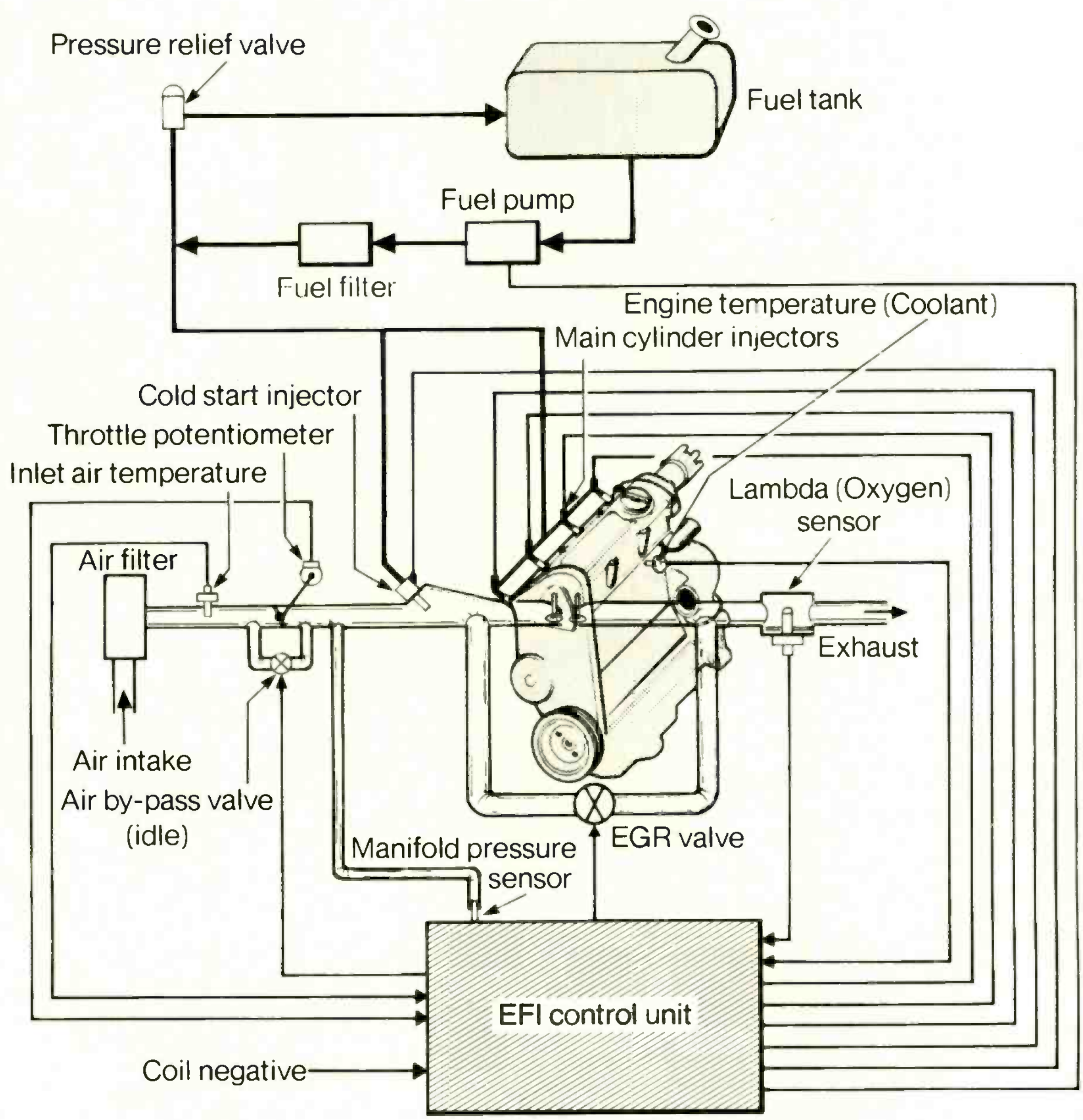
ENGINE MANAGEMENT

Electronic engine management in its simplest form implies merely the combination of the ignition system and the e.f.i. system into one control unit. This is a natural progression as many of the inputs for ignition and fuelling are derived from the same source. The number of inputs, outputs and the amount of computation involved require that processing power equivalent to that of the MC68HC11 is required even for just these two functions (Fig.2 shows an example of such a system).

However, engine management can involve much more than just ignition and fuelling: in its true form it means total control over all engine functions and the drive train. Since there is a marked interaction between the type and quantity of fuel injected and the corresponding ignition timing, it makes sense to co-ordinate these two functions along with the feedback received from the knock sensor and the lambda sensor.

Engine management also incorporates stabilization of the idle speed. This can be

Because of the large number of parameters to be measured and controlled, a fuel injection system consists of many components.



done by modifying either the ignition timing or the intake of air, but it is most effectively done by modifying both together. A fast response is then achieved by modifying the timing (as air intake has a relatively slow response time) and dynamic range is obtained by controlling an air by-pass valve on the throttle. Timing varies idle speed only within very tight constraints and to the detriment of emissions.

An additional function of a full engine management system is control over the drive train or gear box: the power developed at the wheels is clearly also a function of gear ratios. In such a system the drive train would be some form of electronically-controlled automatic gearbox or continously variable transmission (c.v.t.). Indeed Ford (on the Fiesta) and Fiat (on the Uno) have simultaneously released their CTX (Continously variable TransaXle) system which they jointly developed with van Doorne of Holland.

This system is an evolution of the old DAF Variomatic but differs mainly in that the belt is now steel and is pushed instead of pulled. The transmission consists basically of two wet plate clutches (running in oil to allow slip without overheating), one for forward and one for reverse, and two V-shaped pulleys around which the V-shaped steel-block belt is driven.

As the two halves of the pulley separate, the belt will move toward the centre of the pulley: therefore a low ratio is selected by opening the engine driven pulley (small diameter) and closing the pulley which drives the wheels (large diameter). The converse is true for a high ratio and there is an infinite number of ratios between the two extremes. The pulley diameter is modified by an engine-driven pump which is controlled from a hydraulic valve chest.

Parameters which the valve chest requires to determine the ratio are engine speed, road speed, engine load and the position of the driver's PRDNL selector. Knowing this it can determine which clutch should be engaged and the optimum ratio. Although this particular system is completely hydraulic it is an ideal example of one where electronic control could be used. This c.v.t. offers an advantage in that the ratio can be varied from 7.1km/h per 1000 rev/min to 40.4km/h per 1000 rev/min, a range which would compare to a six-speed manual box. Also it is potentially very efficient in that the engine can be allowed to run closer to its optimum revs (around 1500 to 2000 rev/min for most cars). Indeed the fuel consumption figures for the c.v.t. compare favourably with those of the manual equivalent, although on average they are still slightly worse.

Another system which has been under development for some time by Lucas is the Perbury c.v.t., but this has not yet been developed to a production status. Its advantage is that it has no belt (a rather complex construction of steel V-blocks on a steel band) and is more like a variable ratio coupling.

A variation on drive train control which has been implemented on a production vehicle is the Volkswagen Formel E. This turns off the engine automatically when the car is stationary to save fuel, and starts the engine again when the throttle pedal is pressed. The system is based on a dual clutch which can disengage the flywheel from both the engine and the gearbox, thereby retaining energy in the flywheel which can later restart the engine. Should the flywheel lose its energy, the starter motor is used to add more. This is all done automatically by a microprocessor-based control unit and is transparent to the driver.

DIAGNOSTICS

The ever-increasing complexity of engine control systems has made it impossible for the average garage mechanic to debug a fault in the system. Indeed this would be an almost impossible task even for the designer of the system, and so facilities have to be provided to help identify faults when they occur.

For these reasons and the pure economics of warranty returns, all new systems incorporate some form of diagnostic aid. Many systems have quite complex self-diagnostic facilities where the control unit will regularly monitor its own performance (perhaps via the closed-loop feedback from the knock and lambda sensors) and that of the sensors by checking calibration at power-up. The more sophisticated systems will indicate a fault to the driver. Current BMWs give an indication of when a service is due, basing it on how hard the car has been driven.

Besides the self-diagnostic facility, a capability can be provided for 'off-board diagnostics' whereby the garage mechanic will be able to plug his test equipment into the vehicle harness to read out any fault information and execute specific tests on sensors and controllers. This form of communication calls for an on-chip serial interface such as is available on the MC68HC11 and MC68HC05, which can communicate with a terminal or a personal computer. The serial peripheral interface, on the MC6805S3 for example, although a synchronous interface, can also be used asynchronously in a similar manner.

The combination of communications interface and eeprom on the same device also offers tremendous possibilities for diagnostics. Firstly, the self-diagnostic routine can store messages in eeprom when a fault occurs, for later analysis by the off-board diagnostics (this could be especially useful for intermittent faults). Secondly, if engine characteristics are stored in eeprom they can be altered or updated by the garage during a service. The possibilities are endless.

FUTURE OF ENGINE CONTROL

This may all seem very advanced, but believe me, there is better yet to come. Developments are currently under way on self-optimizing and self-adaptive systems for engine control. The drawback of all the systems described previously is that they rely on the accurate mapping of an engine on the test bed to derive the ideal characteristics for ignition timing and injector on-time for any engine condition. Unfortunately, one engine is never the same as the next coming off the production line, and as the engine wears its characteristics may change for the worse and may result in excessive emissions.

The self-adaptive system gets around this problem by monitoring its own performance against its mapped timing. It has the facility to modify certain parameters if it goes out of calibration. A self-optimizing system, on the other hand, does not rely on any mapped characteristic but runs continuously in a closed-loop mode searching for the optimum performance. This (provided it can be made to work reliably) has the obvious advantage of doing away with the need for mapping an engine and it will self adjust as the engine wears.

'Drive by wire' is another intriguing concept, where engine management and continuously variable transmission go hand in hand. In this case the throttle pedal is not connected directly to the actual engine: it is merely a potentiometer connected to the control unit. By detecting the position of the pedal, the control unit determines how much power the driver requires from the engine and automatically selects the best engine speed and gear ratio. This may be a trifle disconcerting to the unsuspecting driver, since engine revs may no longer bear any relation to road speed. However, it is quite easy to become accustomed to. The name is derived from the 'fly by wire' principle applied to fighter aircraft which are inherently unstable and require the help of a computer to control them.

All these advances in engine design, research into alcohol additives to fuel (very popular in Brazil) and incentives toward the use of unleaded fuel and lean-burn engines through government legislation are having an enormous impact on the volume and complexity of electronics which are going into automotive engine control. The trend toward total engine management (including transmission control) on one microcontroller highlights the need for more powerful processors with 16 bit (and perhaps eventually 32 bit) cores and intelligent peripherals to distribute the processing. No one can be sure how engine management will evolve over the next ten years – or even how long the internal combustion engine will survive before it is superseded by some other power source. The only thing we can be sure of is that microcontrollers will play an essential role irrespective of the type of power source.

Pat Jordan is micro applications engineering section manager with Motorola's European Semiconductor Group at East Kilbride. He graduated from the University of Strathclyde in 1978 with a B.Sc. in electrical and electronic engineering. Before joining Motorola he worked for Lucas Electrical at Birmingham on the design and development of engine management systems.

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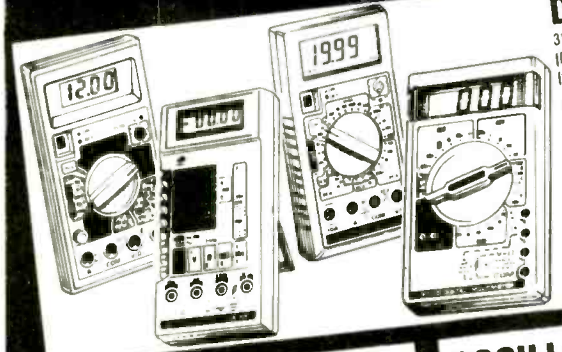

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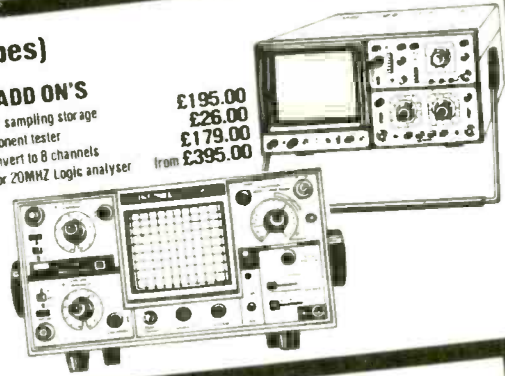

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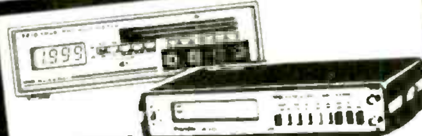

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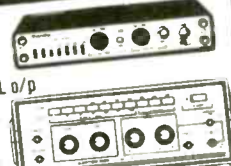

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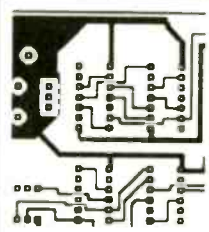
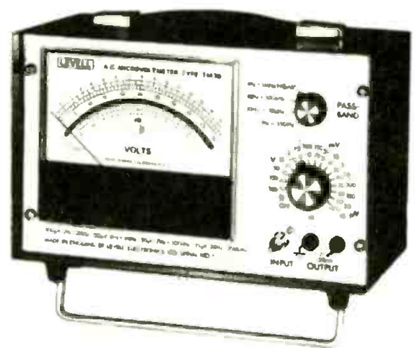
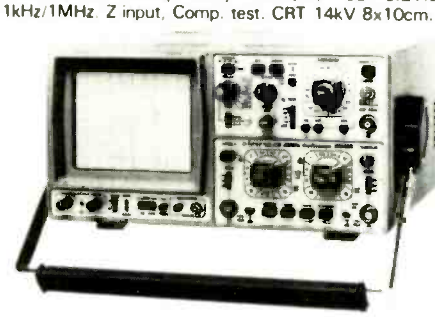






 ENTER 7 ON REPLY CARD

SATELLITE SYSTEMS

Low-speed data for mobile users

Last February we reported on the growing use of very small aperture terminals (v.sats) for medium- and low-speed data communications via satellites. Frequencies in the Ku band, rather than C band, allow smaller dish antennas for a given gain. And if you can afford to spend plenty of time sending your data (low bit-rate) the other two factors in the channel capacity equation, namely bandwidth and signal/noise ratio, can be correspondingly small. With a small noise bandwidth, signal power can be quite low to achieve an adequate signal/noise ratio and bit error rate.

All this refers to stationary earth terminals using the Fixed Satellite Service frequency allocations. A very useful incidental feature of small antennas, however, is that they are compact enough to be mounted on vehicles for mobile satcom services. Ships have plenty of horizontal space available so there is not much of a problem there. But road vehicles and aircraft are a different proposition. Nevertheless there is now a great deal of experimental work going on with a view to providing aircraft and land vehicles with low- or medium-speed data communications, taking advantage of the particular factors outlined above.

These experiments have been made possible because Inmarsat is now promoting both aeronautical and land mobile satcoms in addition to its original functions of providing marine satellite communications (see January issue, p.32). Specifically, this international organization is making available frequency assignments in L-band mobile satellite service for trials working through its Marecs B2 geostationary comsat over the Atlantic Ocean (1.6GHz uplink, 1.5GHz downlink).

As an example, *E&WW* reported in the October issue some trials of radiopaging by satellite to long-distance lorries (p.1035). These are being run by British Telecom Mobile Communications, who are using their existing Message Master terrestrial pagers, their Goonhilly earth station and the Marecs B2 satellite, together with mobile antennas and receivers made by Bell Aerospace.

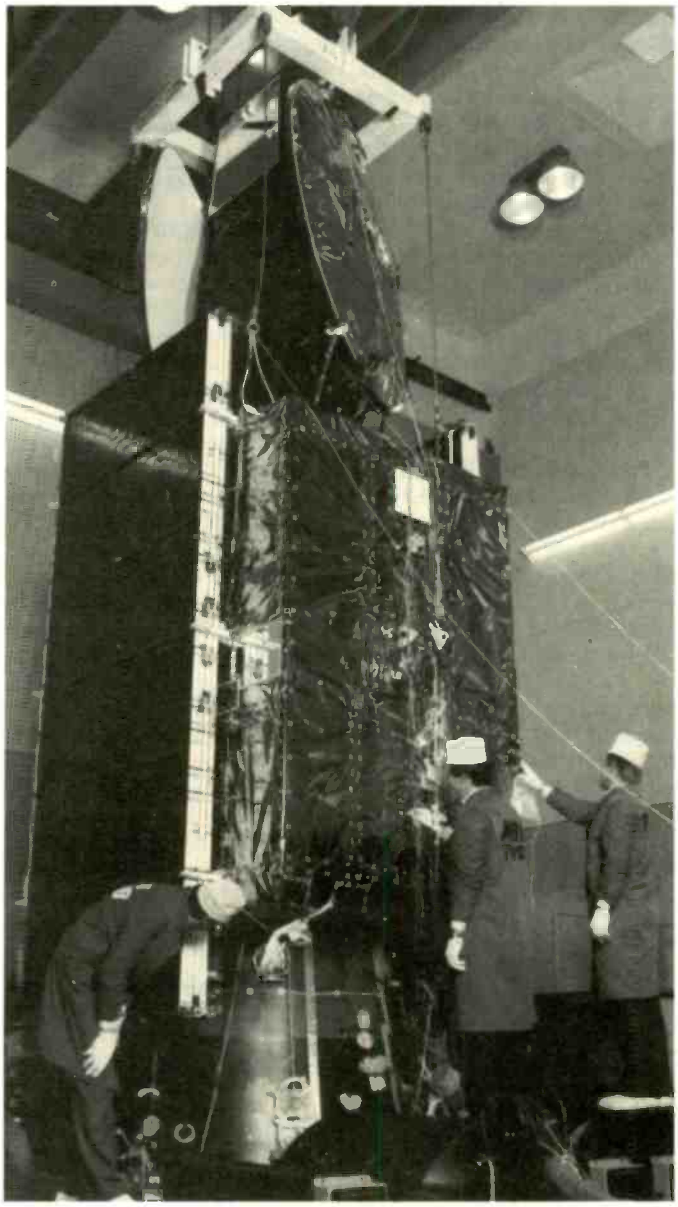
At the same time, the European Space Agency – which, incidentally, leases the Marecs B2 to Inmarsat – is developing a low data rate transmission system called Prodat for two-way data communications with aircraft, ships and land vehicles. Service trials in aircraft are about to begin. At this year's Paris Air Show, Racal-Decca Advanced Development demonstrated the aeronautical Prodat data terminal they have developed and produced for ESA. This company is currently delivering five of the terminals for service trials, four to airlines belonging to the SITA organization (Société Internationale de Télécommunications Aeronautiques) and one to the UK's Civil Aviation Authority.

The first flight trial is due to take place in a Tristar aircraft of TAP—Air Portugal. We hope to give details of the transmission system, which uses spread spectrum c.d.m.a. (code division multiple access) in a later issue.

And Inmarsat itself, as well as providing the space segment, is doing its own trials with mobile terminals. In September, for example, working with the French research organization CNET (Centre National d'Etudes des Télécommunications), it ran a small van fitted with a receive-only data terminal from Calais to the Spanish border. The equipment was an existing marine type terminal designed for automatic reception of safety and other information, made by the Danish firm Thrane & Thrane. It comprised an electronic unit measuring 214×73×279mm, a hard-copy printer and an omnidirectional antenna. Data rates up to 600 bit/s in a formatted signal were received as the van went along.

The helical antenna, designed for the 1.53-1.545GHz receive band, had right-hand circular polarization and was housed in a conical dome 200mm high and 190mm in diameter. G/T figure of merit was −23dB/K at 5° elevation.

According to Inmarsat, measurements taken on motorways, secondary roads, mountainous routes and in cities "yielded very encouraging initial results". Modulation, coding and interleaving in the system were



Europe's first d.b.s. service will come from this spacecraft, the TV-Sat 1, if it is successfully launched from Kourou by Arianespace in November as planned. Here the West German satellite is shown being prepared for vibration tests at MBB-ERNO, the space systems division of the aerospace manufacturer Messerschmitt-Bölkow-Blohm. This company, which is part of the Eurosatellite consortium building the French TDF-1 d.b. satellite as well, has been responsible for the antenna system, propulsion, attitude and orbit control, as well as harness, integration and testing. Details were given in the April issue, p.377, and May issue, p.528.

The 12GHz f.m. broadcasts in 27MHz bandwidth channels will use the D2-MAC/packets transmission standard. This is a version of D-MAC/packets (see September issue, p.928) with reduced sound/data capacity but adapted to existing narrow-band cable tv distribution systems in Europe. The digital sound/data or 'packets' part of the whole time-division multiplex signal is conveyed by a duobinary (three-level) code which directly frequency modulates the carrier along with the analogue vision signal. D2-MAC has a digital channel capacity of 1.52Mbit/s, allowing up to four full-quality sound channels in the broadcast transmission. Straightforward f.m. for the sound/data part, rather than the q.p.s.k. modulation of C-MAC, allows relatively simple receiver circuitry. On the ground the D2-MAC signal is decoded into the PAL colour tv standard for conventional domestic tv sets.

considered to "very effective in a land-mobile environment". On motorways and open roads the percentage of messages received correctly the first time was claimed to be over 96%. Obstacles like bridges, electrical power lines and trees caused "practically no degradation of reception". Messages were re-transmitted as necessary until received, so reception of information was virtually guaranteed.

Papers on low bit-rate data communications for mobile users are likely to be delivered at the IEE's fourth international conference on satellite systems for mobile communications and navigation. This will be held in 1988 at the IEE in London, 17-19 October.

Australasia gets third comsat

When Arianespace successfully resumed its launching programme in September there were sighs of relief from several parts of the world, not just Kourou. Ariane flight V19 went up and stayed up, taking two comsats into geostationary orbit – ECS-4 (see August issue, p.832) and Aussat-3 (see December 1986, p.65).

Relief was felt particularly at the Paris headquarters of Eutelsat, the organization that operates and manages the European comsat system. It had hoped to have a third European satellite, Eutelsat I-F3, in orbit much earlier, but that spacecraft was lost in an Ariane launch failure in September 1985. Now ECS-4 becomes comsat no.3 in the system.

Aussat-3, which accompanied ECS-4, is also a third satellite for a large-area scheme. It is part of the Australian national telecommunications and broadcasting satellite system, owned and operated by Aussat Pty Ltd. But this third comsat, also a Hughes HS376 like the previous two, gives coverage from its position at 164°E not only of Australia but also of New Zealand and the South-West Pacific island countries. The extra coverage is provided by an antenna system using just microwave horns for direct transmission and reception, without reflectors. The 10° wide beams from these horns are circular and are centred on a point between Vanuatu and Fiji.

Nearly 85% of the communications capacity of the first two Aussat spacecraft has been leased, so now this third comsat, originally intended as an in-orbit spare, is going directly into full service.

Aussat-3 is expected to have a slightly longer operational life than the first two comsats – ten years as against seven. This is because the Ariane rocket ejected the spacecraft during launching at the higher altitude of 36 058km. As a result the comsat used less of its own propulsion fuel to get into its final geostationary orbit, leaving more available for the later necessary attitude and orbit corrections.

Relief at the success of flight V19 was also felt at Edinburgh, in the navigation department of Ferranti Defence Systems. This company was partly responsible for getting the comsat payload into correct orbit following the launch. It had supplied an inertial measuring system for the guidance and control equipment of the Ariane's third stage. According to Arianespace the two satellites were placed in orbit with an error of only 0.005% in apogee (a distance of about 2km) and zero error in perigee and inclination.

Intelsat VII on the horizon

With the Intelsat VI comsat hardly out of the Hughes factory and still waiting for its first flight, the international co-operative is already making initial moves to acquire a new group of spacecraft, Intelsat VII, and have the first ones in operation by mid 1992. Intelsat's board of governors has put out a request to manufacturers for proposals to supply two or three satellites initially and a fourth one later. Proposals are due in January 1988 and the initial contract will be awarded in October of that year.

The formal request for proposals includes an option allowing up to nine Intelsat VIIs to be acquired altogether. These spacecraft are being specified to be compatible with shared or dedicated Ariane launching rockets and with shared Titan III rockets.

Step-tracking

In an earlier issue we mentioned a 'step-track' system, as an automatic tracking method for keeping an earth station's antenna beam continously pointed at a communications satellite. Some readers may not be familiar with this term. It means literally that the satellite tracking is done in steps. The earth station antenna is made to turn a small, predetermined distance in one direction. If, as a result of this movement, the signal received from the satellite increases in power, the system deduces that the antenna has been turned in the correct direction and consequently initiates a further move in that direction. If, however, the satellite's signal decreases in power, the system deduces that the antenna has made a wrong move and so turns it in the opposite direction. As a result the antenna beam is automatically kept pointing at the satellite.

C/D/D2-MAC chip-set

A common decoder chip-set for all European domestic receiver systems intended to receive MAC transmissions from direct broadcasting satellites is to be manufactured in the UK. It is the result of co-operation between three European companies.

Called Multimac, it will be a multi-standard chip-set able to decode C, D and D2 MAC/packets signals and also handle data transmissions (see September issue, p. 928, for background on the MAC family of standards). This set of three v.l.s.i. integrated circuits consists of a video chip, a sound chip and a control chip. It has been designed by the company Nordic VLSI, which has behind it the Nordic NR-MSK organization comprising the broadcasters and telecommunications authorities of the five countries Denmark, Finland, Iceland, Norway and Sweden. Manufacture will be by Plessey Semiconductors.

To make the chip-set work as a complete decoder it has to be supported by other semiconductor devices such as a-d and d-a converters, ram storage and a controlling microcomputer. These are to be manufactured by Philips IC Operations.

This multi-standard conditional access chip-set will decode transmissions from the Astra, BSB, TDF, TV Sat and Tele-X European d.b. satellites (see previous reports in this regular feature) and any future transmissions using the MAC/packets family of standards. Plessey say that the choice of architecture, including the incorporation of de-scrambling, is expected to make this multi-standard approach "cost/performance competitive in volume production to the single-standard MAC concept."

For Britain's future d.b.s. service, the Home Secretary has now stated officially that the UK will use the D-MAC version of MAC, as proposed by the IBA, BSB and the Cable Programme Providers Group (see September issue, p.928).

First lady

The first woman to be elected chairman of Intelsat's board of governors is Rosio V. de Aued of Panama. She has previously served on this board for several years as representative of the Central American group of six countries.

Apologies to Ms de Aued and to E&WW readers for incorrectly suggesting that this chairmanship had been given to Susanta De Alwis of Sri Lanka (July issue, p.738). In fact Mr De Alwis became chairman of the Assembly of Parties, which meets every two years to consider Intelsat general policy and long-term objectives. The board of governors, however, meets four times a year to make decisions on more immediate and detailed matters.

Vice-chairman of the board of governors is Michael Israel of Canada, while – another correction to the July report – Juan Ciminari of Argentina is actually deputy chairman of the Assembly of Parties mentioned above.

Satellite Systems is compiled by Tom Ivall.

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IMAGE-10

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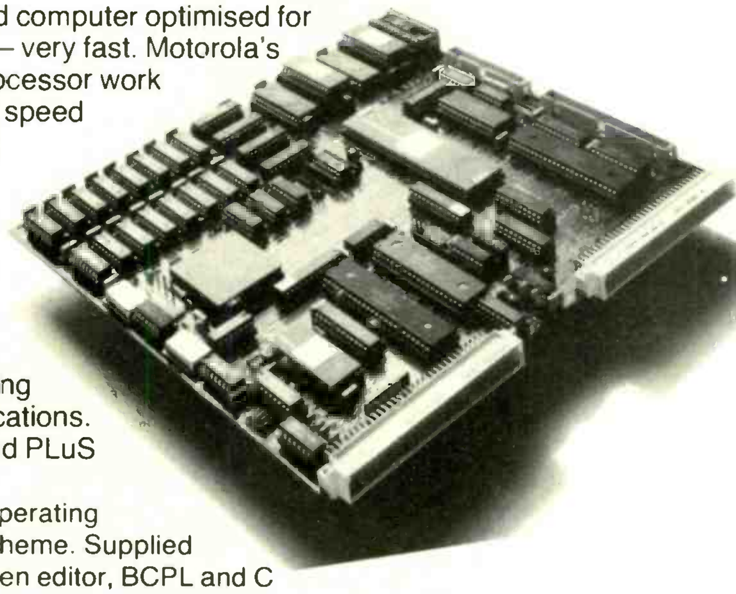

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Image-10 Specification:

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Graphics co-processor – I82786 running with 16Mhz pixel clock.
Display resolution is 768 by 576 pixels (user definable). Actual resolution limited only by memory with instantaneous scroll and pan in any direction plus independent horizontal and vertical zoom from ×1 to ×64. Displayed colours may be 256, 16, 4 or 2 at all resolutions.
Colour look-up table provides a pallette of 262,144 colours. Hardware managed windows.
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TELECOMMS TOPICS

Payphone competition

Mercury Communications has applied to Oftel for permission to install its own payphones following Oftel's publication of the results of its survey into British Telecom's service.

In his report Professor Brian Carsberg, director-general of Oftel, said, "I believe that BT's performance can be improved by greater managerial effort and a tightening up of procedures. Two lines of action need to be considered – the introduction of competition and increased regulatory action to monitor BT's performance and bring further pressures for improvements".

Oftel is looking into the possibility of companies operating payphones on lines that they would lease from either BT or Mercury. It is also drawing up technical standards for rented payphones for installation on private premises – a business where BT currently has the monopoly.

Liberalization in Germany

The PTT Minister, Christian Schwarz-Schilling, has announced that deregulation of West German telecommunications will start in 1989. This follows the completion of a study which considered the restructuring of the Deutsche Bundespost and the future of telecommunications. While it recommended the ending of the Bundespost's monopoly of the supply of equipment it proposed that it should, however, retain its network and telephone service monopoly.

Many people had been hoping for a greater degree of liberalization, possibly with a second carrier being licensed rather like Mercury in the UK, but the Establishment of both left and right was opposed to what it saw as too much change. The trade union and Social Democratic Party (SPD) commissioners were opposed to reform while the major telecommunications suppliers did not want to upset their cosy relationship with the Bundespost.

One major improvement will be the reform of the Bundespost's volume-related leased lines. In Germany, where a leased line is used for more than 80 hours per month, the customer has to pay additionally for the volume of traffic used. The result is that these lines effectively cost around four times as much as in the UK or USA.

Channel Island

British Telecom riggers are working on the Island of Alderney to replace an old microwave dish antenna. The new, more powerful, one is lying on the ground waiting to be hauled hundreds of feet to the top of the mast. Once installed it will link up with dishes on the new tower at Chillerton Down on the Isle of Wight (see E&WW, November, page 1149).

BT helps the two island telecommunications authorities, Guernsey Telecom and Jersey Telecoms, with all the communications links upon which the islands depend. It acts as consultant and all-round advisor as well as maintaining all the microwave links and radio masts.

Successful Ariane launch

Ariane successfully launched two communications satellites from the launch site at Kourou, French Guiana. They were the European ECS4 satellite and the Australian Aussat K3 (see also Satellite Systems, page 1231).

The successful launch by Ariane 3 will do much to restore confidence in Ariane, which had been dogged by a series of launch failures. Two more launches are scheduled before the end of the year: Germany's TVSat, scheduled for November on an Ariane 2 rocket; and, in December, the dual launch of the American telecommunications satellites GSTAR III/Geostar RO1 and the French satellite Telecom 1C.

Gibraltar telecoms

British Telecom and the Government of Gibraltar have formed a joint company to operate international telephone, telex and data services on the Rock for 20 years beginning January 1988.

This new venture succeeds the franchise agreement previously operated by Cable & Wireless.

British Gas goes digital

British Gas Southern has placed with British Telecom a contract to re-equip its entire trunk communications network. Worth over £2 million, the system will be one of the largest private networks supplied by BT and it will be the first complete ready-to-switch-on system to have been provided entirely by BT staff. All work is scheduled to be completed by March 1989 when it will replace the existing analogue equipment.

The network will enable BGS to concentrate most internal telephone, mobile radio traffic and data communications over a single integrated digital system. The system will also carry information about pressure and flow in the region's gas grid.

The backbone of the network consists of 21 microwave radio links operating at 1.5, 7.5 and 13GHz which will be backed-up by fail-safe Megastream digital circuits.

Competition grows in paging

British Telecom is facing growing competition in radiopaging where it currently has an 85% market share. Aircall Communications, the UK's second largest operator, has announced that it will expand its coverage from 45% to 90% of the UK population. Mercury Communications has also expanded its coverage, six months ahead of schedule, to reach 70%. And Racal has launched Vodapage, a further rival system, based on the infrastructure of its cellular radio network.

Most of Aircall's investment of £5M over the next two years will go into additional network infrastructure equipment and regional messaging centres. The company which has some 8% of the market at present, hopes to secure 20% by 1991 with over half of these subscribers using message pagers. Aircall expects

30% of its income to come from airtime from non-Aircall branded products.

If market growth continues at its current 25% per annum, there will be one million pagers by 1991. However, growing competition in the marketplace could well stimulate growth beyond this figure. The major growth area will be in tone paging, with a monthly tariff including the use of airtime (i.e. no separate call charge) becoming the industry standard.

CommunicAsia/ InfotechAsia88

The fifth CommunicAsia/ InfotechAsia88 conference, which is now regarded as the leading forum in South East Asia is to be held from June 8-11, 1988. Taking as its theme "ISDN and the network in transition", it is expected to attract more than 600 delegates. Conference papers are now being sought from users, PTTs and suppliers.

Full conference programme and official abstract form are available from Vivienne Caisey, Overseas Exhibition Services, on 01-487 5831.

Telecom lab expansion

Northern Telecom's R&D subsidiary, Bell-Northern Research (BNR), has opened its new 6700m^2 research complex at Maidenhead, west of London. The centre is the focus for BNR's work to CCITT standards with design teams currently involved in such projects as the development of very large p.b.xs, public telephone switches, network management and control systems, and the definition of global telecommunications standards, such as ISDN.

The laboratory played an integral role in assisting Northern Telecom develop the digital centrex features supplied to Mercury Communications. This was Europe's first such system. Another project was the development of a very small remote line unit that, connected to its host via two 2Mbit/s digital links, can serve up to 64 phone lines and provide them with a full range of centrex facilities.

With more than 5,500 employees worldwide and a 1987 operating budget of US$470 million, BNR is one of the largest privately-owned industrial R&D organizations in North America and is claimed to be one of the most effective in terms of developing profitable telecommunications and integrated business systems. Since establishing its original UK laboratory with a staff of 20 in 1984, BNR has grown to employ some 170 engineers, designers and support staff here.

Transatlantic X.400

Using the X.400 message handling systems and X.25, electronic mail was transferred between ICL in the UK and the Digital Equipment Corporation at the Digital Equipment Corporation show, DECworld '87, in Boston, Massachusetts. The traffic used implementations in their respective office systems – ICL's OfficePower and DEC's All-in-One.

This follows a public demonstration earlier this year at CEBit '87 at Hanover where 14 manufacturers were involved. An even larger demonstration has also just been carried out at Telecom '87 in Geneva where 21 manufacturers and carriers came together to give a further boost to this standard.

Packet switching growth in Germany

The Deutsche Bundespost expects its Datex-P packet switching network to grow to between 100000 and 150000 connections by the 1990s. At present there are more than 22000 direct customers connections with connections being added at a rate of 500 to 600 per month. Another 4000 users, not directly linked, regularly dial into the Datex-P via the ordinary p.s.t.n. They are served by a network of over 50 of NT's SL-10 switches in 17 cities around Germany connected by a mesh configuration of 64 and 128kbit/s trunks.

Consequently, it is currently evaluating competitive switches preparatory to selecting a vendor and placing contracts early next year. Northern Telecom is bidding its new packet switch, in conjunction with the German company AEG, which provides a ten-fold capacity increase on present generation products.

Designated DPN-100, the new switch can handle up to 30000 access lines with a throughput of over 30000 standard packets per second. NT claims that this switch is more powerful by an order of magnitude than switches currently installed by the company or other suppliers.

IBM-compatible data services

British Telecom has introduced two new services, known as MultiStream BPAD and SPAD, which allow access to the X.25 packet switched network for users of IBM and IBM-compatible equipment. It will enable them to adapt and expand their networks to meet changing needs without investment in new hardware or departing from their established protocols.

Among the applications for SPAD and BPAD, which offer accurate and error-free communications, are the transmission of database information, interactive financial transactions, electronic mail, manufacturing and distribution control and inter-company communications. BPAD is for BSC data communications (3270) while SPAD offers support for SDLC/SNA.

Plessey/GEC telecoms merger

Plessey and GEC have reached an agreement, subject to detailed negotiations, to combine their worldwide telecommunications interests. The result will be a fifty-fifty company with assets of £600M and sales totalling around £1.2G. The announcement said that there had been extensive exploratory negotiations focused on enhancing the international competitiveness of the British telecommunications industry.

The companies are both involved in most major sectors of the telecommunications industry: public switching; transmission – copper, fibre optic, and microwave radio; p.a.b.xs; and telephones. Their strengths are not equally balanced, however. For example, GEC is strong in transmission but has no proprietary p.a.b.x. in the over-100 line market while Plessey has its successful ISDX range of p.a.b.xs.

This announcement comes just one year after the UK Monopolies and Mergers Commission blocked GEC's £1.2G bid for Plessey. The aim underlying that bid was to rationalize the development and production of System X. System X accounts for sales of over £200M, mainly in the UK but with some export orders. According to Richard Reynolds, managing director of GEC Telecommunications, the System X business is growing rapidly and could account for £400M of the sales of the new company. This is important because both companies have excess capacity in this sector and there could be need for products and production rationalization.

Mitel development for British Telecom

As part of its strategy to enhance its presence in the world information technology markets, British Telecom is investing up to Can$60 million (£28M) in research and development projects related to the Mitel SX-2000 integrated communications system (i.c.s.).

The work will be carried out under contract by Mitel Corporation, in which Mitel has a 51% interest, at its Canadian headquarters. The work will run until early 1990. BT will receive a levy based on sales of the SX-2000 resulting from these new developments.

Telecomms Topics is compiled by Adrian J. Morant

Timing diagram plotter

Timing diagrams can be a useful aid for logic designers. This program for the BBC Microcomputer offers a quick way to produce them.

QUENTIN RICE

The program should work with any version of BBC Basic from 1 to 5, as new functions and illegal tricks have been avoided. Five possible logic conditions are allowed – high, low, three-state, don't care and change state. *Three-state* draws a signal at midpoint; *don't care* draws the wave at both high and low; and *change state* will show a state reversal of a don't care signal. Use this last option only with the don't care state, as otherwise you will get a misleading plot. The entire table of 16 by 32 points is maintained throughout the program and can be loaded and saved.

Several features of the program are worth pointing out. Editing within a window will not affect the parameters outside that window. Whenever data is being edited, pressing Return on its own will not affect existing data. In the Edit Table mode, two cursor keys may be used at once to move diagonally. All data entries must be followed by a Return, or during Table Edit, by one of the cursor keys. Illegal values and string lengths are corrected in software.

The first and last wave, and the first and last clock define the table window size. This allows you to zoom in on any contiguous area of the table and to plot this area only. When a plot is made from this table, the program auto-scales the waveforms accordingly so that a small 8×8 table will occupy the entire waveform plot area. The delay factor in the waveform table gives a physical shift of the waveform to the right of zero to three-quarters of one cycle, to show the effects of propagation delays.

Since the standard BBC Model B has only 5K or so to play with in Mode 0, I used a byte array instead of a two-dimensional integer array, which would have been faster. This saved around 2K of ram. Spaces and long variable names have been avoided in order to squeeze the program into the available space. If you type this program in, omit the REM comments as these are only for reference.

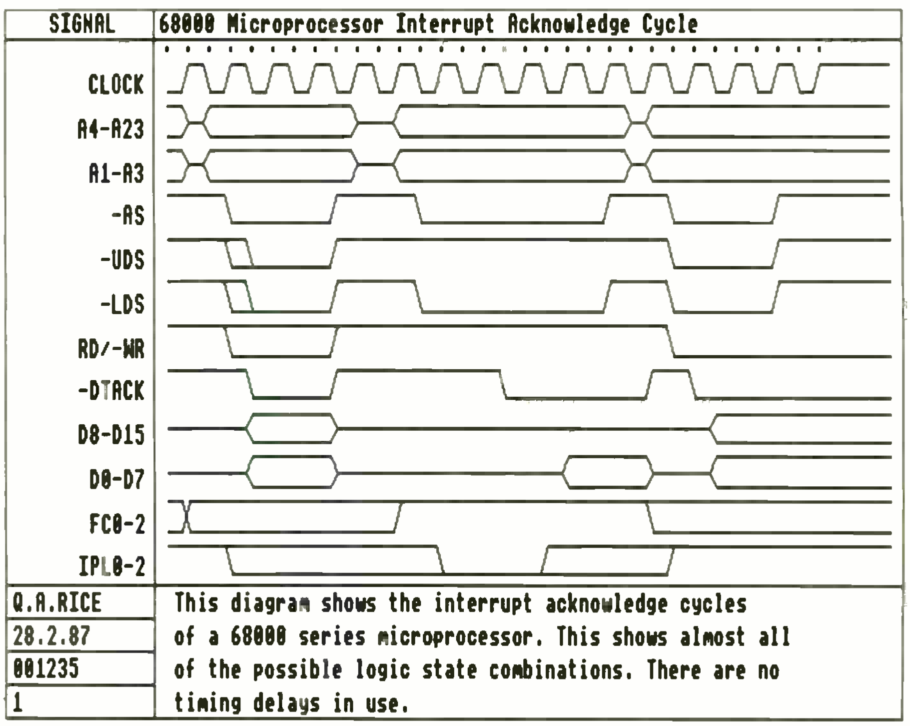
I would have liked to include many more features in the program such as extended utilities (e.g. insert and delete waveform) and possibly some logical calculations, but memory constraints prevented this. Such a program could be converted for other machines by anyone familiar with BBC Basic. But some features are exclusive to the BBC machine and cannot be converted easily, such as *FX4,2 which allows the

TITLE:68000 Microprocessor Interrupt Acknowledge Cycle
ORIG.:Q.A.RICE DATE:28.2.87
DRWG.:001235 REV.:1
First Wave: 1 Last Wave: 12 First Clock: 0 Last Clock: 31

SIGNAL	DLY	0	.	.	.	.	5	.	.	.	.	10.	.	.	.	.	15.	.	.	.	.	20.	.	.	.	.	25.	.	.	.	.	30.	
CLOCK	0	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H
A4-A23	0	D	T	D	D	D	D	D	D	D	T	T	D	D	D	D	D	D	D	D	D	D	D	T	D	D	D	D	D	D	D	D	D
A1-A3	0	D	T	D	D	D	D	D	D	D	T	T	D	D	D	D	D	D	D	D	D	D	D	T	D	D	D	D	D	D	D	D	D
-AS	0	H	H	H	L	L	L	L	L	H	H	H	H	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	L	L	H	H	H
-UDS	0	H	H	H	D	L	L	L	L	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L	H	H	H
-LDS	0	H	H	H	D	L	L	L	L	H	H	H	H	L	L	L	L	L	L	L	L	L	H	H	H	L	L	L	L	L	H	H	H
RD/-WR	0	H	H	H	D	D	D	D	D	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L	L	L	L
-DTACK	0	H	H	H	H	L	L	L	L	H	H	H	H	H	H	H	H	L	L	L	L	L	L	L	H	H	L	L	L	L	L	L	L
D8-D15	0	T	T	T	T	D	D	D	D	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	D	D	D	D	D	D
D0-D7	0	T	T	T	T	D	D	D	D	T	T	T	T	T	T	T	T	T	T	T	D	D	D	D	T	T	T	D	D	D	D	D	D
FC0-2	0	D	C	D	D	D	D	D	D	D	D	D	H	H	H	H	H	H	H	H	H	H	H	H	D	D	D	D	D	D	D	D	D
IPL0-2	0	H	H	H	D	D	D	D	D	D	D	D	D	D	L	L	L	L	L	D	D	D	D	D	D	H	H	H	H	H	H	H	H

L Load File S Save File E Edit Table U Utilities D Dump Data
H Header Data P Plot Diagram * OS Call N Note Page W Wave Edit

Above: the program's edit table. Data entered on this screen (such as the example shown here) can edited, annotated, filed on disc or (below) plotted as a timing diagram.



cursor keys to work as function keys.

The screen dump to printer routine, PROCDUMP, is written for the standard BBC Model B with an Epson printer. However, later versions of the BBC micro may use paged screen ram. And some 'Epson compatible' printers are not: this is due to the character scaling, which means you lose a quarter of the plot. The answer to both of these problems is to use a proprietary rom dump chip suitable for your printer and to replace the PROCDUMP routine with the appropriate dump command. Archimedes and Master Compact users should have no problems. The extra memory means that the byte array can be replaced with an integer array, increasing the speed somewhat.

Quentin Rice describes himself as a 33-year-old transatlantic import. He is a self-taught ex-r&d man who now carries out field servicing of analytical instrumentation for Varian Associates. His pastimes do not include football.

ALL COMMAND FUNCTIONS ARE CALLED BY SINGLE KEYSTROKES:

D dumps the contents of the screen on an 80 column printer. This is not printer code dependent.

E allows direct editing of logic states. Use the cursor keys and press H,L,T,D,C as appropriate. Data is entered by either the return key or the cursor keys. Press Escape to exit.

H allows direct entry of header data including a title, revision number, the first and last wave, and the first and last clock.

L loads a file containing all the screen data. It requires a filename.

N allows four lines of text notes to be printed on the bottom of the plot.

P plots a diagram using all of the data. To obtain a hard copy, press Shift and ! together. To save a Mode 0 screen file, "SCREEN", to disc, press Shift and &. Press any other key to return to the main page.

S saves all file data. Requires a filename.

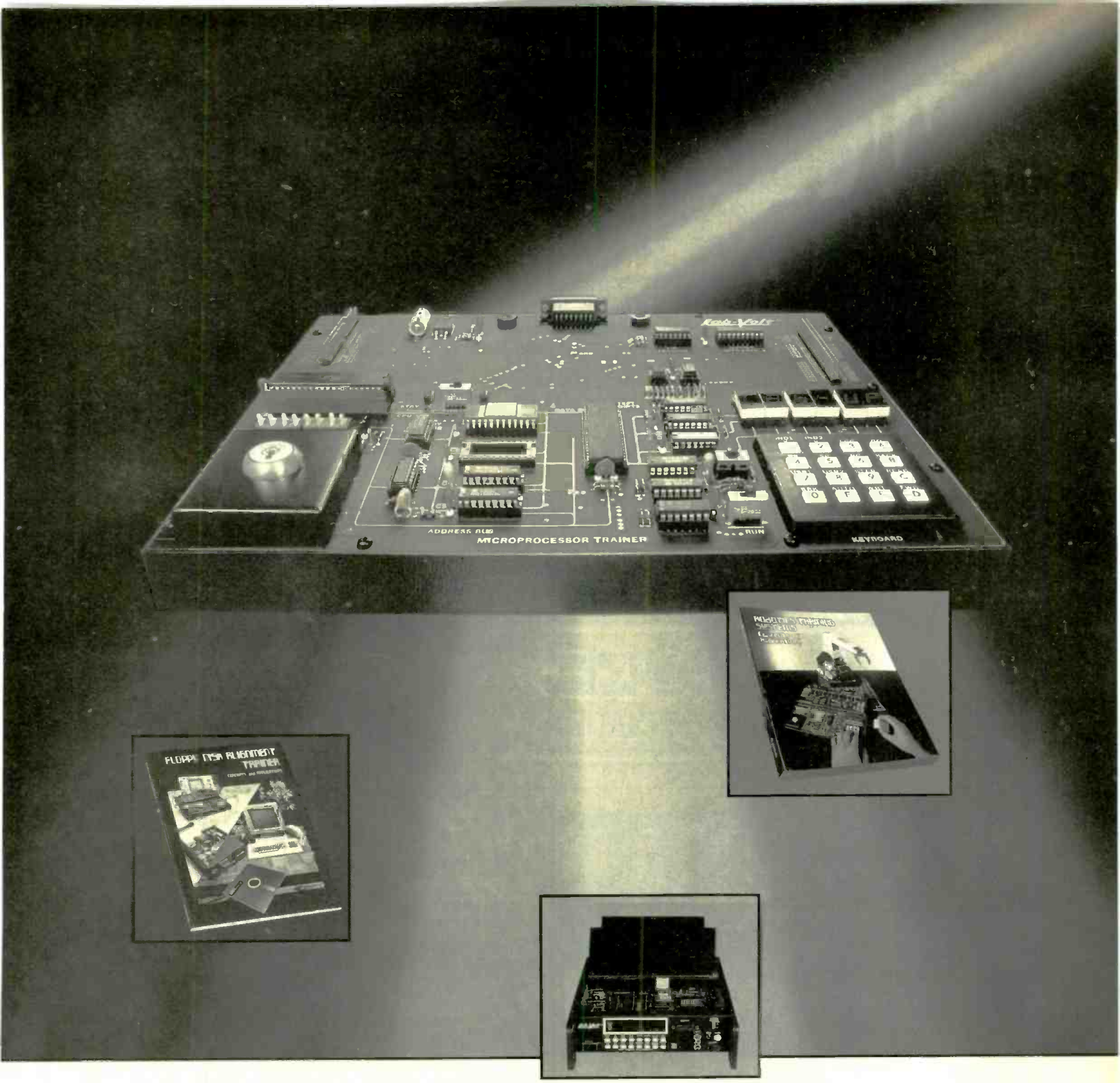
U utilities: gives a menu with the functions listed above. Clock Wave will assign a clock waveform to the selected waveform.

W wave data: waveforms require names of up to 12 characters. This function also allows the entry of the delay factor of 0 to 3. Adding four to this value will cause the waveform to be squared up. Note that slewed waveforms affected by this should have a delay factor of at least one.

★ allows access to machine operating system calls such as ★CAT, ★INFO, ★DELETE.

Complete listing. Since the program uses a computed Gosub at line 120, do not attempt to renumber it. The author can supply a disc (40 or 80 tracks) containing this program together with additional file utilities for £5 including inland postage and packing. His address is 2 Beechland Cottages, Mogador Road, Lower Kingswood, Surrey KT20 7EW.

```
    5 REM ** INITIALIZE
   10 *KEY12|M
   20 *KEY13|M
   30 *KEY14|M
   40 *KEY15|M
   50 @%=0:L%=0:M%=15:N%=0:O%=31
   60 DIMA$(16),B$(16),C$(4),Q%540,R%20
   70 FORI%=0TO4:READC$(I%):NEXT
   80 FORI%=0TO536STEP4:Q%!I%=0:NEXT
   90 ONERROR:PROCMW:REPORT:PROCKP
  100 MODE3:VDU19,1,2;0;3:CLOSE#0:V%=L%:
H%=N%:W%=M%-L%:CLOSE#0:PROCME:PROCMP:*FX
4
  105 REM ** GET KEY, GOSUB FUNCTION
  110 G%=10*INSTR("DEHLNPSUW*",GET$):IFG
%=0GOTO110
  120 GOSUBG%+120:GOTO100
  130 PROCMW:VDU2:PRINT'':PROCMP:PRINT''
"NOTES"':FORI%=5TO8:PRINTB$(I%):NEXT:RET
URN
  140 PROCTED:RETURN
  150 PROCHED:RETURN
  160 PROCLOAD(FNN("LOAD")):RETURN
  170 MODE7:PROCNED:RETURN
  180 MODE0:PROCWAVE:GOSUB230:RETURN
  190 PROCSAVE(FNN("SAVE")):RETURN
  200 MODE7:PROCUTIL:RETURN
  210 PROCWED:RETURN
  220 MODE7:PROCOS:RETURN
  230 G%=GET:IFG%=33:PROCDUMP
  240 IFG%=38:*SAVE SCREEN 3000 7FFF
  250 RETURN
  255 REM ** NOTEPAGE EDIT
  260 DEFPROCNED:PRINT"NOTE PAGE: FOUR L
INES, UP TO 60 CHARS.":PROCFC
  270 FORI%=0TO3:PRINTTAB(0,I%*2+2)I%+1;
".";B$(I%+5):NEXT
  280 FORI%=0TO3:IFFNT(2,I%*2+2):B$(I%+5
)=LEFT$(A$,60)
  290 NEXT:ENDPROC
  295 REM ** HEADER EDIT
  300 DEFPROCHED:PROCFC:VDU26
  310 IFFNT(6,0):B$(0)=LEFT$(A$,68)
  320 IFFNT(6,1):B$(1)=LEFT$(A$,12)
  330 IFFNT(45,1):B$(2)=LEFT$(A$,12)
  340 IFFNT(6,2):B$(3)=LEFT$(A$,12)
  350 IFFNT(45,2):B$(4)=LEFT$(A$,12)
  360 IFFNT(12,3):L%=VALA$-1:IFL%<0:L%=0
  370 IFFNT(31,3):M%=VALA$-1:IFM%>15:M%=
15
  380 IFFNT(53,3):N%=VALA$:IFN%<0:N%=0
  390 IFFNT(72,3):O%=VALA$:IFO%>31:O%=31
  400 ENDPROC
  405 REM ** DATA TABLE EDIT
  410 DEFPROCTED:PROCMW:PRINT" Use Curso
r Keys to move AND enter data, and ESCAP
E to exit"
  420 PRINT" L = LOW     H = HIGH    T = T
RISTATE     D = DON'T CARE      C = CHANGE
 STATE";
  430 VDU26:PROCFC:*FX4,2
  440 REPEAT:IFFNT(H%*2+16,V%+5):PROCEC
  450 IFINKEY-26:H%=H%-1:IFH%<N%:H%=O%
  460 IFINKEY-122:H%=H%+1:IFH%>O%:H%=N%
  470 IFINKEY-42:V%=V%+1:IFV%>M%:V%=L%
  480 IFINKEY-58:V%=V%-1:IFV%<L%:V%=M%
  490 UNTIL0
  495 REM ** CHECK DATA VALIDITY
  500 DEFPROCEC:FORI%=0TO4
  510 IFA$=C$(I%):Q%?FNB(V%,H%)=I%
  520 NEXT:ENDPROC
  530 DEFPROCWED:VDU26:PROCFC
  540 FORI%=0TOW%:J%=I%+512
  550 IFFNT(0,I%+5):A$(I%)=LEFT$(A$,12)
  560 IFFNT(13,I%+5):Q%?J%=VALA$
  570 IFQ%?J%>3:Q%?J%=3
  580 NEXT:ENDPROC
  585 REM ** GET FILENAME
  590 DEFFNN(A$):PROCMW:PRINT'A$;" FILE
";:INPUTA$:=A$
  595 REM ** LOAD FILE
  600 DEFPROCLOAD(A$):X=OPENIN(A$)
  610 FORI%=0TO16:INPUT#X,A$(I%),B$(I%)
  620 NEXT:FORI%=0TO536STEP4
  630 INPUT#X,Q%!I%:NEXT:CLOSE#0
  640 L%=Q%?530:M%=Q%?531:N%=Q%?532:O%=Q
%?533:ENDPROC
  645 REM ** SAVE FILE
  650 DEFPROCSAVE(A$):X=OPENOUT(A$)
  660 Q%?530=L%:Q%?531=M%:Q%?532=N%:Q%?5
33=O%
  670 FORI%=0TO16:PRINT#X,A$(I%),B$(I%)
  680 NEXT:FORI%=0TO536STEP4
  690 PRINT#X,Q%!I%:NEXT:CLOSE#0:ENDPROC
  695 REM ** PLOT WAVEFORMS
  700 DEFPROCWAVE:RESTORE1490:VDU19,1,2;
0;5:W%=M%-L%:T%=O%-N%
  710 C%=940/T%:D%=760DIV(W%+1)
  720 E%=C%DIV4:F%=D%/1.5:IFF%>80F%=80
  730 FORI%=0TO6:READX%,Y%:MOVE0,0
  740 DRAWX%,0:DRAWX%,Y%:DRAW0,Y%
  750 DRAW0,0:NEXT
  760 MOVE64,1014:PRINT"SIGNAL"
  770 MOVE220,1014:PRINTB$(0)
  780 FORI%=1TO4:MOVE10,228-(I%*48):PRIN
TB$(I%)
  790 MOVE240,228-(I%*48):PRINTB$(I%+4):
NEXT
  800 FORI%=0TOT%:MOVEI%*C%+224,986:PRIN
T".":NEXT
  810 FORI%=0TOW%:S%=0:U%=0:K%=I%+L%
  820 A%=Q%?(K%+512)*E%+232
  830 B%=(W%-I%)*D%+208:A$=A$(K%)
  840 MOVE200-(LENA$*16),B%+24:PRINTA$
  850 G%=S%:MOVE232,FNW(FNA(K%,N%))+B%
  860 FORJ%=0TOT%:Z%=J%+N%
  870 DRAWJ%*C%+A%,FNW(FNA(K%,Z%))+B%
  880 PLOT1,E%*3,0:NEXT:DRAW1260,Y%+B%
  890 IFU%=1ANDS%=0:S%=NOTS%:GOTO850
  900 NEXT:ENDPROC
  905 REM ** CHECK LOGIC STATE
  910 DEFFNW(X%):IFX%=0:Y%=0
  920 IFX%=1:Y%=F%
  930 IFX%=2:Y%=F%DIV2
  940 IFX%=3:Y%=ABS(F%*G%):U%=1
  950 IFX%=4:Y%=ABS(F%*NOTS%):G%=NOTG%
  960 =Y%
  965 REM ** DISPLAY MAIN PAGE
  970 DEFPROCMP:COLOUR129:COLOUR0
  980 PRINT"TITLE:";B$(0)
  990 PRINT"ORIG.:";B$(1);TAB(40)"DATE:"
;B$(2)
 1000 PRINT"DRWG.:";B$(3);TAB(40)"REV.:"
;B$(4)
 1010 PRINT"First Wave: "L%+1;TAB(20)"La
st Wave: ";M%+1;TAB(40)"First Clock: "N%
;TAB(60)"Last Clock: ";O%
 1020 COLOUR128:COLOUR1:PRINTTAB(0,4)"SI
GNAL       DLY";
 1030 FORI%=N%TOO%:PRINTTAB(I%*2+16)"";:
IFI%MOD5=0PRINTI%;ELSEPRINT".";
 1040 NEXT:PRINT
 1050 FORI%=0TO15:IFI%<L%ORI%>M%:GOTO109
0
 1060 PRINTA$(I%);TAB(13)Q%?(I%+512);
 1070 FORJ%=N%TOO%:A%=FNA(I%,J%)
 1080 PRINTTAB(J%*2+16)C$(A%);:NEXT
 1090 PRINT:NEXT:ENDPROC
 1095 REM ** UTILITIES
 1100 DEFPROCUTIL:PRINT"UTILITIES"''
 1110 PRINT"1.  CLOCK WAVE"'"2.  SWAP WA
VE"'"3.  QUIT";:G%=GET-48
 1120 IFG%>3ORG%<0:ENDPROC
 1130 IFG%=3:PRINT:END
 1140 CLS:PRINT"WAVEFORM LIST"'
 1150 FORI%=0TOW%:PRINTI%+1;".";TAB(3)A$
(I%):NEXT
 1160 IFG%=1:PROCCLOCK
 1170 IFG%=2:PROCSWAP
 1180 ENDPROC
 1185 REM ** SEED WITH CLOCK
 1190 DEFPROCCLOCK:INPUT'"CLOCK ON WAVEF
ORM No.? "A%
 1200 INPUT"START HIGH OR LOW? H/L "A$:B
%=A$="H"
 1210 FORI%=0TO31:Q%?FNB(A%-1,I%)=ABSB%:
B%=NOTB%:NEXT:ENDPROC
 1215 REM ** SWAP WAVES
 1220 DEFPROCSWAP:INPUT'"SWAP WAVEFORM N
o.? "A%:A%=A%-1
 1230 INPUT"AND  WAVEFORM No.? "B%:B%=B%
-1
 1240 FORI%=0TO31:C%=FNA(A%,I%):Q%?FNB(A
%,I%)=FNA(B%,I%):Q%?FNB(B%,I%)=C%:NEXT
 1250 A$=A$(A%):A$(A%)=A$(B%):A$(B%)=A$:
ENDPROC
 1255 REM ** GENERAL PURPOSE FUNCTIONS
 1260 DEFPROCMW:VDU28,0,23,79,22,12:ENDP
ROC
 1270 DEFFNA(X%,Y%)=Q%?(X%*32+Y%)
 1280 DEFFNB(X%,Y%)=(X%*32+Y%)
 1290 DEFFNT(X%,Y%):INPUTTAB(X%,Y%)""A$:
=A$<>""
 1300 DEFPROCFC:VDU23;10,0;0;0;0;:ENDPRO
C
 1310 DEFPROCME:PROCMW:COLOUR129:COLOUR0
 1320 PRINT" L   Load File     S  Save Fil
e      E  Edit Table   U  Utilities     D
Dump Data  "
 1330 PRINT" H   Header Data   P  Plot Dia
gram     *  OS Call      N  Note Page     W
Wave Edit   ";:VDU26:ENDPROC
 1340 DEFPROCOS:INPUT"OS CALL: *"$R%
 1350 X%=R%MOD256:Y%=R%DIV256:CALL&FFF7
 1360 PROCKP:ENDPROC
 1370 DEFPROCKP:PRINT'"PRESS ANY KEY";:R
EPEATUNTILGET:ENDPROC
 1375 REM ** MODE 0 PRINTER DUMP
 1380 DEFPROCDUMP
 1390 VDU28,0,31,1,31
 1400 VDU2,1,19,1,17,1,27,1,64
 1410 VDU1,27,1,108,1,20
 1420 PRINT'''':VDU2,1,27,1,49
 1430 FORI%=&3000TO&3278STEP8
 1440 VDU1,27,1,75,1,0,1,2
 1450 FORJ%=&4D80TO0STEP-640:L%=I%+J%
 1460 FORK%=7TO0STEP-1:VDU1,L%?K%,1,L%?K
%
 1470 NEXT,:PRINT:NEXT:VDU1,27,1,64:ENDP
ROC
 1480 DATA L,H,T,D,C
 1490 DATA1279,1023,212,1023,1279,978,12
79,192,212,144,212,96,212,48
```



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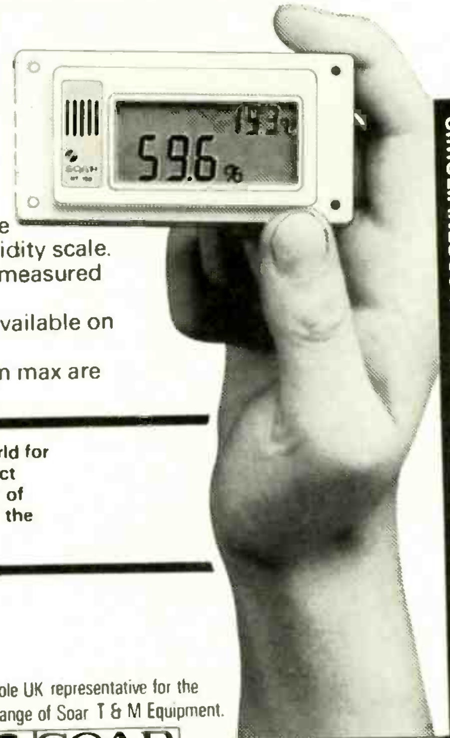
59.6
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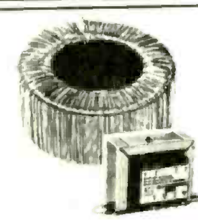


Synchronous static ram

Using a new static-ram structure featuring a clock input, zero wait-state memory access at 40MHz processor speed is possible with a 25ns device.

DAVID JONES

As microprocessor clock speeds increase, it becomes more and more difficult to design memory capable of keeping up with them. There is no problem with interfacing slow memory systems to the MC68030 microprocessor since the device's asynchronous mode allows wait states to be inserted into memory accesses. But if maximum throughput is needed, memory accesses must be done without these delays.

Traditionally, very-fast static ram has been used to allow memory to be accessed at the speed required by high-performance microprocessors. In the case of a 25MHz 68020 for example static rams with a 25 or 35ns access-time are used. With the 68030 however, access time is reduced still further when the bus controller burst-fills the on-chip caches. Now, data can be accessed in only one clock cycle.

Figure 1 shows a typical microprocessor static-ram design. Although the rams have an access time of only 25ns, control logic required for address decoding, etc., reduces the time available for accessing the devices. As you can see from the diagram, addresses need to be qualified by the address strobe before they can be used to ensure data integrity.

With synchronous static rams, the microprocessor clock feeds directly into the ram access logic to reduce access time. These new memory devices also require less exter-

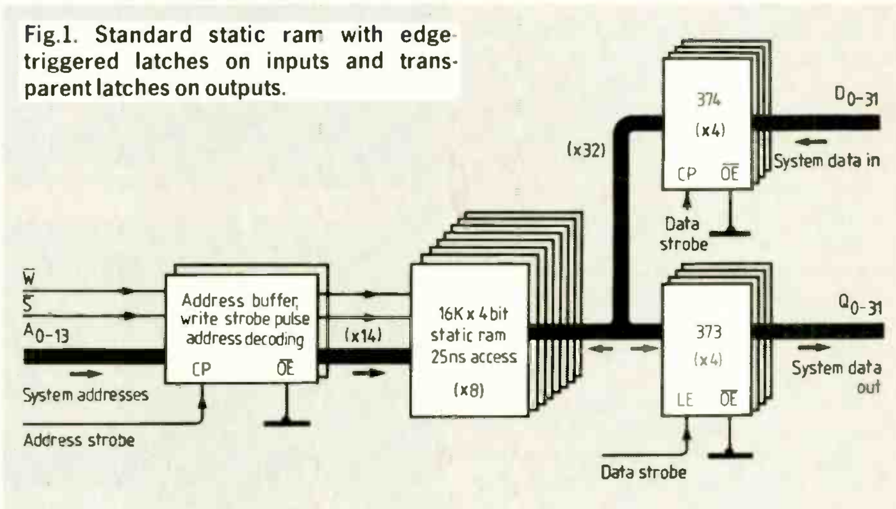


Fig.1. Standard static ram with edge triggered latches on inputs and transparent latches on outputs.

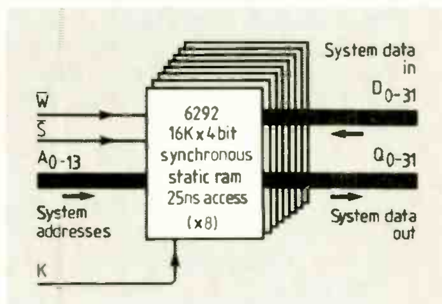
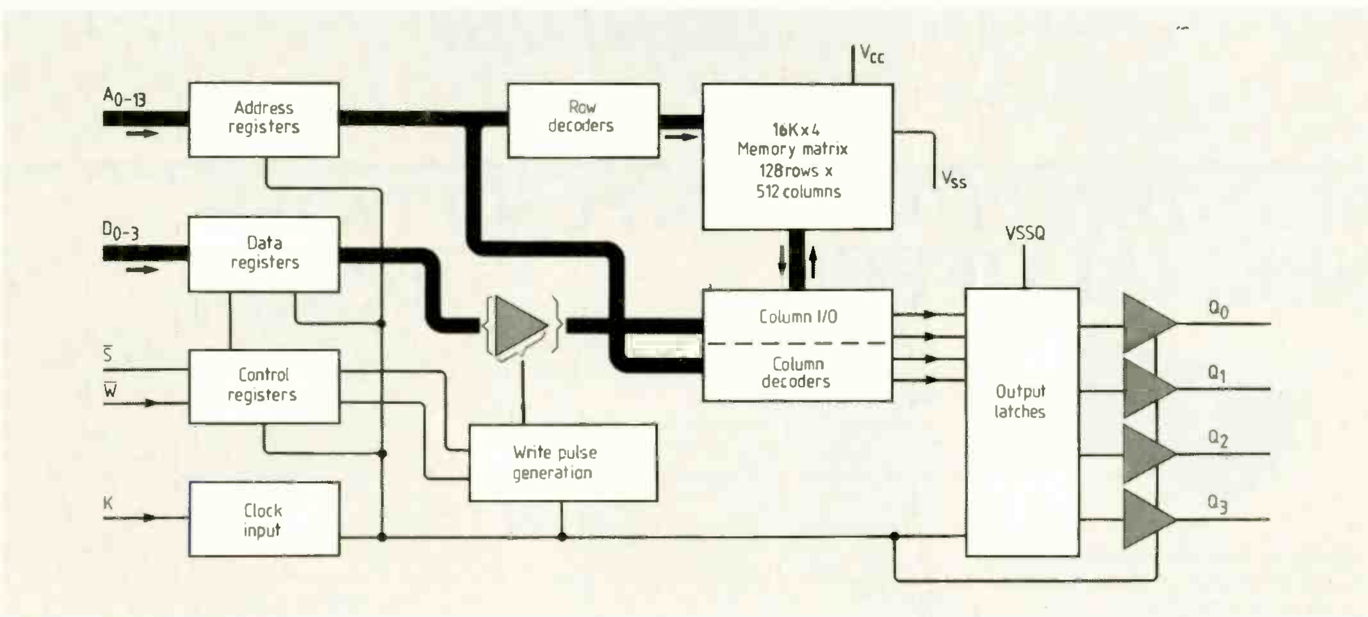


Fig.2. Synchronous static ram needs less external control logic than conventional static rams because of its clock input (K). Synchronous devices with 25 and 35ns access times replace expensive high-speed static rams with 5 to 10ns access times.

Fig.3. Internal structure of an MCM6292 synchronous static ram. Write-pulse logic required for standard static ram is on chip so fewer external control components are needed.



nal logic to interface them to the microprocessor, as Fig.2 shows. Internal elements of the synchronous static ram are illustrated in Fig.3.

Samples of four synchronous ram types will be available from Motorola by the end of this year. The MCM6292 is a 16K×4bit device produced using the HCMOS III process. It has fourteen address inputs, four separate data inputs and outputs, a write-enable line, chip-select input and a clock input designated K.

Operation of the device is as follows. On the positive-going edge of the input clock, all chip inputs including control lines are latched. In addition, when the clock is low, the output latches are transparent (open) and are then held in the correct state when the clock goes high.

If the address and chip-select signals can be supplied with the correct set-up and hold times with respect to the rising edge of the microprocessor clock, data can be read on the next rising edge of the clock. The time between these edges is therefore the cycle time of the memory.

During a write cycle, if the processor can supply address, control and data on the same clock edge then all can be latched together. Complex write-pulse generation logic required with standard ram is now an on-chip function. Figures 4 and 5 show read and write timing for the 6292.

With the exception that its outputs are registered instead of latched the MCM6293 is the same as the 6292. In register-output mode, data that is valid when the clock goes high is from the previous cycle. The MCM6294 and 6295 are the same as the 6292 and 6293 respectively except that they have an output-enable control instead of a chip-select input. These two devices are designed to permit asynchronous control of the output buffers.

It is now possible to build high-performance microprocessor systems with very-fast external caches. In conventional designs, using synchronous static ram is equivalent to using ordinary static rams with 10 to 15ns access times – which are very expensive and of lower density. Synchronous static rams with 25ns access time allow a processor to operate at up to 40MHz without wait states.

David Jones is an applications engineer at Motorola's East Kilbride plant.

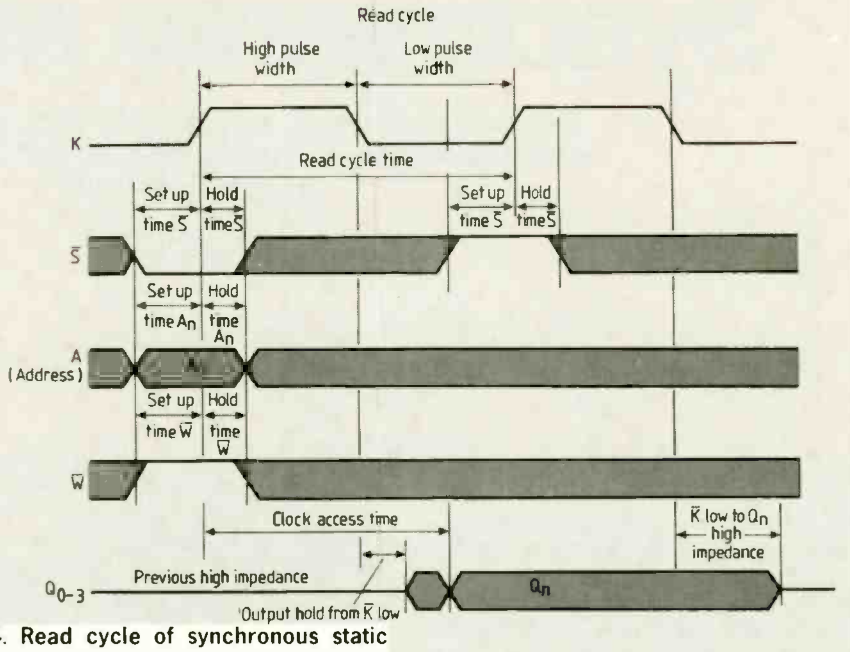


Fig.4. Read cycle of synchronous static ram.

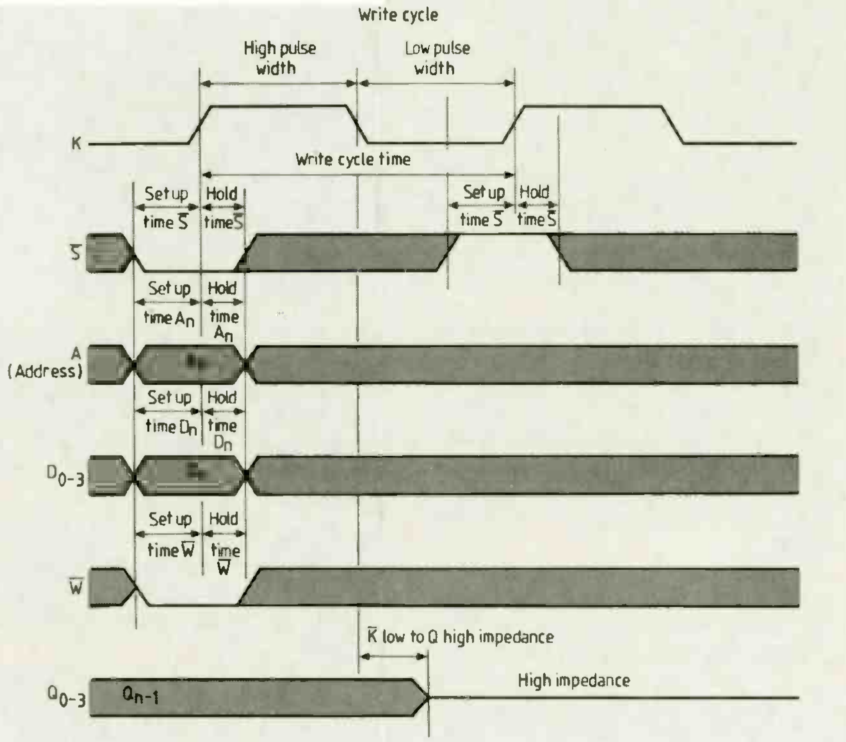


Fig.5. Synchronous static ram write cycle.

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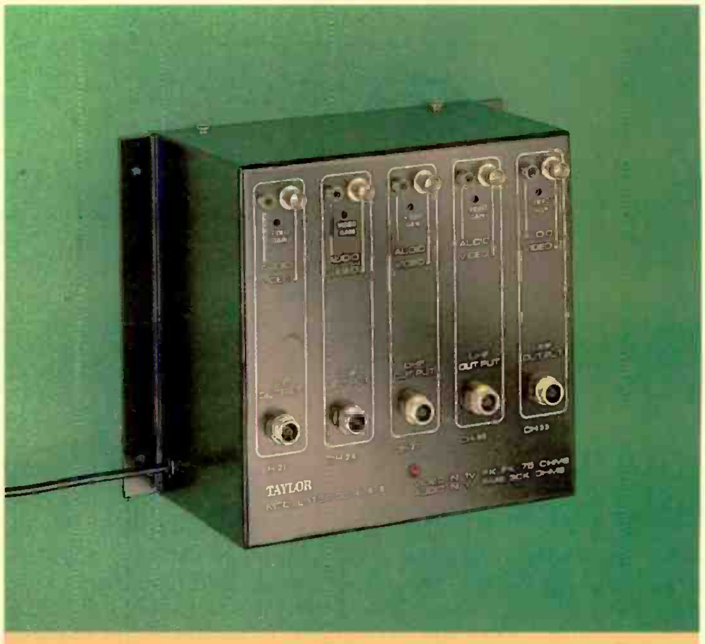

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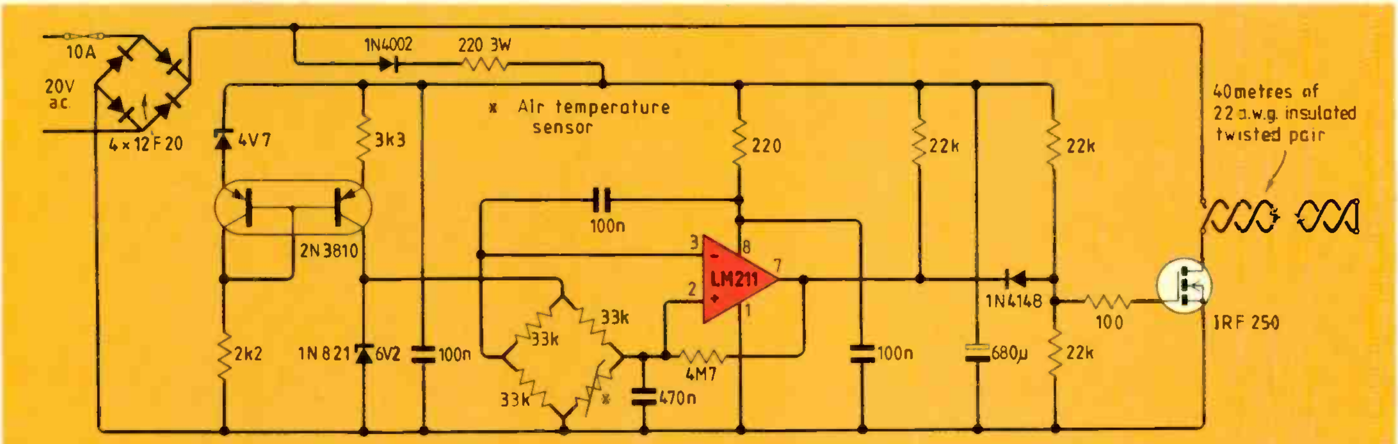
CIRCUIT IDEAS



Frost protection

A length of wire and control circuit protect exposed water pipes against frost. When air temperature falls below about 1.5°C, the control circuit switches mains-isolated 20V unsmoothed d.c. into the insulated wire, warming it up. During heating, consumption is about 100W.

Twisted-pair wire tucked inside foam pipe lagging forms the heater. Ordinary insulated twisted-pair wire (23 SWG, 22 AWG) was used for convenience. With the 20V, 5A transformer, 40m of wire and components shown, the circuit will protect about 20m of pipe; the wire is wound round the pipe.

Power is switched to the wire when air temperature falls below about 1.5°C using a reference voltage, thermistor bridge, comparator and fet switch. For other thermistors, only the bridge resistors need altering to correspond to the thermistor resistance at 0°C (in this case 33kΩ).

Should component failure cause continuous power to be applied to the wire, there should be no problems provided that the control components and transformer are adequately rated. Heating of the wire is barely perceptible to the touch.

K.M. Redford, Gloucestershire

Centronics handshaking incompatibility

Centronics interfaces provide both acknowledge and busy signals, but only one of these is needed. Our Amstrad 128 looks for a busy signal and the Oric 4 colour plotter that we wanted to use with it sends an acknowledge signal so the two are incompatible.

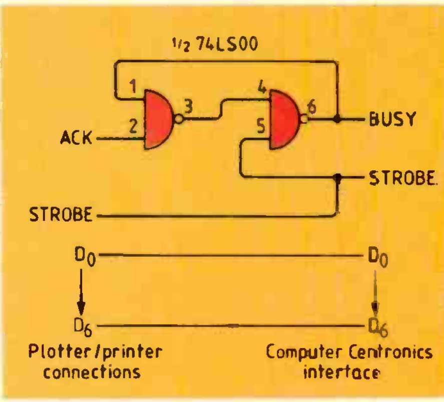
Adding a simple circuit to latch the busy line when the strobe appears and delatch it when acknowledge from the plotter is sent can overcome this problem.

As far as we know the Centronics data strobe is always inverted but there are differences in the acknowledge and busy signals, which are only sometimes inverted*. With other combinations of computer and printer, is may be necessary to invert one of the signals; the remaining two 74LS00 gates could be used for this.

Unfortunately there is no 5V supply line on the Centronics interface. Less than 20mA is drawn by the circuit so it should be possible to use the computer power supply in most cases.

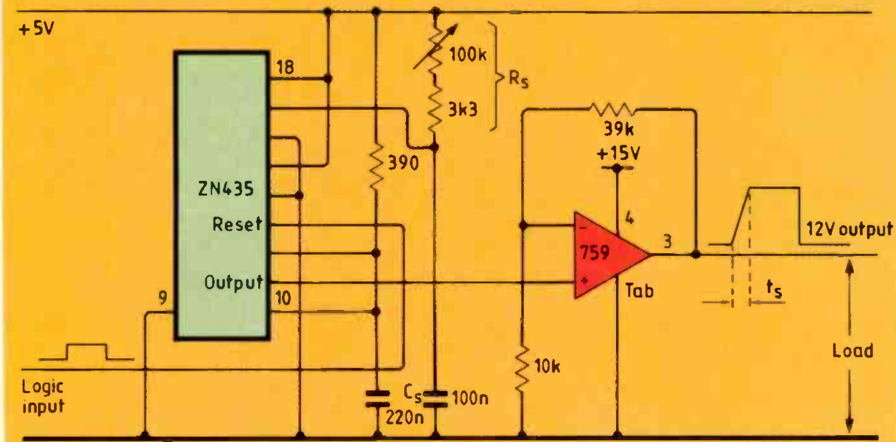
Neville Frewin
Fontainbleau
South Africa

*In the Centronics 739 printer manual, data strobe and acknowledge signals are active low and the busy line is active high – Ed.



Soft power switch

Controlling power circuits from logic-derived signals often requires gradual switch on with instantaneous switch off. This circuit provides control of the switch-on ramp using a d-to-a converter.



Logic low input at t.t.l. level resets the ZN435 data converter so the power output is off. When the input goes high the converter, wired as a 255-step ramp generator, ramps up to 2.5V. Duration of the ramp(t_s) depends on the clock frequency which is set by timing components R_s and C_s;

$$F = \frac{1}{2R_sC_s}$$

where f is in Hz. Converter output feeds a non-inverting power op-amp giving 12V output for a 2.5V input. Any similar power op-amp should be suitable.

Other waveforms, such as a downward ramp for instantaneous switch on and gradual switch off, should be possible.

T.G. Barnett
London

High-speed microprocessor link

Conventional processors can be connected in parallel in a similar way to Inmos transputers. This high-speed link is basically a processor peripheral and relies on interrupts.

After receipt of the first byte, interrupts are disabled and the status register polled instead (alternately with the read/write register) until an end-of-communication byte is received.

Register selection is done using RS. When high, RS signals register reading/writing and when low, selects control/status registers. In the control register, bit zero enables data-available interrupt signal $\overline{DAI}$ and bit one enables register-empty interrupt signal $\overline{REI}$. In the status register, bit zero flags the conditon of $\overline{DAI}$, bit one flags condition of $\overline{REI}$ and bit two and three signal data available and register empty respectively.

With CS and RS high and R/$\overline{W}$ low, IC_{1a} output is high. This allows the lower F374 to latch data from the bus. It also sets the lower bistable i.c. to provide $\overline{DAI}$ for the second processor and resets $\overline{REI}$ of the first.

When CS, RS and R/$\overline{W}$ are high, gate IC_{1b} enables outputs of the upper F374 latch. It also resets the upper bistable i.c., resetting $\overline{DAI}$ to the first processor and sending $\overline{REI}$ to the second. If now RS and R/$\overline{W}$ go low, gate IC_{1a} causes the lower two bits of the bus to be latched into half of the F77. These bits provide interrupt-enable signals to gates $IC_{1e,f}$.

Finally, with CS and R/$\overline{W}$ high and RS low, gate IC_{1c} causes latching of the interrupt-enable and status signals on the lower four bus lines. The second processor interface acts in exactly the same way.

I have not built the circuit. Provided that sufficiently high-speed logic is used, the only problem that I foresee is when one processor is reading from the circuit simultaneously with the other writing to it. Although the data transfer will take place, the associated RS bistable device will settle in an undefined state and may cause the reading processor to reread the same value. Provided that interrupt status is continuously monitored, this condition is unlikely to arise, especially if the processors run at different speeds.

Note that pin CP of the F374 must go high and low again before bus data becomes invalid. For most processors, CS and R/W signals will change before data is removed, but check this.

For high-speed work, for example with two 68020 processors running at 25MHz, 'F' logic i.cs are recommended. Expansion of the circuit for 16 or 32bit operation is simply a matter of adding F374 latches and feeding them from the existing $\overline{OE}$ and CP lines.

George I. Hiyiannis
Nicosia
Cyprus

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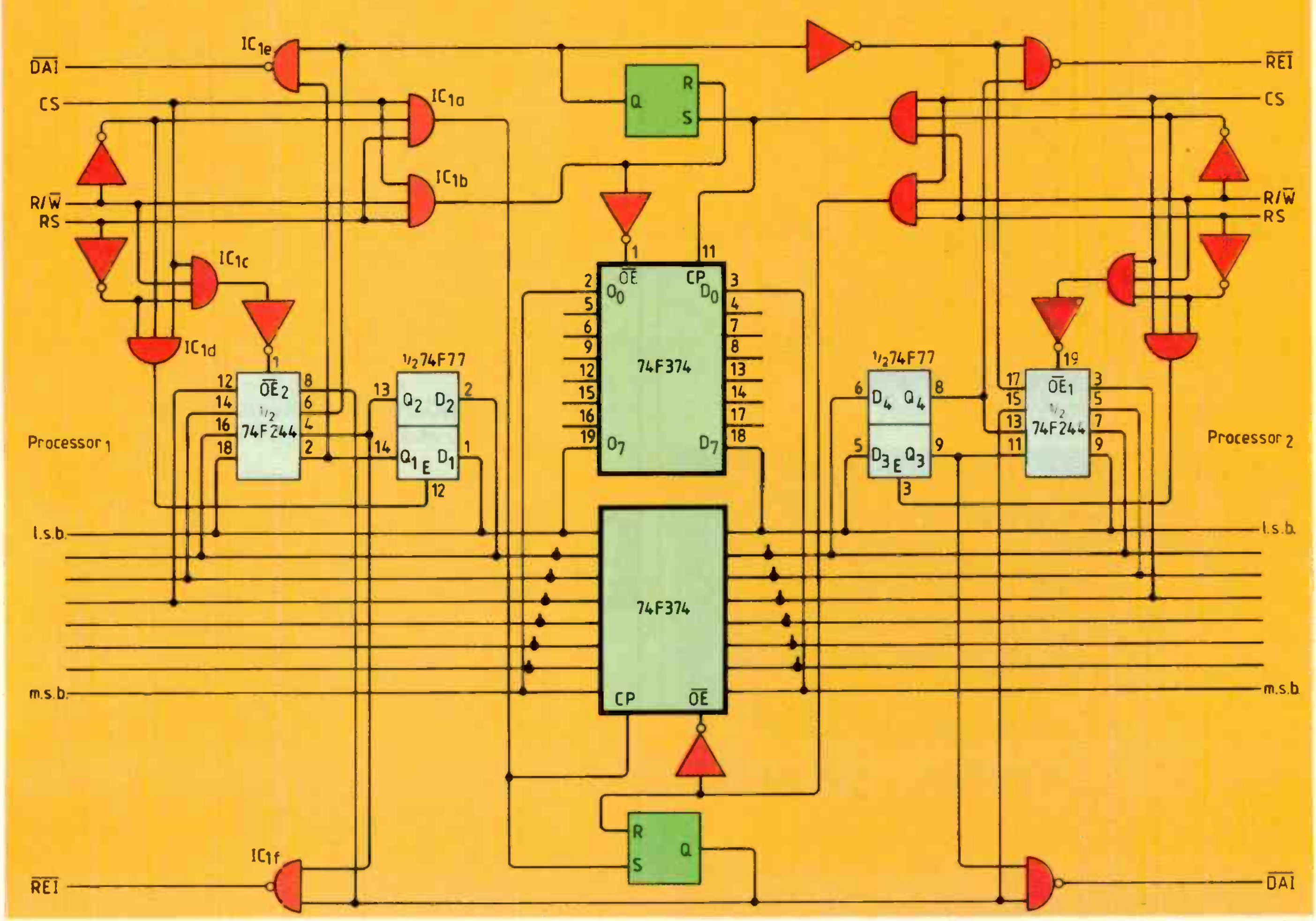

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The conquest of thought

Ivor Catt claims that the Establishment response to a new theory is to re-state the old one in the belief that there is a lack of understanding.

IVOR CATT

In his book "One Dimensional Man", Herbert Marcuse discusses the prevailing drive that tends to reduce all varieties of temperament and desire to one universal system of thought and behaviour. He believes that the source of this drive is technology. "The technological controls appear to be the very embodiment of Reason for the benefit of all social groups and interests – to such an extent that all contradiction seems irrational and all counteraction impossible."

Marcuse sees science-technology as a monolithic force which is in the process of engulfing his society.

I have been excited to find that the totalitarian mechanisms which he says make "The intellectual and emotional refusal 'to go along' appear(s) neurotic and impotent" are also, perhaps unknown to Marcuse, effective in suppressing dissidence (and therefore progress) within science itself.

Marcuse is a philosopher and may not be in a position to know about the totalitarian suppression of alternative, richer views in science, partly because Establishment science suppresses evidence of discord within itself. He knows that Functionalism, which he also calls Operationalism, reduces the possibility of communication of ideas, but may not know that this suppression is also occurring within science-technology itself. He describes Operationalism as follows:

> "...to make the concept synonymous with the corresponding set of operations. ...This technological reasoning, tends 'to identify things and their functions.'"

He cites an example from within science of a reductionist, or operationalist, definition, in this case of the term "length".

> ...The concept of length is therefore fixed when the operations by which length is measured are fixed: that is, the concept of length involves as much and nothing more than the set of operations by which length is determined. ...the concept is synonymous with the corresponding set of operations."

Marcuse, the political philosopher, only sees the disastrous effect of this kind of (behaviourist) attitude when imposed upon the non-scientific society that he cherishes. He may not know about the damage it inflicts on science-technology itself.

In an editorial "The map is not the territory" in February 1979, Tom Ivall, then editor of *Wireless World*, discussed this kind of confusion, but to little avail. A recent example of many such confusions is in the recent 'Joules Watt' articles, where the author clearly thinks that vector algebra, the operation, is synonymous with the concept of electromagnetism. In the subtitle of his August 1987 article the distinction between vector algebra and electromagnetic fields is fogged by the use of the hybrid phrase "vector field theory".* In a later editorial, The decline of the philosophical spirit, it was said that whereas in the nineteenth century scientists were interested in whether a mathematical construct did or did not have a basis in physical reality, today scientists no longer care. Under the destructive philosophy of science today, called "Instrumentalism" by Karl Popper (Conjectures and Refutations, RKP 1965,†), the distinction is blurred anyway. I see Bohr's Correspondence Principle as part of the destructive philosophy.

I attempted to satirize the idea that mathematical constructs were equally important whether or not they were based on anything physically real when I developed the concept of "circularity" by mathematically manipulating the circumference, area and diameter of a circle.* However, Bohr's Correspondence Principle is only used to retain bogus concepts which arose during this century, not to reinstate bogus concepts from the past, like phlogiston, and also not to permit the frivolous introduction of no less valid new concepts like circularity. The Correspondence Principle, magically, only applies in cases when its application will smooth the career path of entrenched professors operating today. T.S. Kuhn says that had Bohr's Correspondence Principle held sway at the time, oxidation would not have succeeded in suppressing the preceding theory of phlogiston, and we would still be teaching phlogiston in our classes today. (T.S. Kuhn, The Structure of Scientific Revolutions, Univ. of Chicago Press, 1970,). However, Kuhn admits that today his (and mine) is a minority view. And Joules Watt, July 1987, paragraph 3, has the temerity to claim that Kuhn supported him in clinging to the past, paraphrasing Kuhn in a manner directly opposite to what Kuhn actually says in the previously quoted book.

In the 1970s, my co-researcher and I made major advances in electromagnetic theory, but were astonished to encounter resentment, obstruction and suppression when we proceeded to try to communicate our discoveries. After many travails, we succeeded in publishing the first part of our discoveries, entitled "Displacement current", in *Wireless World*, December 1978. The total Establishment response was a reply, "No radio without displacement current", in *Wireless World*, August 1979, by D.A. Bell, Professor of Electrical Engineering at Hull University and previously Reader in Electromagnetism in Birmingham University. During the next ten years, although articles and letters discussed our theories in nearly every issue of *Wireless World*, there was no further response of any significance from Establishment figures until the July 1987 article "Maxwell's e.m. theory revisited" by a university lecturer, 'Joules Watt', who specializes in electromagnetic theory.

Both Bell* and J.W. although clearly replying to Catt theories, never reference Catt or his writings. Also, in both cases, they merely re-state the classical position. It is not possible to point to anything in their writings where they relate in any way to the new theory. Their writing is a total regression to the time before the Catt theory was propounded.

We can understand this behaviour if we study the theory of MacRoberts and MacRoberts, (MM), and develop their ideas a

* This term was not due to Joules Watt, but was inserted at the sub-editing stage – Ed.

† I Catt. Electromagnetic Theory Vol 1, C.A.M. Publishing 1979.

* Recently, Bell has written that the Aug. 79 article was not a reply to my Dec. 78 article.

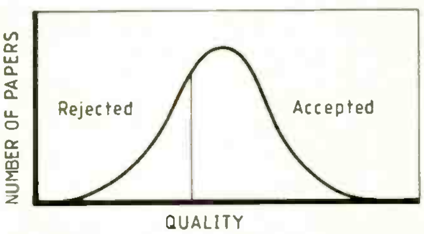
"It is the sphere farthest removed from the concreteness of society which may show most clearly the extent of the conquest of thought by society."

One Dimensional Man, by H. Marcuse

"Emerson truly said that society is a conspiracy against the independence of each of its members."

Originality, by T.S. Knowlson

little further* MM say that during a scientific revolution, which Kuhn calls a shift to a new paradigm, the Establishment pre-revolutionaries appraise the quality of any attempts to communicate the new theory in terms of the old theory.



In a graphical illustration of the problem (Fig.1), they show that any attempt to communicate the new theory will be adjudged a shoddy contribution, and so rejected for publication in any reputable journal. MM say that there is asymmetry. The old Establishment scientists do not comprehend the new paradigm, whereas the revolutionaries comprehend both paradigms, the one they reject and also the new one that they propose. (It is difficult to attach meaning to a process of rejecting a theory that one does not understand.) Any communication of the new paradigm will fall off the curve, out of the range of good communications based on the *old* paradigm, and so will always be rejected by journal referees – every attempt by me to publish any article on electromagnetism has been rejected by every referee of every learned journal in Britain during the past ten years.

What MM do not discuss is the *symmetry* in the structure during a revolution. The revolutionaries know that the Establishment do not understand their revolutionary theory. But also, the Establishment believe that the revolutionaries do not understand the established theory. They further believe that the very existence of the new theory is a result of failure of comprehension of the old (for them perfectly good) theory. This explains why, in the Establishment replies, it is deemed necessary only to re-state the old theory, as clearly as possible, and unnecessary to refer *at all* to the new theory. Also, this explains why their replies are littered with hints, or even assertions, that there is a major problem of comprehension in this particular subject.

"Maxwell...was at home with the mathematics of vectors..." – D.A.Bell August 1979.

"To understand why there are four of Maxwell's equations, we must look at..." – D.A.Bell August 1979.

"You ought to know a little about the accepted norm." J.W. July 1987.

"...those – curls and things.... – do seem to remain unpopular with students, probably the reason is bad teaching again..." J.W. July 1987.

"....a student friend... said that... he still couldn't see the wood for the trees. 'You see', he went on, 'I'm none the wiser about what curl and div – to say nothing of grad – really mean... we had a ghastly maths course about them. That course is still a poor one, you know.'" – J.W. August 1987.

".... a surprising number of quite senior engineers and technicians also tend to avoid complex numbers if they can, when working out problems. – J.W. September 1987.

"People in this unfortunate situation have to face the fact that Fourier and Laplace transforms. Bode plots, poles and zeros, frequency and phase response, many differential equations, Smith charts – and even common old impedance itself all remain a closed book." – J.W. September 1987.

None of the constructs (except impedance) mentioned in the last four quotations receive any mention in any of my writings, except when I satirize them (e.g. November 1985). I regard them as not relevant to the theory of electromagnetism, but the Establishment, noting their absence, assumes either that I am unfamiliar with them or incompetent with them, and proceeds to give me (and you) lessons in them. Truly a dialogue of the deaf, as outlined by Polanyi and Kuhn.**

The solution to the conundrum, that Bell claims he was not replying in August 1979 to the Catt article of December 1978, is that the way the Establishment replies to a new theory is to restate the old theory, and so his claim arises out of semantic ambiguity.

* The Scientific Referee System, *Speculations in Science and Technology*, Vol. 3, No 5, 1980, p573-578.

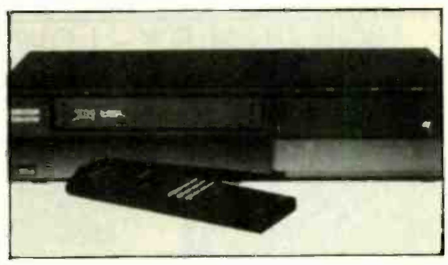
** M Polanyi, Personal Knowledge, RKP, T.S.Kuhn, Op cit

First v.c.r. with Nicam digital audio

This video cassette recorder from Ferguson is the first piece of consumer equipment to include a decoder for Nicam 728, the digital sound transmission system developed by the BBC as an enhancement to existing European tv standards.

Besides bringing digital quality to tv audio, Nicam will enable broadcasters to offer stereo or bilingual sound.

Ferguson's FV14T v.c.r. uses a two-chip decoder, though later products will be based on a single-chip version designed by the company and now being manufactured by Texas Instruments. High-quality sound output is available via Peritel (Scart) and audio sockets, but the v.c.r., which retails at about £750, records and plays only in analogue form. Laying a digital audio track on the tape would have meant a substantial change to the machine's VHS format. The rival Video 8 standard promoted by Sony does include a digital sound recording capability, but its signal format differs from Nicam 728.



Although Nicam 728 has been adopted as a standard by the British Government, regular broadcasts still seem some way off. BBC-tv's London transmitters at Crystal Palace already carry experimental ones, notably live outside broadcasts such as the Wogan chat-show and relays from the Henry Wood Promenade Concerts. But at other times the digital sound channels are occupied by fill-in music from compact discs, leaving the tv audience to switch to the ordinary f.m. sound carrier. More extensive use of stereo sound with tv is likely to have to wait until money is available for the replacement of existing equipment and distribution links.

Over on the IBA's channels, there's hope of a start in the London area in early 1989. Re-engineering work now in progress should make it possible to bring a Nicam service to the provinces later on.

Other countries said to be taking an interest in Nicam digital sound are Hong Kong (which needs the ability to carry independent bilingual sound channels), Australia, Scandinavia – and even West Germany, whose dual-carrier f.m. system the BBC tried out before deciding to press ahead with its digital approach.

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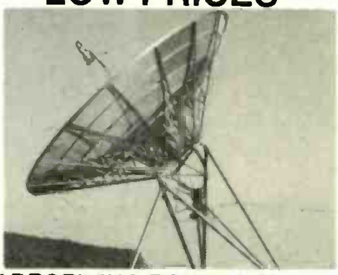

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86	.20	.49
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41464	64K×1	3.30
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2114LP	1K×4	1.50
2128LP	2K×8	2.50
SRAM 5V CMOS		
6116LP	2K×8	1.40
6264LP	8K×8	2.40
62256LP	32K×8	14.50
EPROMS 5V NMOS		
2716	2K×8	2.70
2732	4K×8	2.65
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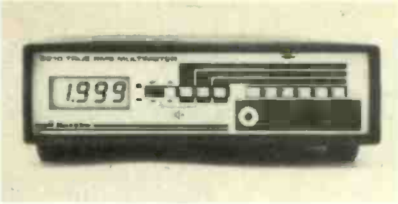

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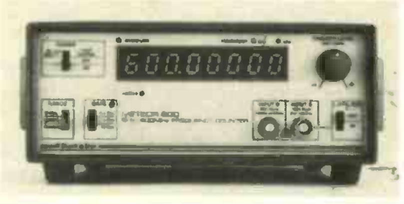

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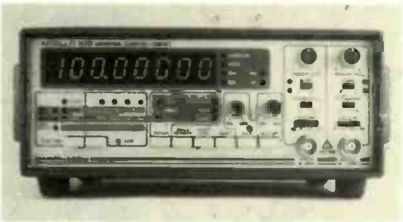

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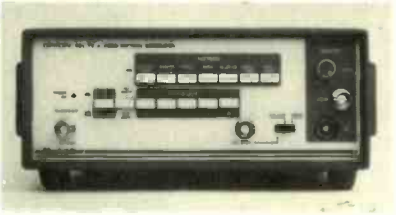

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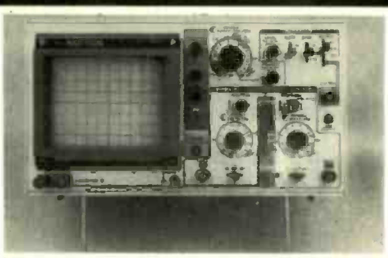

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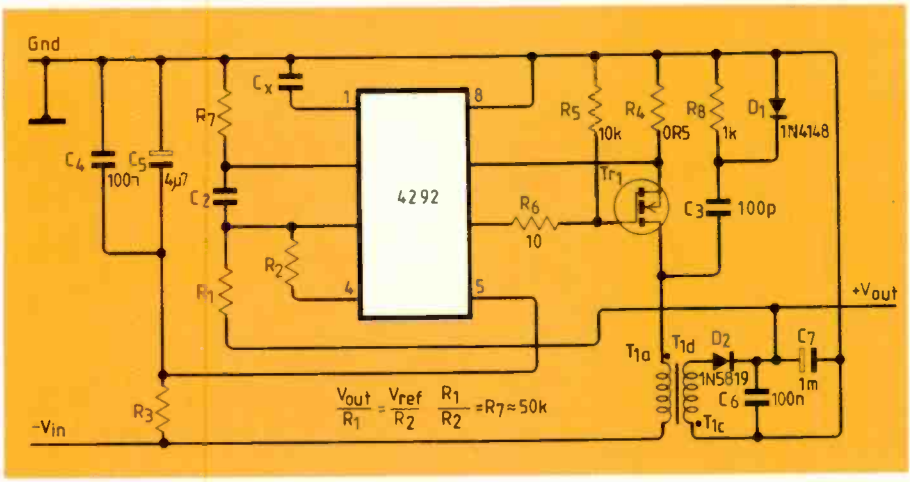
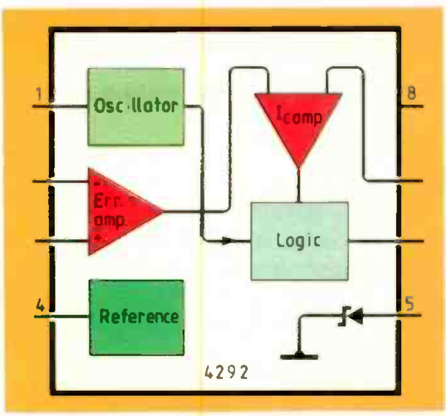
APPLICATIONS SUMMARY





Negative-input switching regulator

Various configurations for the RC4292 negative switching regulator are shown in the device's preliminary product specification. Full component details are given for this negative-input to +5V regulator which works with inputs of up to −90V and delivers about 120mA.

At full load, inputs from −60 to −30V cause an output variation of 20mV; load regulation is 15mV from 10 to 120mA. One of the main features of this Raytheon device is that it operates with inputs of up to −120V so it is suitable for use in telephone line-driven supplies. At −48V input, this circuit is 60% efficient. A dual-output (−5.5V and +5V) regulator specifically for a p.b.x. off-hook supply of −48V is one of the remaining four circuits given in the specification.

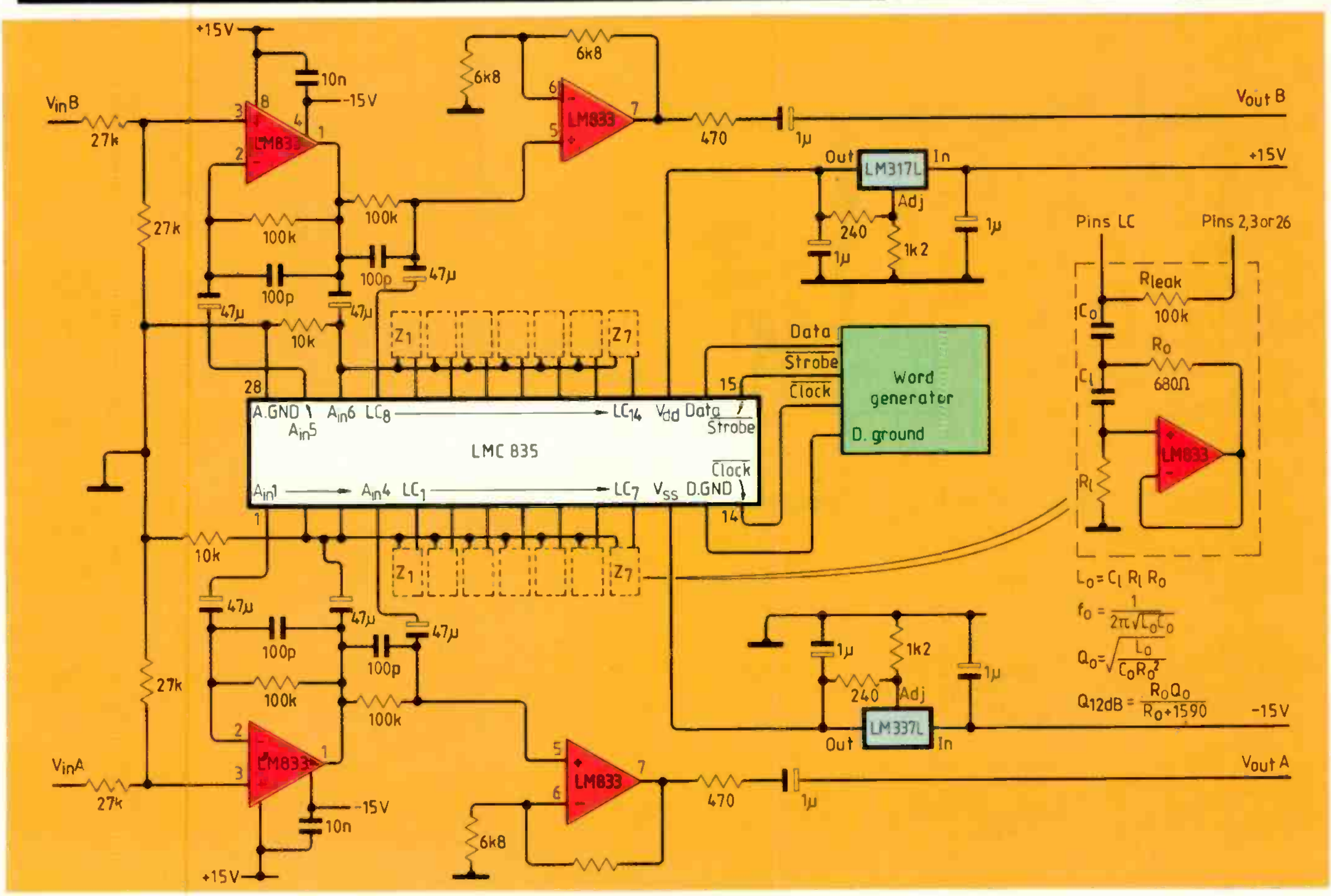
Digitally controlled graphic equalizer

Computer control of the curve of this seven-band stereo graphic equalizer requires three digital signals – one containing serial data, one to clock the data and one to strobe data words. The circuit is one of six application ideas contained in National Semiconductor's data sheet for the LMC835 c-mos graphic equalizer with digital control inputs.

Signal-to-noise ratio of the 835 ranges from 106 to 116dB, depending on level settings, and t.h.d. is 0.0015% at 1kHz, rising to 0.1% at 20kHz.

Gyrator component values

	f_o(Hz)	C_o	C_l	R_l	R_o
Z_1	63	1μ	100n	100k	680
Z_2	160	470n	33n	100k	680
Z_3	400	150n	15n	100k	680
Z_4	1k	68n	6.8n	82k	680
Z_5	2.5k	22n	3.3n	82k	680
Z_6	6.3k	10n	1.5n	62k	680
Z_7	16k	4.7n	680p	47k	680

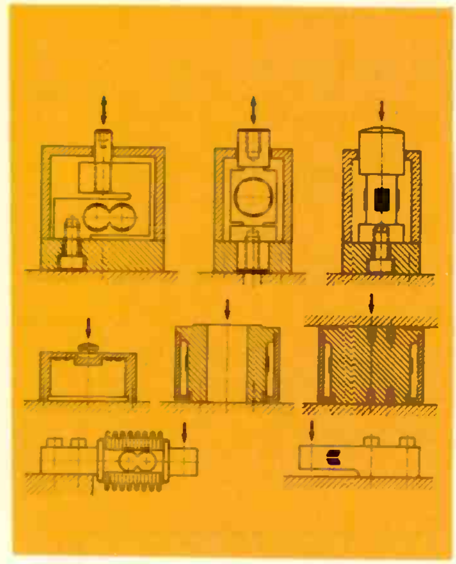


APPLICATIONS SUMMARY

Installation of load cells

One of the load cell's chief industrial applications is the weighing of containers. Where heavy, fixed containers are concerned, load cells are particularly useful when checking the level within a container is impractical or when the volume-to-weight ratio of the container's content varies.

Electrical and mechanical considerations for load-cell installation are discussed in Hottinger Baldwin Messtechnik publication G21 03 1 e. The guide outlines how to connect cells to minimize electrical interference effects and how to mount the cells to prevent bending and torsional moments. These diagrams show some of the load-cell variations available: black portions indicate the sensing area.

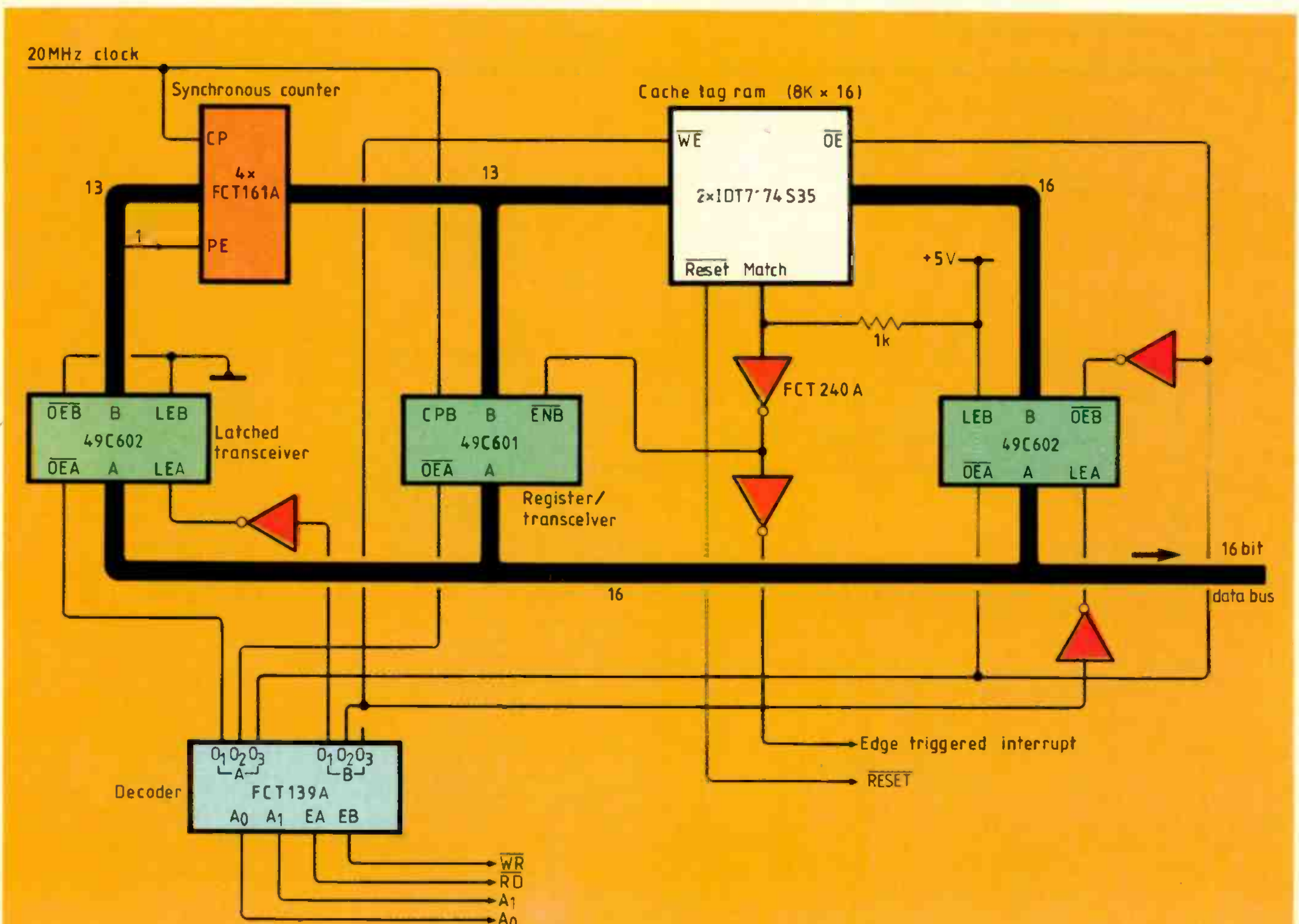


Using tag ram for con tent-addressable memory

Content-addressable memory is the inverse of look-up table memory. According to IDT application note EA001, entitled Content-addressable memory system using IDT7174 cache tag ram, look-up memory is analogous to a normal telephone directory and content-addressable memory is analogous to a directory indexed by telephone number.

Comparing names and addresses involves comparing large numbers of data bytes, but comparing telephone numbers' takes only one byte. Therefore content-addressable memory is useful for searching through large amounts of memory at high speed, for example in data-bases.

Within the IDT7174 cache tag ram is a high-speed comparator and 64K of c-mos memory: this combination allows data comparisons to be made in less than 37ns. The note briefly describes the tag ram and the circuit shown here.



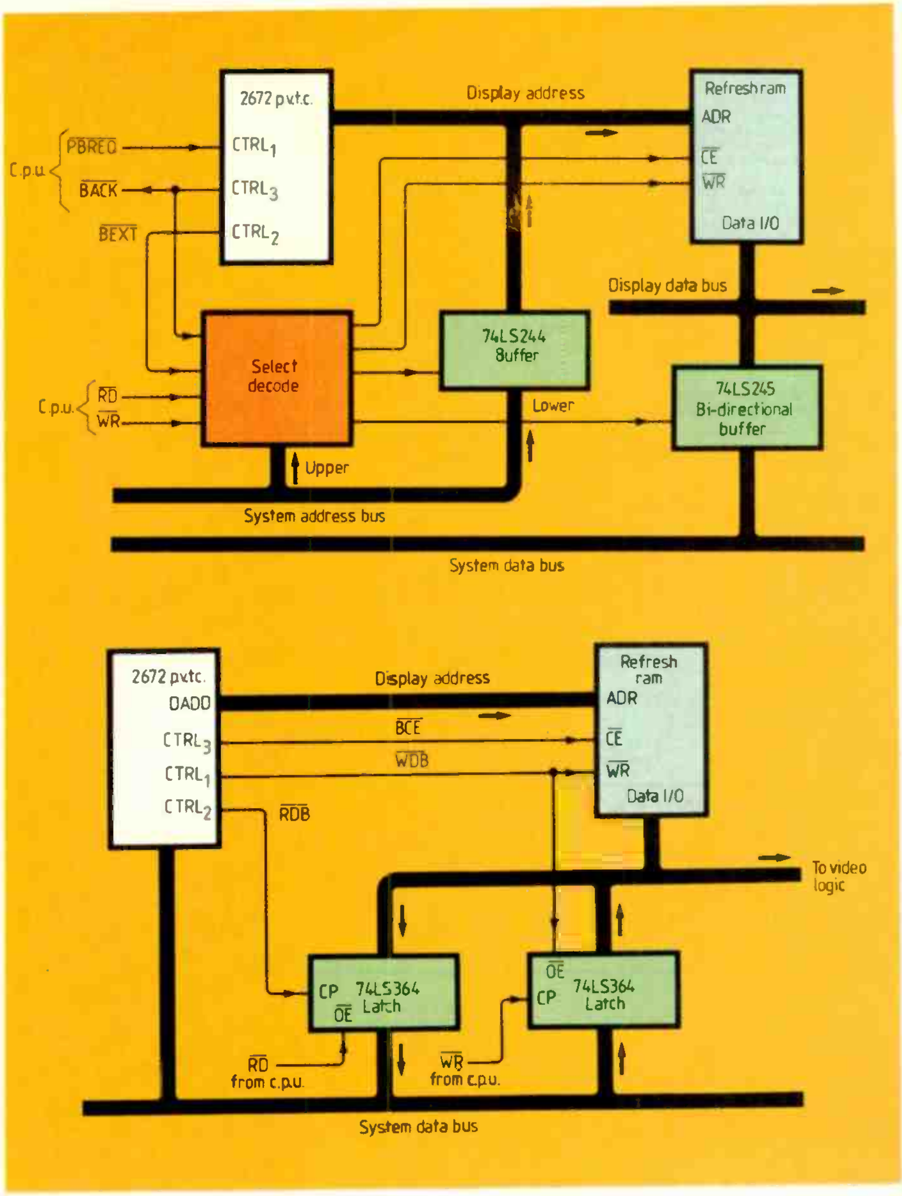
APPLICATIONS SUMMARY

Programmable video-timing controller

Address and data lines from the SCN2672 programmable video-timing controller connect directly to up to 16K of dynamic ram for refresh and display access. When computer address and data buses need to access the display ram for updating, the video-controller bus lines can be floated so only one set of three-state buffers is needed to avoid bus contention.

The Mullard SCN2672, designed for raster-scanning systems, has two modes. In shared mode, top, the computer and video controller share the video memory; display update addresses from the computer feed the display-ram address bus through buffers. In independent mode, bottom, display ram is addressed only via the controller; display-update addresses from the computer enter the controller through the data bus so this mode requires only data-bus latches.

Within the 2672 controller, eleven registers select display-buffer, split-screen and cursor addresses, video sync timing and double-height/underline/cursor-blink functions. Up to 128 character rows and 256 characters-per-row can be displayed; character height can be between 1 and 16 scan lines. Timing signals and various configurations in block-diagram form are given in the 23-page data sheet.



Addresses

Mullard
Mullard House
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Stepper motors and control systems

In ordinary a.c. and d.c. motor applications, acceleration and deceleration phases represent only a small design problem but with stepping motors, these phases are of primary importance since stepping motors spend most of their time accelerating and decelerating.

In Bulletin ST-AD from Bodine, effects of this type of 'transient-state' motor are discussed. Solutions to the problems involved are particularly Bodine oriented but the discussions of the problems are of general interest, particularly on the mechanical side. This table is from the brochure's section describing formulas relating to stepper-motor choice. There is also a section on motor-sizing calculations.

It is pleasing to see that safety aspects of choosing a stepper motor take a good proportion of the first page of this 13-page American brochure.

Torque conversion

	Nm	dyn cm	kp m	oz in	lb ft	lb in
Nm	1	10^7	0.102	1.416×10^2	0.7376	8.851
dyn cm	10^{-7}	1	1.012×10^{-8}	1.416×10^{-5}	7.376×10^{-8}	8.851×10^{-7}
kp m	9.807	9.807×10^7	1	1.389×10^3	7.233	86.8
oz in	7.062×10^{-3}	7.062×10^4	7.201×10^{-4}	1	5.208×10^{-3}	6.250×10^{-2}
lb ft	1.356	1.356×10^7	0.1383	192	1	12
lb in	0.113	1.13×10^6	1.152×10^{-2}	16	8.333×10^{-2}	1

Data error correction

An internationally-agreed standard for high-speed data communications is urgently needed.

ADRIAN J. MORANT

This modem by Microcom uses the company's MNP, now an industry standard protocol for high-speed links. Over 100 manufacturers have bought licences for its higher levels.

Figures from the USA suggest that nearly 20% of personal computers there have modems attached, as compared with around 3% in the UK. Many reasons can be advanced for this, including lower telephone charges; an open and competitive marketplace which has resulted in lower prices and a plethora of products; and a greater maturity of the whole microcomputer industry.

However, irrespective of the reasons, the use of communications between micros is not growing as rapidly as one could reasonably expect in view of the increasing number of micros installed.

According to a Frost & Sullivan report "Data Communications Equipment Market in Europe", published at the beginning of this year, the demand for data communications equipment wil grow from the $746M of 1986 to more than $1.1G in 1990. While modems accounted for nearly 60% of this spend last year, F&S predicts that this proportion will reduce by 1990 but will still be over 40% of the market. With a value of some $500M, technical matters tend to merge closely with marketing and political issues.

In the UK, in particular, unreliability and errors in transmission have resulted in data communications frequently being seen as an arcane art, more a toy for the enthusiast than a serious business tool. Even though error correction software and modems have been available for some time, the lack of a formally agreed standard – even though there is a *de facto* one – has been a barrier.

Changes always occur slowly in telecommunications, with progress being slow until the installed base reaches the critical mass to fuel a more rapid and accelerating growth. The most widely used electronic communications system in the world, telex, still uses the telegraph system developed in the electro-mechanical era. Teleprinters then were limited to operating at around 60 to 100 words per minute using start/stop operation. Each character was composed of a serially-transmitted five-bit code group preceded by a start pulse and terminated by a stop pulse. The structure was designed to tolerate noise on the line as well as taking into account speed variations that occur with electromechanical devices. In practice, the receiving machine idles, awaiting the start pulse which indicates the beginning of the next character. This could follow immediately after the previous one or may be minutes later. Even though modern telex machines are very similar to printers used on microcomputers, they are still constrained by the same character set.

The 32 combinations from a five-bit code are inadequate for normal communications where a full alphabet plus numerals and punctuation marks are required. Consequently, two combinations are reserved for figure and letter shifts which indicate how the characters following are to be interpreted. Over the years, the speed of data transmission has increased from 50 baud to 300 and now to 1 200, 2 400 and beyond. At the same time, changes have been made in the code used. The most widely used code now is the American Standard Code for Information Interchange (Ascii).

Ascii, which was subsequently ratified as the International Alphabet no.5, provides seven data bits together with an eighth parity bit which can be used for error control. They are framed by start and stop elements. Some systems ignore parity checking; but where it is used the parity bit is chosen so that the total number of 1s in that particular sequence of eight bits is either even or odd. If the requirement is not to use Ascii but to have a transparent system that will treat all eight bits as data there is no redundant error-checking element.

This can be dealt with by error checking methods which, instead of treating each character as a self-contained entity, are block-related. Characters to be sent are collected in a buffer; and then at intervals, either when the buffer is full or after a suitable period, the block is sent down the line together with additional security information such as longitudinal parity. Once the block has been judged to have been received successfully (by using the appended error checking information), all redundant framing information will be stripped from it, leaving the actual data. Then, a confirmation is sent to the sending end requesting the next block. If, however, the block had not been received successfully, a repeat-request would have been returned.

Where the sender has to wait for acknowledgement of one block before sending the next, the transmission link is not being used very efficiently. Consequently, a moving window can be used which allows blocks to be sent one after another without waiting for acknowledgement, though one will follow in due course. Should the receiver need a corrupt block to be retransmitted it will return a request to that effect.

MNP: A *DE FACTO* STANDARD

Over the years, the modem manufacturer Microcom has developed its Microcom Networking Protocol, MNP. This is an evolving multi-level standard, the lower levels of which the company has placed in the public domain. As there is no error correction standard protocol it became the *de facto* one. This is rather similar to the way that the AT command set used by Hayes Microcomputer Products in its modems is virtually universal.

MNP has been enhanced periodically to meet demands for higher performance. The lowest level employs basic error protection, but in the higher MNP classes improved protection and data compression are employed. This is of great significance to business users to whom integrity of data is vital and who have large quantities to transfer. They are prepared to pay a higher price for their modems because this results in lower telephone line costs.

The higher classes of MNP, class 5 and beyond, are available through a Microcom licensee programme. Over 100 MNP modem manufacturers have taken licences. These include British Telecom, Case-Rixon, Gandalf, Hayes and Racal-Vadic. To date, over 100 000 MNP modems have been delivered, and they constitute the largest installed base of error-correcting modems.

The original MNP Class 1 implementation used an asynchronous byte-orientated half-duplex method of exchanging data which imposed minimal demands on processor speeds and memory storage. The protocol efficiency, i.e. the actual data throughput as compared with the system without error protection, is around 70%. Hence a device using MNP Class 1 with a 2400 bit/s modem will realize 1690 bit/s throughput. Modern microprocessors have become so powerful that MNP Class 1 implementations are now uncommon and it has, essentially, been overtaken by Class 2.

Class 2 is very similar to Class 1 except that it is full duplex: the sending end does not have to stop sending and wait for an acknowledgement from the receiving unit prior to sending the next block. Almost all microprocessor-based hardware is capable of supporting Class 2 performance. Common implementations are based on Z80 and 6800 micros. The protocol efficiency rises to around 84%.

The next level, MNP Class 3, uses synchronous bit-orientated full-duplex data exchange. This is inherently more efficient than the asynchronous byte-orientated data format because the stop and start bits are stripped from each individual character and the data bits packed together. Knowing that each character is 8 bits long it is a simple matter to convert the bit-stream back to its original characters on receipt.

The user still sends data asynchronously to the Class 3 modem, while the modems communicate with each other synchronously. The protocol efficiency of a Class 3 implementation is about 108%. Hence, a device using Class 3 with a 2400 bit/s modem will realize 2600 bit/s throughput. Thus, not only will the user get error-free transmission, he will also obtain increased data throughput.

MNP Class 4 introduces two new concepts: adaptive packet assembly and data phase optimization. Both are aimed at reducing transmission overheads.

During data transfer, MNP monitors the reliability of the transmission medium and, if the data channel is relatively error free, it assembles larger data blocks to increase throughput. If the data channel is introducing many errors, MNP reduces the size of the blocks sent. While smaller data blocks increase the protocol overhead (the overhead per block being constant), they concurrently decrease the throughput penalty of retransmissions of data. The result of smaller data blocks is that more data is successfully transmitted on the first try.

Once a data call has been initiated, most of the administrative information during the subsequent data transfer phase of a connection never changes. Data phase optimization provides a method for eliminating some of the administrative information and so further reduces protocol overhead. The overall result is that the protocol efficiency of a Class 4 implementation is about 120%. Thus this level of MNP gives a 20% improvement over an ordinary modem without MNP.

DATA COMPRESSION

The next feature added to MNP was data compression (Class 5) using a real-time adaptive algorithm. The real-time aspects of the algorithm allow compression to operate on interactive terminal data as well as file transfer data.

The algorithm's adaptive nature means the data compression is always optimised for the user's data. The compression algorithm continuously analyses the user data and adjusts the compression parameters to maximize data throughput.

Data compression algorithms, like sort algorithms, are sensitive to the data pattern being processed. Most data being transmitted will benefit from compression. The user will see compression performance of between 1.3:1 and 2:1. Some files may be compressed at even higher ratios. The following types of common user files are listed in order of increasing compressibility: COM or EXE computer program files; spreadsheet files; word processing text files; and print files.

A realistic estimate of the overall compression factor a user will experience is 63%. In total, this is equivalent to a net protocol efficiency of 200% for an MNP Class 5 implementation so that, at Class 5 performance, the protocol doubles the throughput of an ordinary modem.

A further class, Class 6, adds universal link negotiation and statistical duplexing. The former allows MNP modems to being operation at a common lower speed and negotiate the use of an alternate high speed modulation technique.

Microcom's AX/9624C is an example of a modem that uses universal link negotiation. One of these modems would normally initiate a data call using the 2400 bit/s V.22bis standard to negotiate the link. If its negotiation revealed that the modem at the other end of the link was suitable for MNP Class 6 operation, both would shift to operation using 9600 bit/s V.29. Furthermore, in the case where the high-speed carrier technology uses half-duplex operation, Class 6 statistical duplexing monitors the user data traffic pattern to allocate the half-duplex modulation dynamically to deliver full-duplex service.

The outcome is that an MNP Class 6 modem based on the V.29 standard delivers maximum performance in file transfer applications where data is travelling in one direction, the only information returned being to acknowledge the successful (or otherwise) receipt of data blocks. Under these circumstances, a throughput of up to 19.2kbit/s is possible on dial-up circuits.

Although MNP has been evolving to keep pace with needs, it has no authority. However, the CCITT (the International Telegraph and Telephone Consultative Committee) Study Group XVII is aiming to set an official standard and MNP is one of the main contenders alongside LAPB and LAPD. In a very great oversimplification, MNP is the existing de facto standard employed by hundreds of thousands of users around the world while the LAP (link access procedure) protocols are employed by the CCITT in the X.25 protocol used for packet switching.

There has been much discussion within CCITT Study Group XVII. Some contributions have come from national administrations and others from modem manufacturers. Many modem suppliers obviously have a vested interest in continuing with MNP and having Class 4 adopted by the CCITT. However, end-users need a large installed base of compatible modems if they are to be able to communicate freely.

PTTs, on the other hand, frequently take a long term strategic view, without full appreciation of problems faced by users, and look at matters in the context of compatibility with other CCITT protocols. To quote from an AT&T contribution, "...while it may be unclear whether either protocol has a technical advantage over the other, there are several non-technical points in favor of each. For LAPD, the concept of synergy with other work in SGXVII and CCITT is important. For MNP, the main point seems to be an installed base of modems..."

Proponents exist for both schemes; and in the longer term it is likely that compatibility with other standards will be important. But looking to the reality of telecommunications it is worth citing another contribution: "Until now the discussions on the error correcting protocol have concentrated mainly on the technical aspects. However, the acceptance of a new recommendation V.erc will depend on the usefulness of its contents to the users and network/service providers. The protocol that is most useful to them will become the practical standard..."

Surface-mount p-i-n diodes operate beyond 2GHz

Until recently p-i-n diode switches with good performance beyond the few hundred of megahertz range have been difficult and expensive to manufacture. With the introduction of triple p-i-n diodes in a surface-mount package, Siemens claim to have overcome both these problems.

There are four main parameters which describe p-i-n diode switch operation: insertion loss, isolation, switching speed and power handling capability. Insertion loss is a measure of the loss attributed to the diodes when the switch is in the on-state. For low loss, low resistance is needed in the series arms of the switch, and low capacitance in the shunt arms. Specifications for the BAR60 and BAR61 devices show a low resistance value of 5Ω (typical) at a forward current of 20mA, and an exceptionally low capacitance for this type of device of 0.25pF (typically, V_R=50f F=1MHz) making them suitable for use up to and beyond the 2GHz region.

Isolation is the r.f. leakage between the input and output terminals when the switch is in the open-circuit condition. Resistance and capacitance are again important, but for high isolation the diodes concerned are in the shunt and series arms respectively.

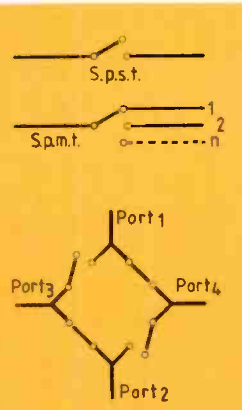
Another important parameter in many applications is switching speed, and this can be specified in terms of the reverse recovery time of the p-i-n diodes being used. This is a measure of the time to switch the device from the on to the off state – the time to switch between off and on being shorter.

The r.f. power handling capability of a p-i-n device (c.w. or pulse) is mainly dependent on thermal considerations. Maximum power handling can be determined from the given figures for maximum junction temperature and thermal resistance from junction to ambient, taking into account biasing (and hence diode resistance) and ambient temperature. Pulse width and duty cycle have to be considered in the case of pulsed operation.

SWITCH CONFIGURATIONS

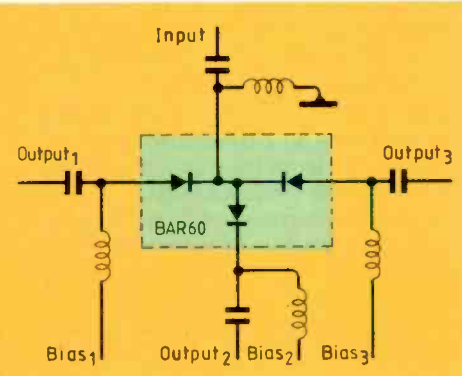
Diode switches can be split into two categories: reflective switches and non-reflective types. Although both types connect a source to a load in the on state, they differ in that the reflective switch reflects any power incident on to it in the off state, back to the source. The non reflective type, on the other hand, terminates any incident power with the characteristic impedance of the system.

The switches can be further sub-divided according to function i.e. s.p.s.t., s.p.m.t. and transfer. The switching mechanism of these three types is as shown in Fig.1. Each of these types can be produced employing either all series, all shunt, or series-shunt elements. Although the BAR60 and BAR61 devices have been designed for use in broadband series/shunt arrangements, a very sim-

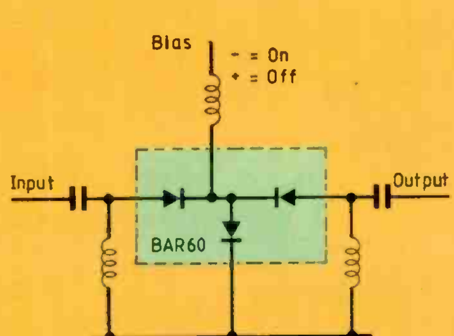


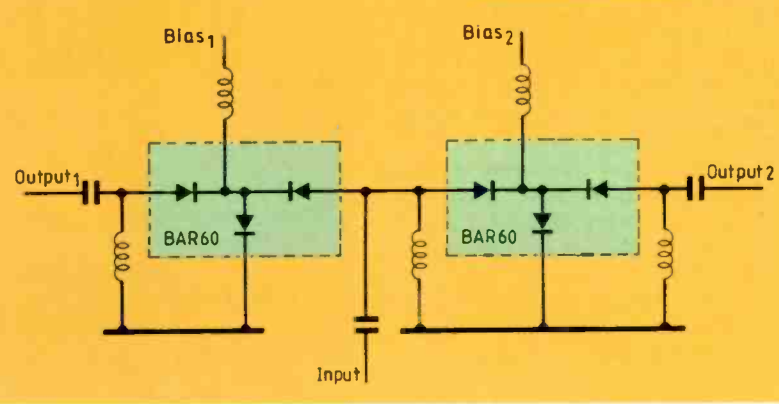
State	On	Off
Q	1 to 4	1 to 3
	2 to 3	2 to 4
Q̄	1 to 3	1 to 4
	2 to 4	2 to 3

1. (left) A wide range of switch configurations can be produced using p-i-n diodes. The high speed diodes enable switching rates of up to 2GHz.
2. (right) A sigle-pole three-throw switch can be produced using a single three-diode i.c.
3. (below left) Better performance than that of Fig. 2 can be obtained by this configuration off a s.p.s.t. switch. In order to obtain multithrow switches it is possible to duplicate the circuit as in Fig. 4 (below right).



	On	Off
Output 1	+	-
Output 2	-	+
Output 3	+	-





ple s.p.3.t. switch can be built using the BAR60 in the configuration shown in Fig.2.

REFLECTIVE SWITCHES

A switch with better performance than that of Fig.2 is shown in Fig.3. Here the three diodes of the BAR60 are used in a 2 series/1 shunt s.p.s.t. arrangement, providing for more isolation in the off state than can be obtained with one diode. When the bias voltage V is positive, both D_1 and D_3 will be reverse biased, and so will be in the high impedance state; D_2, on the other hand, will be forward biased and so have a low impedance value, dependent on the bias current being used. It is obvious, therefore, that the switch is in the high impedence (input-to-output) off state. By reversing the bias voltage, D_2 now becomes reverse biased, and D_1, D_3 are forward biased. This is the low insertion loss on state.

Because the BAR60 is in the small SOT143 package, the parasitic elements of the package inductance and capacitance are kept to a minimum, making this a very effective switch for use in the u.h.f. and low microwave frequency range.

The only drawback in the series/shunt arrangement is in its low compression point, owing to the fact that the reverse bias voltage on the shunt diode is restricted to the forward voltage of the series diodes. This enables a small r.f. voltage to forward bias the shunt element. However, the advantages of the series/shunt arrangement, namely multi-octave bandwidth, high isolation and short transition times, make this the most common form of reflective switch.

An s.p.m.t. switch (Fig.4) can be fabricated simply by duplicating the s.p.s.t. switch by the required number of throws. In this case, a single earth return L_1 is needed on the input side of the switches, thus reducing the component count.

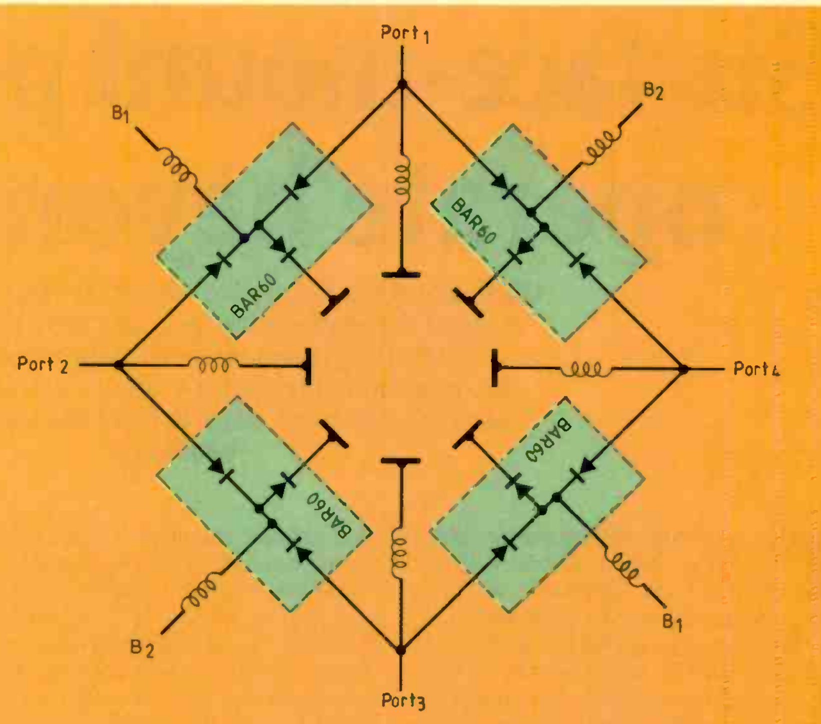
A more novel application of the BAR60 device is shown in the transfer switch of Fig.5. As shown in the truth table, the circuit basically provides a two-state switch, whereby port 1 is connected to port 2, and port 3 is connected to port 4, or vice versa. By using the BAR60 the component count has been reduced from a total of 20 parts including 12 microwave diodes, to four surface-mounted devices and a handful of inductors.

NON-REFLECTIVE SWITCHES

By placing a shunt diode terminated in the characteristic impedance of the system at either end of a reflective switch, the switch becomes non-reflective. This arrangement is shown in fig.6. Here the resistor absorbs the r.f. energy when the switch is in the off state, the power rating of the resistor being a restriction on the maximum power handling capability of the switch.

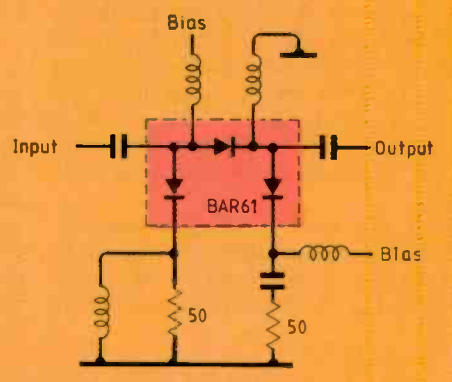
There are as many variations of non-reflective switches as there are of reflective types, the exact nature of a p-i-n switch being largely dependent on the imagination and ingenuity of the designer. Due to the simplicity and performance of the BAR60/61 devices, there are myriads of other circuits and applications yet to be discovered.

Based on information provided by Siemens electronic components group.



Negative bias on	Connected pair	Disconnected pair
B1	1 to 2	2 to 3
	3 to 4	1 to 4
B2	2 to 3	1 to 2
	1 to 4	3 to 4

5. (above) An arrangement of diode i.cs to give a two-state switch. The i.cs reduce the component count from 20 parts to just four surface-mounted components and a few inductors.



6. (above right) The use of the shunt diodes at either end of the switch produces a non-reflective device.

These p.i.n. photodiodes can detect 565Mbit/s.

NEW PRODUCTS

Optical worm drive with high capacity

An optical disc drive in the Topaz range uses write-once-read-many (worm) technology in a 12in exchangeable double-sided disc to provide a total memory capacity of 2000Mbyte. This is the equivalent of 150 high-resolution full colour pictures or up to 2000 A0-size drawings in a compressed format with grey scale for anti-aliasing.

The optical drive communicates with the Topaz graphics system through a dedicated d.m.a. controller which allows large blocks of data to be transferred directly into the image memory at 300kbyte/s. Images are read into the memory from a high-resolution scanner.

Multiple disc drives can be installed in a system to give access to a very large number of images, as may be used in libraries, art galleries, museums requiring rapid retrieval of images and/or text from a large database. Primagraphics Ltd, Melbourn Science Park, Melbourn, Royston, Herts SG8 6EJ. Tel: 0763 62041.

PADS-PCB updated

Several enhancements have been added to the PADS-PCB program to produce version 1.5. Included in the new version are: an 'area move' facility that lets the user define and move a group of components and their associated connections and routes at the same time. The ability to 'design-on-the-fly' allows the creation of a layout without starting with a netlist; pad stacks can be used at a single command and solder mask pad sizes can be defined for one position and then used wherever needed. The finished design can be checked automatically against a netlist or parts list. It is also easier to update the components library. Text can be added to a board design and displayed at true width. Microtel Supplies Ltd, PO Box 18, Egham, Surrey TW20 9AQ. Tel: 0784 35364.

Circuit design system

An upgrade to the Schema circuit diagram capture package may be used for p.c.b. layout, circuit simulation, gate-array designs, programmable logic arrays and other programmable logic devices. The package, now called Schema II, runs on IBM PC, XT, AT, 386 and clones and can be used with a variety of graphics adaptors, printers plotters and input devices, like the mouse. Net and pin list outputs can be interfaced with other systems that can accept an ASCII net or pin list.

The Drawing Editor contains a schematic editor, which produces the drawings, and an object editor which is used to create the symbols. The drawing editor has instant screen panning, a three-windowed zoom facility and allows simultaneous viewing of all drawing contents, including text and labels. Parts of a drawing can be altered and merged with the complete drawing. Special details can be drawn pixel-by-pixel.

The package also offers flexible post-processing software which can check errors in design rules, provide a bill of materials and wire lists. It includes libraries of discrete, analogue, t.t.l. c-mos ics, and a number of microprocessors and other devices. Each library can contain up to 4,000 symbols. Engineering Solutions Ltd, Kings House, Kings Street, Maidenhead, Berks SL6 1EF. Tel: 0628 36052.

Inductors for switchers

Low winding resistance and high current ratings in the Taiyo Yuden range of inductors make them especially suitable for switch-mode power supplies. Inductances from 5 to 370μH are available with open-circuit resistance of 0.1Ω, and current ratings from 0.6 to 11A. ECC Electronics Ltd, 9 Blenheim Road, High Wycombe, Bucks HP12 3RT. Tel: 0494 36113.

High-power Darlingtons

The collector is directly connected to the baseplate in these 500A transistors from Fuji. This improves the heat dissipation of the devices at the higher collector currents. The high thermal conductivity of the device allows the dissipation of up to 3.5kW. The module features a d.c. current gain of 500 at V_{CE} of 2V and I_c of 500A. The devices can be used in electric vehicles, high-power and uninterruptible power supplies. Available through ECC Electronics (UK) Ltd, 9 Blenheim Road, High Wycombe, Bucks HP12 3RT. Tel: 0494 36113.

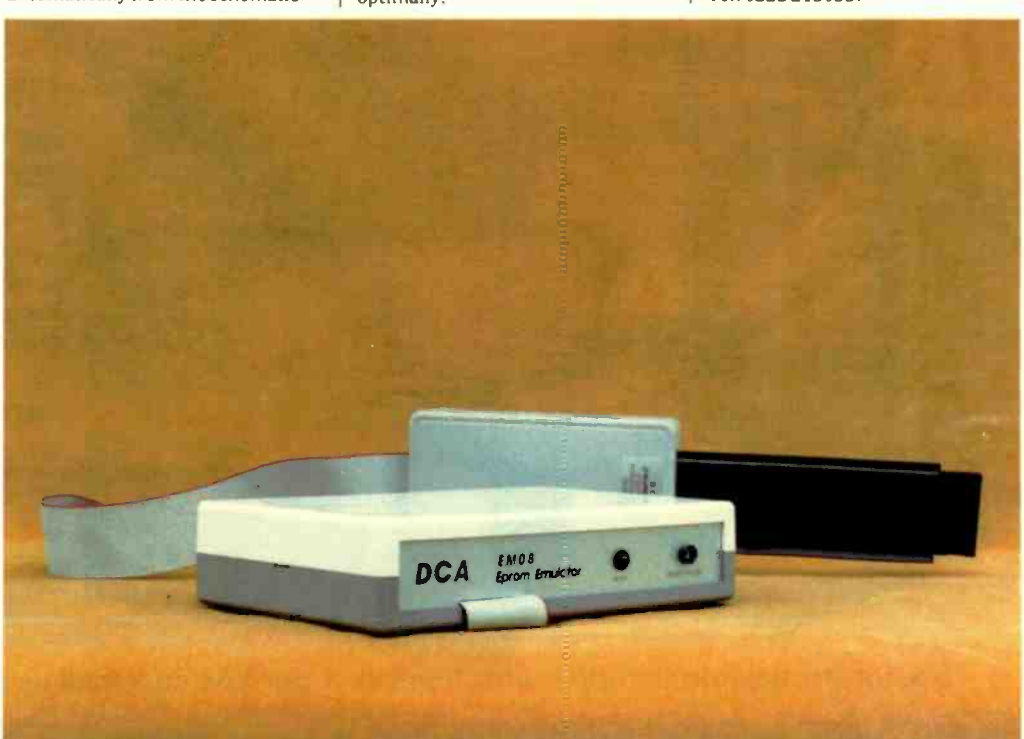
Multilayer board designer

The Boardmaster software package from Daisy provides desktop access to the whole Daisy design system. Included are all stages in the production of a board from specification and circuit diagram to p.c.b. layout, verification and manufacture. P.c.b. layouts are possible with many layers, and high density. The major features of the placement and routing facility are the ability to specify detailed design rules; a gridless routing system, and a non-sequential routing algorithm. The layout database is created automatically from the schematic data and netlists, part list and bills of materials can be provided. Design rules can apply to individual traces, layers or for specific board areas or items.

The placement algorithms minimise component crowding and optimize etch length, and etch density. The global router guides the initial track layout while a routing map can identify possible problems. The routing system works on all signals and all layers at the same time. There is no restriction on the track angles so board areas are used optimally.

The system interfaces to a range of tools including plotters, and routers, automatic drilling and componet insertion machines. It can also output all mechanical documentation; creating assembly instructions, detailed drawings, and technical documents.

Personal Boardmaster, as the system is called, runs on a AT-based computer and can be linked through Ethernet, to other members of the Daisy CAE workstation family. Available through Hi-Tek CAE, Ditton Walk, Cambridge, CB5 8QT. Tel: 0223 215055.



NEW PRODUCTS

COMPUTING

Drop-proof multimeters

A shock-absorbent rubber waffle housing protects the MAN'X range of multimeters from rough handling and even accidental dropping. It has the added advantage of providing a grip and preventing slipping on smooth circuits. Five models offer various sensitivities and ranges including one digital instrument, and another that has a clamp for non-contact current reading. MAN'X 01 has 27 ranges including 30A direct and alternating measurement. MAN'X 02 has a sensitivity of 20kΩ/V; MAN'X 04 is a high sensitivity version with 40kΩ/V. Accessories are available for all these meters to enable them to measure high currents (100A direct and 1000A alternating) and they can be used with a photocell for light-intensity measurements. Manufactured by Chauvin Arnoux in France and available in the UK through Global Specialities, Saffron Walden, Essex CB11 3AQ. Tel: 0799 21682.

Universal programmable peripheral

It is no longer necessary to go to the considerable expense of designing a special-purpose microprocessor peripheral. The functions can be programmed into an erasable programmable logic device (e.l.p.d.) which is claimed to cost a fraction of that normally required by application-specific i.cs. Based on c-mos eprom, the EPB1400, made by Altera, will operate with the majority of 8, 16 or 32-bit processors at up to 25MHz clock rate with zero wait-state memory. It can be easily programmed to cater for a wide range of applications. The EPB1400 integrates a 20-macrocell, general-purpose core e.p.l.d. together with dedicated microprocessor peripheral input/output logic. This includes multiple latches, registers and an 8-bit bus port transceiver. A total of 52 user-configurable storage elements are provided. Seven control macrocells are programmed to interface the device with the chosen micro-processor. The 8-bit i/o bus port has enhanced drive capability, specified at 24mA, which allows direct connection to the processor bus. A single device will operate directly with 8-bit processors or with 16 and 32-bit m.p.us operating in the 8-bit peripheral mode. Multiple elements can be cascaded if full 16 or 32-bit width operation is required. 1.2 micro c-mos eprom geometry provides a.c. performance specifications which support a 25MHz 68020 processor with zero wait states.

General-purpose macrocells include many facilities to make the device particularly useful in peripheral functions. Typical applications include read/write counters and timers, parallel-to-serial and serial-to-parallel data converters, frequency dividers, data communications transceivers and configurable i/o ports. This configurability makes the device suitable for immediate use in the emerging proprietary bus standards such as the IBM PS/2 Micro Channel.

The device is now available as a 40-pin ceramic dil package; 44-pin j-lead and plastic packages are to become available soon.

Special software, running on a PC, is available to design the functions of the device and there is a complete development system. An optional library of 'macrofunctions' includes emulations of a number of standard interface devices. After design entry, compilation time is typically less than five minutes and programming the device takes seconds. Available through Ambar Cascom Ltd, Rabans Close, Aylesbury, Bucks HP19 3RS. Tel: 0296 434141.

Circuit-board designer

Schematic capture, two auto-routers for double-sided and multi-layer boards, analogue and digital simulators, surface-mounted boards, and a portfolio of design functions are included in the version 2.5 of the EIE Executive cad system. The basic package costs £8350 and includes all the software, a high-speed, high-resolution graphics board, a mouse and documentation. It runs on a PC/AT or compatible microcomputer. A complete system to include the computer costs £10,000. Electronic Industries Equipment (UK) Ltd, Midland House, New Road, Halesowen, West Midlands B63 3HY. Tel: 021 550 9758.

100,000 gates on one asic

High-density logic gates and memory cells are combined to allow 100k usable gates on one chip. LSI Logic have developed a 0.7micron channel-length h.c-mos process to produce the LCA100K Compacted array plus. The array can be used in a variety of combinations. For example, 16K-bits of static ram, 64Kbit of rom and 46 thousand usable logic gates can be combined in a single array. However new applications are likely to be found in application-specific microprocessors – the 100K array can hold the equivalent of the c.p.u. logic in a VAX 780 computer. LSI Logic plc, Grenville Place, The Ring, Bracknell, Berks RG12 1BP. Tel: 0344 426544.

Low-cost tv signal generators

A series of test signal generators for monochrome or colour receivers comes from Simon Maddox Engineering of Crawley. They have the generic name of Arthur, and Arthur 350 gives a switched output of pluge*, for setting brightness and contrast; a grille for setting convergence and a non-linear greyscale to highlight colour difference. Optional colour saturation test signals will become available. The unit comes with a remote control panel, a power supply for mains operation and comprehensive instructions; all for £175. Simon Maddox Engineering, Unit 7, Forge Wood Estate, Crawley, Sussex RH10 2PG. Tel: 0293 542275.

*Picture line-up generation equipment.

NEW PRODUCTS

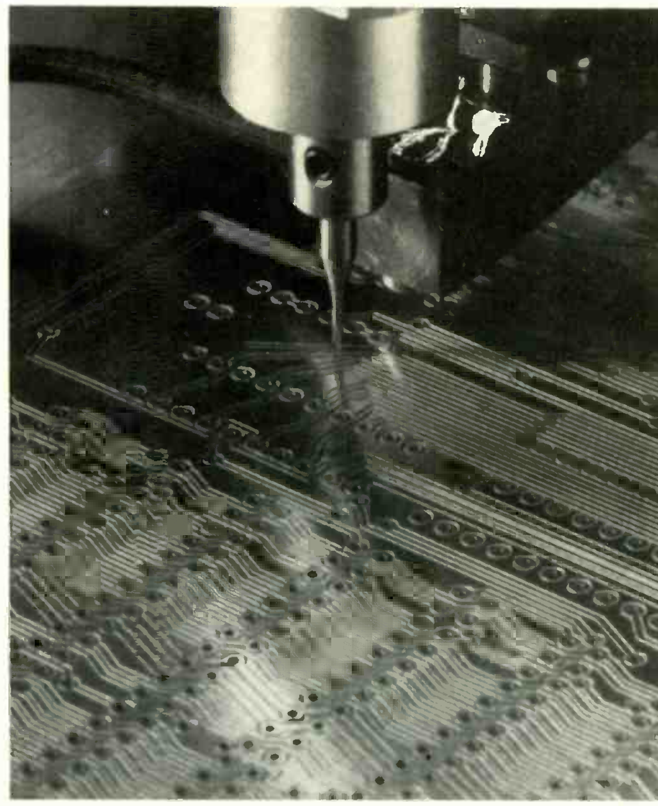
Transputer-aided p.c.b. design

A p.c.b. design system from Hanover is a fraction of the cost of rival systems and yet provides similar or improved facilities. The LPKF colorCam system incorporates high-resolution colour graphics, autorouting and a milling facility that can produce a prototype p.c.b. directly controlled by the design program in the computer. The same mill can also be used to cut a film for photographic production of p.c.bs.

Layout parameters are selected by the user, so the system is suitable for any type of circuit board; analogue, digital, high-frequency or surface-mount or any combination of these. The system starts with a circuit diagram: a file of the required symbols is provided. One of the programs in the suite, Cad Link, automatically produces a connection list, a component list, a graphical display of the pins to be connected and also checks the layout for missing components, missing or reversed connections, short circuits and spacing checks.

The program includes the ability to draw geometrical shapes and text and the library of components provided can be extended as necessary by the user. Component placement can be rotated, copied, erased and moved (retaining the connections). The components are laid onto a grid with a minimum dimension of 10microns. Up to 60 levels can be defined. Many of the functions can be assigned to programmable keys so that pads, or groups of connections can be laid with a single keystroke.

Plotter output is provided as well as a Pascal source program to cater for plotters that may not be includeed in its repertoire. A photoplotter output is also provided. Other options include outputs for drilling machines. G.H. Systems, 12 Coningsby, Bracknell, Berks RD12 4BE. Tel: 0344 860420.



Programmable communications exchange

An 'advanced programming option' has been added to the NDX data exchange to allow virtually all computers to communicate with each other and with peripherals. It can also remove the need for a local-area network. The system has the Basic computer language embedded in it so that protocol conversions can be programmed in. Both EBCDIC and Baudot character codes are incorporated to make it possible to communicate with non-ASCII equipment. And the exchange can even be used to translate data between languages, English to French, for example, or reformat text to suit different page sizes or layouts. Furthermore, because it is software driven, the NDX can be converted to enable non-English users to program it in their own languages, including those which involve non-English character sets – Arabic, Hebrew and Russian, for example.

Based on a modular design, the NDX features four dual-interface card slots, allowing the user to specify the connections to be supplied. Both parallel and serial interfaces can be provided in any combination.

Each of the eight communications ports of the NDX is dissociated by software from the attached 'device'. Unlike the majority of other data exchanges, it can therefore act both as a terminal multiplexer, connecting several v.d.us to computer terminal ports, and as a printer/plotter multiplexer, sharing several computers between one output device, with each protocol fine-tuned to the precise requirements of the device attached to it.

This also means that if two identical devices are linked to two of the ports the NDX will transmit data to whichever of them is free. In addition, the user can identify a 'halt' port which will hold information either until it is required, or until the destination is specified.

NDX has an integral buffer memory of up to 1Mbyte, which is dynamically allocated between different users, and which operates at a high output rate (up to 1500 character/s). The high-speed buffering means that equipment which is currently sending data does not need to recognize any flow control protocol unless the buffer actually fills up. Inputs are not scanned, so the unit is ready to receive data at all times.

A further feature of the NDX is that the user can load and save programs in units of 16Kbyte on 27178A eproms. This is particularly valuable for test purposes, since the user can program the NDX to behave in several different ways. The exchange is built in the UK by Nighthawk Electronics, PO Box 44, Saffron Walden, Essex CB11 3ND. Tel: 0799 40881.

NEW PRODUCTS

Memory editor for eprom microcomputer

A number of manufacturers offer programmers for 68,000 series eprom-based single-chip microcomputers but Stag have gone one better by offering an instrument that can also read the contents of the computer's memory. Their 68MR00 Micro Reader is intended for use with MC68705 U3 and R3 microcomputers. It allows the contents of the memory to be transferred to the ram of a programmer for editing or copying. Information transfer is fast, since the microprocessor is plugged directly into the Micro Reader. Stag also make the programmers and can provide a complete system to read and modify programs in the computers.

The 68705 is used extensively in automotive and control applications and it has been hitherto impossible to read its contents after programming the device. Stag plan to have similar facilities for other microcomputers. Stag Electronics Designs, Welwyn Garden City, Herts AL7 1AU. Tel: 0707 325136.

Digital oscilloscope with signal analysis

A compact digital storage oscilloscope from ITT has two 8-bit 2MHz a-to-d converters and offers an analogue dual-trace bandwidth of 20MHz. The instrument is claimed to be easy to use for those new to oscilloscopes, with a well-designed layout of controls. A major feature of the OX750B is its range of signal analysis facilities. The memory can hold up to 2048 samples/channel of which 2000 can be displayed while the remaining locations store the reference position. To aid analysis, the trace can be expanded up to 32 times horizontally when a cursor is used to select the area of interest on the stored waveform.

The instrument can capture one or two signals individually or simultaneously and then superimpose them for comparison. The wide timebase enables the capture of slow-changing events in real time, similar to a chart recorder. This slower setting can also be used in the single-shot and refresh modes.

Memory contents can be plotted on an X-Y recorder and

an autoplot option transfers the data at the completion of a reading cycle. Battery-backed memory retains the records in the absence of power and can be used to collect waveforms in the field for subsequent analysis. The internal 8085 processor also acts as a watchdog and warns against incompatible functions. The 2MHz converters are integrated circuits with an accuracy of 7.2 data bits at 200kHz. ITT feel that the instrument would be particularly suitable in industrial laboratories for studying physical phenomena such as shock, vibration, electrical supply drop-outs and switching spikes.

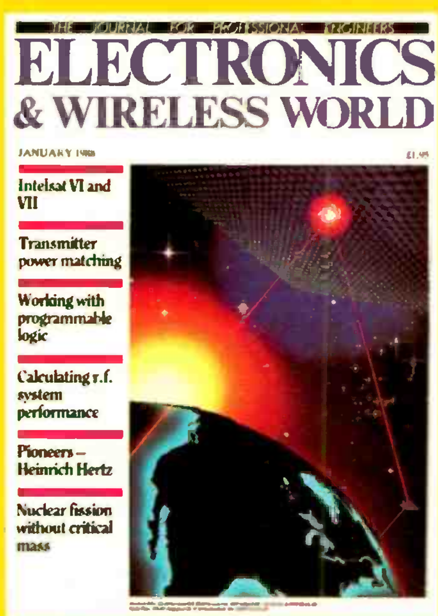
ITT Instruments, 346 Edinburgh Avenue, Slough, Berks SL1 4TU. Tel: 0753 824131.

NEXT MONTH

R.f. power matching. Joules Watt discusses the use of L, pi and T networks to match transmitter power output stages to antennas, explaining on the way why "lossy ells" are so-called. He leaves behind him a problem for readers to solve.

Programmable logic devices. This family of i.cs, which includes proms, pals and p.l.as, offer the flexibility of custom chips at a lower cost, and the benefits of a simpler design procedure. This article describes the process of programming and provides practical information on equipment to do the job.

Pioneers – Heinrich Hertz. In 1865 Maxwell predicted the existence of electric waves in space: Hertz proved it in 1887 by using a spark-gap transmitting antenna and receiving loop. This was probably the first use of antennas.



Electromagnetically induced atomic fission. It begins to seem possible that the establishment of a critical mass might not be the only way to induce fission. This article suggests that electromagnetism could be used and lead to the production of small, non-polluting reactors.

Radio-frequency link budgets. Calculating the s:n ratio of an r.f. communications link from known characteristics such as antenna gain and transmitter power output – a "link budget" calculation – avoids the necessity of building the system to find its performance.

Microcoding and bit-slice. A combination of these two techniques can facilitate the rapid simulatioin of existing processor instruction sets and the design of hardware with better performance than that of microprocessors.

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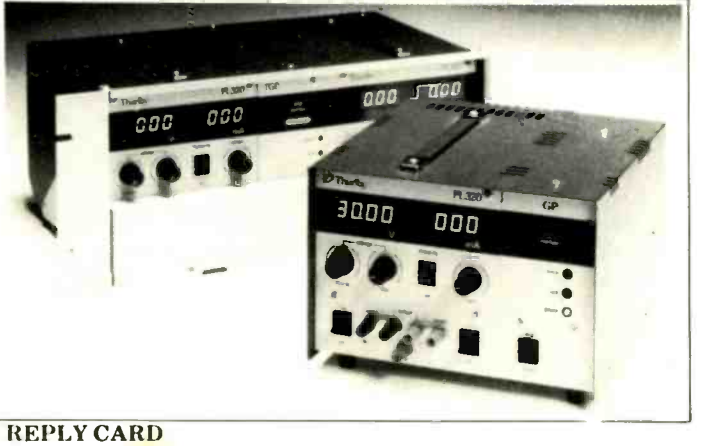

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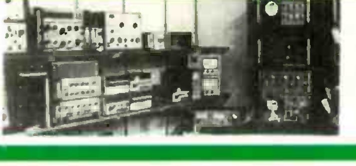

MARCONI INSTRUMENTS

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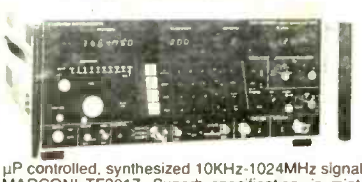

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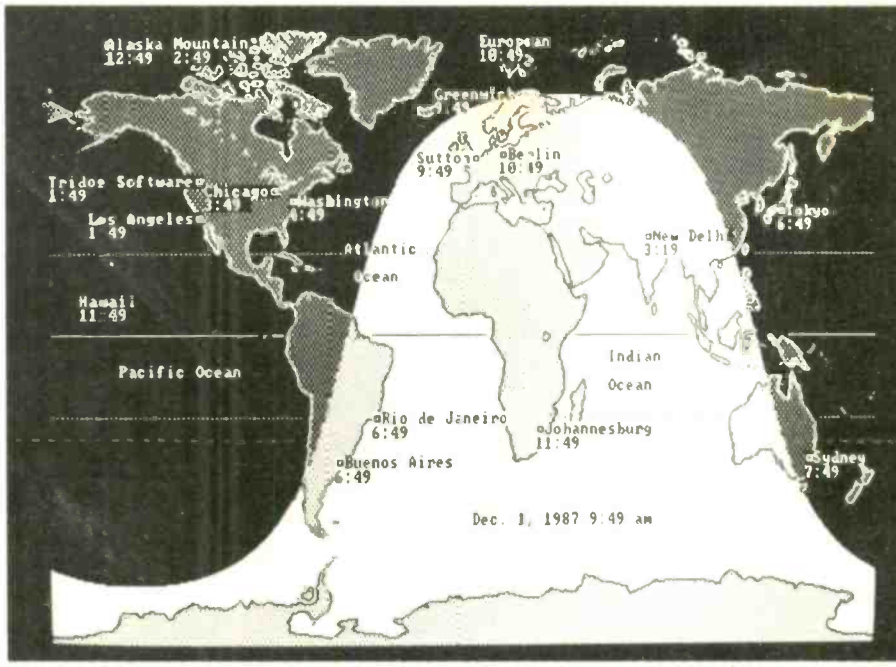
Graphic world clock for the radio engineer



Terminator is a software package for the IBM personal computer which displays a graphic real-time world clock. Its special feature is that it accurately plots the terminator, the Earth's daylight-to-darkness border, taking into account astronomical factors such as the declination of the Sun (the angle it makes with the Earth's equator), the apparent size of the Sun's disc, the refraction of sunlight by the atmosphere and the Earth's elliptical path around the Sun.

The program should be of particular interest to h.f. radio operators and propagation engineers, who need to know whether a path is in daylight, in darkness or along the grey-line.

A choice of world maps is supplied on the disc, showing time-zones, latitude and longitude lines, or just the land-masses alone; and the extensive parameter file can be easily altered with a text editor to select different home time-zones or to mark cities or other legends. Local daylight-saving time can be allowed for, too. The program can run independently or as a memory-resident pop-up program from within other applications.

Terminator is available from Tridos Software Publishers at 4004 SW Barbur Boulevard, Portland, Oregon 97201, USA (telephone 0101-503 228 4432) at $39.95. Other products from Tridos include Go Between, which inter-converts text files in eight of the most popular p.c. word-processing packages: and snOOp, which claims to disassemble and comment automatically any software, making it easy to understand how it works.

Digital audio

The European Broadcasting Union is committed to seeking a frequency allocation around 1GHz for direct sound broadcasting from satellites and many engineers believe that the most' suitable system would involve the use of highly-elliptical Molniya-type orbits. To provide a 24-hour service this would require three satellites, each of which would remain virtually directly over the target area for a period of eight hours, thus permitting car reception with a flat roof-mounted array pointed directly upwards. EBU members are also seeking a satellite frequency allocation for Region 1 around 20GHz (22GHz is already a d.b.s. allocation in Region 2) which would be able to provide channels wide enough for high definition tv transmission.

But clearly 1GHz direct radio from satellites is unlikely to be operational in Europe for a decade and this could give time for the establishment of a universally-agreed standard for digital stereo or surround sound, rather than attempting to adapt for satellite transmission the present terrestrial pilot-tone stereo f.m. system with its many recognized shortcomings. With the 'not invented here' syndrome still prevalent in broadcast engineering this will not be an easy or quick process.

It is a paradox that the BBC-developed and now UK-standard digital stereo system (Nicam 728) for television sound, still awaiting a firm timetable for its introduction, promises to give television superior audio in homes than commonly results from pilot-tone analogue radio broadcast.

In the USA, the BTSC multi-channel analogue television sound system has already come under attack from Craig Todd of Dolby Laboratories where a compatible digital audio format, akin to but suitable for use on NTSC broadcast and cable television, has been developed (*IEEE Trans. on Consumer Electronics*, August 1987, pages 297 to 305).

Todd writes: "The BTSC multi-channel tv sound system, which is being adopted by some US broadcasters, is based on analogue techniques. While theoretically capable of excellent performance, the realities of intercarrier analogue sound detection prevent its full potential from being realized. The output of a BTSC stereo decoder invariably contains numerous 'birdie' and 'buzz' products. The resulting quality is inferior to all other common consumer audio formats: compact disc, compact cassette, f.m. radio, long-playing disc, v.c.r. and LaserDisc. Numerous problems affect the carriage of the BTSC signal in cable television. While many (US) cable systems are successfully carrying the signal, success is deemed achieved when the received audio quality may be judged 'adequate'. Since stereo tv sound is such a novelty, the quality of BTSC is not presently an issue... television sound quality has typically been poor. The adoption of stereo has, fortunately, stimulated improvement in all areas of tv sound production... eventually the improved source material and the quality conscious consumer will meet in mass and analogue BTSC stereo will become a limitation."

This is an endorsement of the UK view that it is usually better not to rush into new broadcast systems without first fully investigating the possibility whether new technologies offer scope for advancement.

The Japanese Ministry of Posts and Telecommunications has recently set guidelines for digital audio broadcasting and is reported to be drawing up a detailed broadcast specification in association with broadcasters and industry so that Europe may soon be faced with a *fait accompli*. The guidelines are apparently intended to ensure that the broadcast system will be compatible with digital audio tape (DAT).

There seems little prospect that the restricted coverage of pilot-tone stereo transmissions, with stereo requiring some 12dB more minimum signal than mono, will lead in Europe to any adoption of the CBS-developed FMX system, although Sanyo Electric has reported the development of a one-chip decoder integrated circuit, type LA3440.

USA seeks better a.m.

In September 1985, the American National Radio Standards Committee (NRSC) adopted a resolution to study proposals to standardize the pre-emphasis/de-emphasis characteristics used for medium-wave a.m. broadcast transmissions/receivers. A year later an interim draft voluntary standard ("interim" until approved by the American National Standards Institute) was agreed. Target date for its use by broadcast stations was last January and by receiver manufacturers January 1988. It was also agreed to review the situation annually for five years to determined whether fidelity goals are being realized.

The aim is to raise the fidelity of the a.m. transmission/reception system from its current state to a quality level approaching that achieved in practice on v.h.f./f.m. broadcasting. For several years there has been increasing use both in North America and Europe of medium-wave audio processing incorporating a significant degree of pre-emphasis in order to counter the top-cutting effect of the very narrow i.f. response of most a.m. broadcast receivers. But without a standard, the broadcaster has not been able to match accurately the de-emphasis characteristics of a variety of receivers. NRSC believes that better matching of pre- and de-emphasis curves will increase the overall satisfaction of listeners with a.m. broadcasting in the 10kHz channels allotted in Region 2.

The proposed bandwidth-limiting filter response of NRSC is far more generous than the filtering recommended by EBU for use with the 9kHz European channels.

RDS on the move

The BBC completed ahead of schedule the first phase of its installation of radio data service (RDS) equipment at its 72 main v.h.f./f.m. network and local radio transmitters in England, which, together with off-air relays which re-transmit the RDS signals, represent some 150 transmitters.

RDS signals are also to be provided by early 1988 on the v.h.f./f.m. transmissions of 17 of the Independent Radio stations including some in Wales and Scotland.

It is no secret that the UK broadcasters have found it difficult to persuade chip-makers and the receiver industry to commit themselves to RDS production. The BBC in seeking to persuade radio receiver manufacturers to make sets incorporating RDS facilities has made it known that it is willing to allow the use of "BBC" as a brand name for the receiver.

At the 1987 International Conference on Consumer Electronics, Kenichi Taura and Ryo Tomohiro of Mitsubishi Electric described an automatic-tuning car radio based on RDS and including integration of the decoder/demodulator RDS circuits into a single-chip i.c., adoption of a single r.f. front-end structure to realize the automatic tuning features, compatibility with the German ARI traffic information system and adaption of the Mitsubishi microcomputer automatic station selector (MASS) system. This receiver incorporates an eight-character alpha numeric dot-matrix liquid crystal display. It was claimed that the usefulness of the functions based on RDS have been confirmed in Sweden and West Germany where RDS test transmissions have been made for some time. RDS is due to become operational in West Germany in April 1988.

ARI-compatible decoder chips have also been developed by Sanyo Electric with the RDS data decoding and bit-rate clock recovery blocks integrated in a 1150-element, 24-pin bipolar package with an additional data analysis system based on a microcomputer.

Radio Broadcast is compiled by Pat Hawker.

Microwave broadcasting

The search for practical means of distributing more television programme channels to homes without incurring the very high start-up costs of cable and/or satellite has led to a revival of interest in 12GHz terrestrial systems, in 2.5GHz multichannel multipoint distribution systems (m.m.d.s.) and the British Telecom proposal of a 29GHz version (millimetre-wave multichannel, multipoint video distribution service or M^3VDS for short) as well as the possibility of squeezing in another network into the u.h.f. bands augmented by the four channels in the gap between Bands 4 and 5. The Cable Authority has recently changed its position and has decided to seek Government approval for m.m.d.s. in the UK as part of its cable franchising operation.

Tv on 12GHz

Although the French and German tests of 12 GHz terrestrial broadcasting tended to highlight the problems of purely line-of-sight propagation, the Russians seem convinced that the system could be made to work by adopting frequency modulation. V.A. Bykhovsky of the Russian Scientific Research Institute of Radio Communications (N.I.I.R) has suggested that the building of a terrestrial tv network in the 12GHz band would open up some new possibilities for multi-programme broadcasting and would be a step towards the development of h.d.t.v. systems. He stresses that in developing a new microwave system, the decisive problem is the choice of modulation since this impinges on the use of the radio spectrum, the energy balance in the service area, the maintenance of electromagnetic compatibility as well as the technical solution of suitable transmitting and receiving equipment.

The main propagation constraint is that the attenuation from obstacles is significantly greater, exceeding that at u.h.f. by some 10 to 20dB. There must be direct visibility between transmitting and receiving antennas but, he points out, in difficult cases this could be overcome by raising the receiving antenna and organizing a community television system. It is also essential to provide sufficient reserve of signal level to cope with attenuation due to rain, fog, snow etc. At a distance of 10km this would need to be about 4dB, at 20km about 7dB and at 30km about 12dB.

Bykhovsky envisages 12GHz service areas of roughly the same radii as u.h.f. (15, 25 and 50km) using omnidirectional transmitting antennas providing roughly 16dB v.r.p. gain. For a service area of about 25km radius (presumably in fairly flat terrain), he believes this could be achieved with an f.m. vision transmitter output of 10W; for 50km radius about 100W. This is based on a receiver-converter noise factor of 10dB, and a parabolic dish antenna of 60cm diameter. He envisages 12GHz being used for both terrestrial and satellite broadcasting, with care being taken to provide sufficient terrestrial and channel separation between their service areas.

M^3VDS

British Telecom believes that a prime market sector for a 29GHz system delivering 10 to 20 channels of broadcast-quality television, and offering possibilities for future high-definition (h.d.t.v.) services, would be conurbations of 10 000 to 100 000 households, as found in many English country towns. Cable is not seen as likely to penetrate substantially into this sector until at least the turn of the century.

Because of strict line-of-sight requirements and the obstructions offered by trees and tall buildings, 29GHz distribution would be limited to around 70 to 80% of households within the general coverage area, and m.a.tv systems would be needed to maximize coverage.

The proposed BT system is designed for use with satellite-type receivers having a broadband first i.f. of 950 to 1750MHz. The 29GHz down-converter would require a receiving dish antenna of only 15cm maximum dimension, offering easy mounting and installation. Down converter cost is seen as the key to realization of the system. M. Pilgrim of BTRL has pointed out that "until now almost any piece of millimetre-wave hardware has carried a many-thousand-pound price tag. But monolithic microwave integrated circuit technology is now with us and progress is such that GaAs versions in the 25 to 40GHz range appear likely to be ready for production in two to five years time with M^3VDS an ideal application. With an m.m.w.i.c. chip a complete outdoor downconverter could be built and installed at a cost comparable with that of a functionally similar 12GHz d.b.s. unit. To explore the practical aspects, BTRL propose to establish a trial system operating in the 29GHz band and incorporating m.m.w.i.c. technology."

More on u.h.f.?

The report to the Home Office on subscription television prepared by Dr Charles Jonscher of CSP International has concentrated attention on the feasibility of providing additional tv programme channels by means of conventional terrestrial u.h.f. or v.h.f. networks still capable of "providing much the cheapest method of access for UK households to television programming".

CSPI mooted as one possibility a "fifth" tv service within the existing u.h.f. channels, augmented when available under ITU Radio Regulations by channels 35, 36, 37 and 38, which now comprise the gap between Bands 4 and 5 and have so far never been used in Europe for television broadcasting.

Not unexpectedly, radio astronomers, led by Dr Graham Smith, the Astronomer Royal, have made known their strong opposition to any broadcasting on Channel 38 as this would threaten their observations on 610MHz. The IBA, with its concern with the three UK d.b.s. channels to be provided by BSB, is suggesting that an extra terrestrial channel should logically be known as Channel 8 rather than 5 and its engineers have drawn attention to problems that would arise. They believe, however, that it would be possible to reach 60 to 70 per cent of the UK population by means of about 50 new transmitters; that many owners of video recorders would need to retune their equipment; and that there is a possibility of local oscillator radiation interference to viewers of the existing channels in neighbouring houses.

In his inaugural address as Chairman of the IEE Electronics Division, Dr John Forrest, IBA director of engineering, noted that the geographical separation of co-channel transmitters could be reduced by the use of 'precision offset' which gives about 10dB more protection against noticeable co-channel interference. And that with modern tv receivers less attention need be paid to local oscillator radiation interference which currently inhibits the use of the n−5 and n+9 channels in a given locality.

Even more could be achieved if international agreement could be reached to a revision of the Stockholm Plan of 1963. This plan led to the preferred assignments of four channels out of eleven (n, n+3, n+6, n+10) so that c.c.i. could not arise from an adjacent area, but with one channel not used by any of three adjacent blocks., Since 1963 there has been a dramatic improvement in receiver adjacent channel selectivity as a result of the introduction of surface acoustic wave i.f. filters. In conjunction with precision offset it might now be possible to fit at least five channels in each block of eleven without serious interference. Some American cable systems (without the worry of c.c.i.) distribute programmes in adjacent channels. Conversion of existing networks to precision offset would be an expensive business, though small in comparison with the start-up costs of satellite or cable.

Television Broadcast is written by Pat Hawker.

RADIO COMMUNICATIONS

Stabilized super-regen

One of the never-quite-made-it stories of radio technology has been Armstrong's super-regenerative circuit which he stumbled across by serendipity in 1921 while setting up a conventional regenerative receiver. According to his biographer, Lawrence Lessing ("Man of high fidelity: Edwin Howard Armstrong", Bantam Books, 1969), Armstrong suddenly heard a signal coming through at a strength far beyond normal. He had time only to identify it as a transmitter in the Brooklyn Navy Yard and to receive several other stations at many times normal volume when, just as suddenly as it had begun, the effect disappeared.

Characteristically, Armstrong then spent weeks of intensive work in order to pin down the cause of this 'super-regeneration' as an extension of the positive-feedback principle, finally demonstrating that greatly enhanced amplification is possible when a regenerative detector is interrupted (quenched) at supersonic frequencies of the order of 20 to 100KHz. Later it was shown that the ratio of signal frequency to quench frequency should preferably be of the order of 100 to 1000, making the system less effective at medium-wave frequencies.

Initially, Armstrong saw super-regeneration primarily as an aid to medium-wave broadcast reception since it enabled a simple two-stage circuit to provide loudspeaker reception of weak signals. He convinced RCA which in 1922 bought Armstrong's super-generation patent for the princely sum of $200 000 and an even more valuable 60 000 RCA shares. But it was soon found that the rapidly increasing number of US broadcast stations highlighted the extreme lack of selectivity inherent in super-regeneration and RCA concentrated instead on marketing receivers based on Armstrong's superhet configuration that he had developed by 1919.*

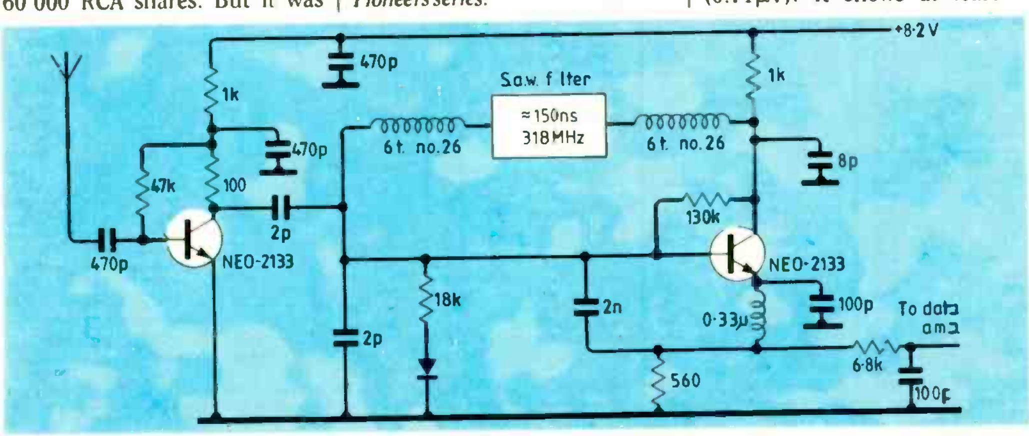
Nevertheless the simplicity and relative lack of sensitivity to drift (resulting from its poor selectivity) led to widespread use of super-regenerative receivers in the 1930s and 1940s for v.h.f. reception and as the basis of a very simple form of transceiver. During the second world war it found application as part of the No.19 set for tank-to-tank communications, for clandestine telephony (S-phone) and for the pulse responders (i.f.f.) for radar identification of aircraft and ships.

Since the i.f.f. units needed to be produced in large numbers, the initial design needed to be reasonably stable and reproducible. This led to intensive work at T.R.E. Malvern (now R.S.R.E.) by J.R. Whitehead and Dr G.G. Macfarlane (see "Super-regenerative receivers" by J.R. Whitehead, Cambridge University Press, 1950). Subsequent development has amounted to little more than the substitution of semiconductors for valves and there has been a general loss of interest in the technique except for short-range applications where low cost is the dominant factor. Super-regen receivers for v.h.f. and u.h.f. continue to be made in large numbers for such applications as garage-door openers, low-cost wireless security systems, data-link receivers on the grounds of low-cost, simplicity, low-power consumption and the ability to cope with both f.m. and a.m. modes.

**See also the article on Armstrong last month in W.A. Atherton's Pioneers series.*

A decade ago, a New Zealand radio amateur, Nat Bradley, ZL3VN drew attention to the continued value of the super-regen receiver at frequencies from about 20MHz up to 1000MHz and showed that "the application of modern techniques to its design and construction can give it added performance and versatility at low cost". One of his many suggestions was that "lower frequency (i.e. h.f.) superregenerative receivers can utilize a crystal just as effectively as an LC resonant circuit and very useful reductions in bandwidth can be gained for fixed-frequency use".

A novel extension of this idea was described at the 1987 International Conference on Consumer Electronics by Darrell L. Ash of R.F. Monolithics ("A low cost super-regenerative s.a.w. stabilized receiver", *IEEE Trans CE-33*, August 1987, pages 395 to 404). Ash shows how a low-loss, single-phase, surface-accoustic-wave delayline can be used to stabilize either a self-quenched fixed-tuned receiver. A 150 nanosecond delay-line in a TO-39 package results in a 318MHz centre frequency and overcomes the frequency drift and bandwidth problems of most conventional state-of-the-art regenerative receivers with little or no sacrifice in receiver simplicity and cost. The performance, he claims, more closely approximates that of a superhet but retains the simplicity of a super-regenerative receiver. Such a receiver typically has a sensitivity level 20dB better than a non-stabilized super-regenerative receiver and with laboratory adjustment can be −110dBm (0.71µV). It shows at least a factor of ten decrease in receiver bandwidth; quartz temperature stability; and a large reduction in the bandwidth of the emitted spectrum over those of conventional LC-controlled super-regen receivers.



Improving shipborne d.f.

The history of shipborne direction finding (d.f.) stretches back more than 65 years, but there have been surprisingly few significant improvements on the traditional use of cross-loop (Bellini-Tosi) antennas. It has long been appreciated that the relatively poor performance of such systems is due to polarization errors largely brought about by proximity to mast and structural resonances. Work at the German Institut für Hochfrequenztechnik, reported by Professor G. Mönich in *Proc IEE* 134, Part F, No 6, October 1987, has revived, with modern technology, the additional use of a parallel loop arrangement first pioneered in the UK and Germany as long ago as 1936 but never widely adopted. The work has shown that the parallel loop can significantly improve performance in the azimuth regions abreast of the ship, where crossed loops provide their least accurate bearings, including ambiguity. The combined bearing information from the two-loop configurations can then be sufficently accurate to permit compensation by means of computer-stored correction tables.

Who's listening?

My item "XXX gets Australian MP the sack" (*E&WW*, June) somehow got its lines hopelessly crossed. The politician sacked from the Opposition shadow cabinet was Mr Andrew Peacock, his overheard car radio conversation was with Mr Jeff Kennett, and the Opposition leader who did the sacking was Mr John Howard. Apologies all round! And thanks to Mrs Kay Collins of Victoria, Australia for spotting the errors.

Radio Communications is written by Pat Hawker.

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EL83	7.50
EL84 BRIMAR	0.95
EL84 MULLARD	2.95
EL85	4.50
EL86	1.75
EL90	1.75
EL91	6.00
EL95	1.75
EL152	15.00
EL360	6.75
EL500	1.95
EL504	1.95
EL506	5.95
EL509	5.25
EL519	6.95
EL802	3.65
EL821	6.95
EL822	12.95
ELL80	22.50
EM34	12.50
EM83	1.65
EM84	1.65
EM85	3.95
EM87	2.50
EN32	15.00
EN91	1.95
EN92	4.50
EY51	0.80
EY70	7.50
EY81	2.35
EY82	1.15
EY83	1.50
EY84	5.95
EY86/87	0.50
EY88	0.55
EY91	5.50
EY500A	1.50
EY802	0.70
EZ35	1.00
EZ40	2.75
EZ41	2.75
EZ80	0.75
EZ81	0.75
EZ90	1.50
FW4-800	2.95
G55/1K	9.00
G180/2M	6.95
G240/2D	9.00
GC10B	17.50
GC10D	17.50
GC10/4B	17.50
GC10/4E	17.50
GC12/4B	17.50
GD86W	6.00
GDT120M	5.00
GN4	6.00
GN10	15.00
GR10G	4.00
GS10C	16.50
GS10H	12.00
GS12D	12.00
GT1C	14.00
GU20	35.00
GU50	17.50
GXU1	13.50
GXU3	24.00
GXU50SS	14.50
GY501	1.50
GY802	1.50
GZ30	2.50
GZ31	2.50
GZ32	2.50
GZ33	4.50
GZ34	2.50
GZ37	4.50
HABC80	1.50
HBC90	1.95
HBC91	1.95
HF93	1.50
HF94	1.95
HK90	1.95
HL41	3.50
HL90	3.50
HL92	1.50
KT8C	7.00
KT33C	3.50
KT36	2.00
KT44	4.00
KT45	4.00
KT61	5.00
KT63	2.00
KT66 USA	9.95
KT66 GEC	18.50
KT67	9.00
KT77 Gold Lion	11.95

KT81	7.00
KT88 USA	10.95
KT88 Selectron	15.00
KT88 Gold Lion	22.50
KTW61	2.50
KTW62	2.50
KTW63	2.00
KTZ63	2.50
LB7-20	95.00
LS9B	6.95
M508	195.00
M5143	155.00
M5199	295.00
M8079	6.00
M8082	7.50
M8083	3.25
M8091	7.50
M8096	3.00
M8098	5.50
M8099	5.00
M8100	5.50
M8136	7.00
M8137	7.95
M8161	6.50
M8162	5.50
M8163	5.50
M8190	4.50
M8195	6.50
M8196	5.50
M8204	5.50
M8223	4.50
M8224	2.00
M8225	3.95
ME1400	3.50
ME1401	29.50
ME1402	29.50
MHLD6	4.00
MP25	195.00
MS4B	5.50
MU14	3.50
N37	12.50
N78	9.85
OA2	1.50
OA2WA	2.50
OA3	2.50
OB2	1.50
OB2WA	2.50
OC3	2.50
OD3	2.50
OM4	2.50
OM5B	3.00
OM6	1.75
ORP43	2.50
ORP50	3.95
P61	2.50
P41	2.50
PABC80	0.75
PC86	0.75
PC88	0.75
PC92	3.50
PC97	1.10
PC900	1.25
PCC84	0.40
PCC85	0.55
PCC88	0.70
PCC89	0.70
PCC189	0.70
PCC805	0.70
PCC806	0.80
PCE82	0.80
PCF80	0.65
PCF82	0.60
PCF84	0.65
PCF86	1.20
PCF87	1.25
PCF200	1.80
PCF201	1.80
PCF801	1.35
PCF802	0.85
PCF805	1.25
PCF806	1.00
PCF808	1.25
PCH200	1.50
PCL82	0.85
PCL83	2.50
PCL84	0.75
PCL85	0.80
PCL86	0.85
PCL805	0.90
PD500	5.95
PE1-100	69.00
PEN25	2.00
PEN40D	3.00
PEN45	3.00
PEN45DD	3.00
PEN46	2.00
PE06-40N	42.00
PFL200	0.95
PL21	2.50
PL36	1.75
PL38	1.50
PL81	1.25
PL82	0.60
PL83	0.52
PL84	0.78
PL500	1.10
PL504	1.15
PL508	1.75
PL509	4.85
PL519	4.95
PL802	6.00
PL802T	3.50
PL820	2.95
PY32	0.60
PY33	0.50
PY81	0.70
PY82	0.70
PY83	0.70
PY88	0.65

PY500A	1.95
PY800	0.79
PY801	0.79
QB3-300	72.00
QB3-1750	139.00
QB3.5-700	72.00
QB5-1750	195.00
QB5-3500	595.00
QE08-200	145.00
QQE02-5	19.50
QQE03-12	7.95
QQE03-20	35.00
QQE06-40	45.00
QQV02-6	19.50
QQV03-10	5.50
QQV03-10 MULLARD	15.00
QQV03-20	25.00
QQV06-40A	27.50
QQV06-40A MULLARD	39.50
QQV07-50	55.00
QQZ03-20	42.50
QS75/20	1.50
QS95/10	4.85
QS108/45	4.00
QS150/15	6.95
QS150/30	1.15
QS150/40	7.00
QS1205	3.95
QS1213	5.00
QU37	9.50
QV03-12	5.75
QV05-25	2.50
QV06-20	29.50
QV08-100B	145.00
QY3-125	72.00
QY4-250	72.00
QY4-400	85.00
R10	4.00
R18	2.50
RG1-240A	14.50
RG3-250A	6.50
RG3-1250A	35.00
RR3-250	15.00
RR3-1250	35.00
S11E12	38.00
S104-2K	10.00
SC1/1300	6.00
SP61	3.50
STV280/40	11.95
TB2-5/300	85.00
TB2-300	195.00
TB3-750	95.00
TB3-2000	450.00
TBL2-300	395.00
TBL2-500	495.00
TD03-10/D/E/F	35.00
TT15	45.00
TT21	45.00
TT22	45.00
TT100	69.00
TY2-125A	85.00
TY4-400	85.00
TY7-6000A	600.00
TY8-600W	365.00
U19	9.50
U26	0.90
U35	3.50
U37	9.00
U41	6.95
U50	2.00
UB2	3.00
U191	0.70
U192	1.00
U193	1.00
U251	2.50
U801	3.50
UABC80	0.65
UAF42	1.00
UBF80	0.60
UBC41	2.25
UBC81	1.50
UBF89	1.00
UBL21	1.75
UC92	1.20
UCC84	0.70
UCC85	0.60
UCF80	1.00
UCH21	1.20
UCH41	2.50
UCH42	2.50
UCH81	1.00
UCL82	1.75
UCL83	2.50
UF41	1.15
UF42	1.15
UF80	1.75
UF85	1.20
UF89	2.00
UL41	5.50
UL44	3.50
UL84	1.50
UL85	0.85
UU5	3.50
UU6	6.00
UU7	8.00

UU8	9.00
UY41	3.50
UY85	0.70
V235A/1K	250.00
V238A/1K	295.00
V246A/2K	315.00
V241C/1K	195.00
V453	12.00
VLS631	10.95
VP4B	4.50
VP41	4.95
VR101	2.50
VR105/30	2.50
VR150/30	2.50
VU39	1.50
W21	4.50
W61	4.50
W77	5.00
W81M	4.50
W739	1.50
X24	4.50
X41	4.50
X66/X65	4.95
X76M	1.95
XC24	1.50
XC25	0.50
XFW47	1.50
XFW50	1.50
XG1-2500	75.00
XG5-500	22.50
XL628FT	7.50
XNP12	2.50
XR1/1600A	49.50
XR1/3200A	79.50
XR1-6400A	149.50
Y65	6.95
YD1100	75.00
YJ1060	265.00
YL1020	42.50
YL1060	195.00
YL1070	195.00
YL1071	195.00
YL1290	65.00
YL1440	450.00
Z77	1.20
Z300T	6.00
Z302C	12.00
Z359	9.00
Z520M	4.00
Z700U	9.50
Z759	19.85
Z803U	18.95
ZA1000	12.50
ZA1001	1.50
ZM1001	12.00
ZM1005	8.00
ZM1020	6.00
ZM1021	8.00
ZM1023	7.95
ZM1041	14.00
ZM1082	9.00
ZM1084	10.00
ZM1175	6.50
ZM1177	9.00
ZM1202	55.00
ZM1263	4.00
1A3	4.50
1AE4	3.50
1AX2	3.50
1B22	10.00
1B27	55.00
1B35A	45.00
1B63A	75.00
1K3	2.50
1N5GT	2.50
1P28	25.00
1R5	0.90
1S5	1.50
1T4	1.00
1U4	1.75
1U5	1.00
1X25	2.50
2A3	16.50
2AS15A	11.50
2B7	2.50
2B22	69.50
2C36	70.00
2C39A	32.50
2C39BA	39.50
2C40	37.00
2C42	29.50
2C43	60.00
2C51	2.50
2CY5	1.50
2D21	1.95
2D21W	3.15
2E22	49.00
2E26	7.95
2J55	295.00
2K25	35.00
2K25 RAYTHEON	75.00
2K26	95.00
2K29	250.00
2K48	140.00
2K56	250.00
2X2A	5.00
3A/107B	12.00
3A/108A	9.00
3A/109B	11.00
3A/110B	12.00
3A/141K	11.50
3A/146J	7.50
3A/147J	7.50
3A/167M	10.00

3A3A	3.95
3A4	1.10
3A5	4.50
3AT2	3.35
3B22	25.00
3B24	12.00
3B26	24.00
3B28	15.00
3BZ6	1.50
3C45	24.00
3CX3000A7	650.00
3CY5	1.50
3D21A	29.50
3E22	49.50
3E29	39.50
3EJ7	1.95
3H	0.40
3J.170E	1450.00
3J.187E	1450.00
3L	0.40
3Q4	2.50
3V4	3.50
4-65A	65.00
4-250A	79.50
4-400A	87.50
4-1000A	425.00
4B32	35.00
4B/551B	125.00
4BQ7A	1.75
4BZ6	1.95
4C28	25.00
4C35	145.00
4XC125C EIMAC	150.00
4CX250B	49.00
4CX250B EIMAC	59.50
4CX250BM	65.00
4CX250K EIMAC	115.00
4CX250R AMPEREX	125.00
4CX350A	100.00
4CX350F	95.00
4CX1000A	425.00
4CX1500B	398.00
4CX5000A	1000.00
4D21/4-125A	85.00
4D32	125.00
4GS7	2.25
4GV7	2.25
4J6A	2.95
4KT6	1.50
4X150A	35.00
4X500A	350.00
5A/102D	9.50
5A152M	9.00
5A163K	10.00
5A170K	6.25
5A-180M	9.00
5A-206K	10.00
5AM8	2.15
5AN8	1.20
5B-110M	10.00
5B-255M	14.50
5B-255M	19.50
5B-256M	15.00
5B-257M	15.00
5B258M	14.50
5C22	125.00
5CL8A	2.50
5J180E	2950.00
5JL8	2.95
5R4GB	5.50
5R4GJ	4.95
5T4	5.95
5T8A	1.95
5U4G	2.95
5U4GB	4.50
5V4G	1.50
5X4	4.95
5Y3GT	1.95
5Z3	4.50
5Z4GT	2.50
6/30L2	0.70
6A/203K	9.00
6A7	4.95
6A8	1.50
6AB4	3.50
6AC7WA	2.00
6AG5	2.50
6AG7	1.95
6AH6	3.50
6AJ4	3.50
6AJ7	2.00
6AK5	1.95
6AK6	2.50
6AL5	0.60
6AM4	3.25
6AM5	6.00
6AM6	1.95
6AN5	4.50
6AN8A	4.50
6AQ5	1.75
6AQ8	0.85
6AR5	5.95
6AS5	1.50
6AS6	2.50
6AS7G	4.50
6AT6	0.90
6AT8	1.75
6AU4GT	2.00
6AU5GT	4.50
6AU6	0.95
6AV6	0.90

6AW8A	3.50
6AX4GT	1.95
6AY3B	1.95
6AZ8	4.50
6B4G	5.50
6B8G	1.50
6B10	1.95
6BA6	1.50
6BA7	4.50
6BA8A	3.50
6BC8	0.85
6BE6	1.50
6BG6G	3.00
6BH6	1.95
6BH8	1.50
6BJ6	1.50
6BK4	4.00
6BL6	85.00
6BL8	1.15
6BM6	115.00
6BN6	1.65
6BN8	3.95
6BQ5	0.95
6BQ7A	1.50
6BR7	4.95
6BS7	5.50
6BW6	5.35
6BW7	1.50
6BZ6	2.50
6BZ7	2.95
6C4	1.50
6C5	1.95
6C6	3.50
6CB6	1.50
6C9	4.95
6CA4	4.95
6CA7	3.50
6CB5	3.95
6BC6	1.95
6CD6GA	4.50
6CF6	1.95
6CG7	3.50
6CH6	6.95
6CL6	3.25
6CL8A	1.50
6CM7	2.95
6CS6	0.75
6CS7	0.95
6CW4	8.00
6DC6	2.35
6DJ8	0.95
6DK6	1.50
6DQ5	8.50
6DQ6B	2.50
6DT6A	1.50
6DW4B	21.5
6E5	3.95
6EA7	2.50
6EA8	2.50
6EB8	1.75
6EJ7	0.65
6EM5	2.50
6EM7	2.50
6EU8	1.75
6EV7	2.95
6EW6	1.50
6EW7	4.50
6F1	2.00
6F5	5.50
6F7	5.50
6F13	3.00
6F14	1.00
6F17	2.75
6F23	0.60
6F24	1.25
6F25	1.25
6F28	1.25
6F32	1.25
6F33	17.00
6FH5	6.50
6FH8	5.95
6FL2	4.50
6FQ7	3.50
6GE5	3.95
6GH8A	2.50
6GJ7	0.85
6GK6	1.95
6GM6	2.65
6GS7	21.5
6GV8	0.95
6GW8	2.50
6GY5	3.95
6GY6	2.50
6H1	9.50
6H6GT	1.95
6HB7	1.95
6HF5	5.50
6HF8	2.50
6HM5	2.50
6HQ5	3.50
6HS6	4.95
6HS8	2.95
6HZ6	3.50
6J4	2.15
6J5GT	2.50
6J6	2.00
6J7	4.15
6J7G	4.15
6JB6A	4.50
6JE6C	6.50
6JM6	3.95
6JU8A	2.50
6JS6C	6.50
6K7G	2.00
6KB6	3.00
6KD6	6.50
6KG6A	6.95
6L1	2.50
6L6GC	2.95
6L6GC(G.E.)	5.75
6L6GC PHILIPS	6.50

6L6GAY	5.50
6L6GT	2.50
6L6WGC	5.50
6L7	3.50
6L15	3.15
6L19	3.95
6LJ8	2.50
6LD20	1.15
6LF50	7.50
6LQ6	6.50
6P28	2.00
6Q7GT	1.20
6R7	3.15
6RHH8	10.00
6S4A	1.50
6SA7	1.35
6SC7	1.50
6SG7	2.50
6SH7	1.35
6SJ7GT	1.20
6SK7	1.35
6SL7GT	1.50
6SN7GT	1.50
6SQ7GT	1.35
6SS7	1.95
6T8	2.00
6U6GT	3.50
6U7G	3.50
6U8A	1.50
6V6G	1.25
6V6GT	1.95
6W4GT	1.95
6Y6G	3.95
6X2N	1.00
6X4	1.50
6X5GT	1.00
6X5GTY	1.00
6X8A	2.25
7A6	4.50
7AU7	1.50
7B6	3.50
7B7	2.50
7D8	4.50
7J7	5.50
7K7	7.50
7L	1.50
7Q7	4.50
7Y4	2.50
8B8	2.50
8B10	2.50
8BQ5	1.95
8CW5	1.50
8EB8	1.50
8FQ7	1.95
10CW5	1.50
10D2	1.25
10DE7	2.50
10DX8	2.50
10EB8	1.95
10EW7	2.95
10F1	0.75
10GK6	1.95
10P14	2.50
11E3	55.00
11R3	5.50
12A6	3.95
12AD6	1.50
12AE6	5.50
12AH7GT	4.95
12AL5	1.00
12AT6	1.25
12AT7	1.15
12AT7WA	2.50
12AU6	1.50
12AU7	0.65
12AV6	1.95
12AV7	2.50
12AX4GTB	1.50
12AX7	0.85
12AX7WA	2.50
12AX7S	7.95
12AY7	3.95
12B4A	4.50
12BA6	1.50
12BE6	1.95
12BH7A	2.95
12BL6	1.75
12BR3	1.95
12BY7A	2.75
12C8	2.50
12CA5	1.95
12CX6	1.20
12DQ6B	3.50
12DW4A	3.50
12DZ6	3.95
12E1	19.50
12E14	38.00
12FX5	1.95
12GN7	3.95
12GH7	3.95
12J5GT	3.95
12J7GT	3.50
12JZ8	2.95
12K8GT	1.50
12K8Y	1.95
12KU7	1.95
12S7GT	1.50
12SA7GT	1.95
12SG7	4.75
12SK7	1.95
12SJ7	1.50
12SH7GT	1.85
12SW7	3.50
12SY7	4.50
12X4	1.95
13D3	3.20
13D7	3.20
13D8	3.20
13DE7	2.50
13DR7	2.95
13E1	145.00
13EM7	3.50

14B6	4.50
14R7	3.50
15E	5.50
16AQ3	1.95
16GY5	2.95
16H	0.40
16L	0.40
17AB	3.50
17AX4GTA	1.95
17BE3	2.50
17DW4A	2.95
17EW8	0.95
17JZ8	4.50
18D3	6.00
18GB5	3.50
19AQ5	3.50
19AU4GT	2.50
19BG6	3.50
19G3	19.50
19G6	9.00
19H4	35.00
19H5	33.50
20CV	9.50
20D1	0.70
20LF56	7.95
20L1	0.95
20P1	0.55
20P4	1.95
20P5	1.15
21JZ6	4.95
21KQ6	4.95
21LU8	3.75
24B1	39.50
24B9	39.50
25BQ6	1.75
25DQ6B	2.95
25L6GT	1.75
29C1	19.50
29KQ6	6.50
30C15	0.50
30C17	0.40
30C18	1.48
30FL2	1.35
30FL12	0.95
30FL13	1.10
30FL14	1.25
30L1	0.45
30L15	0.60
30L17	0.60
30P4MR	1.00
30P12	1.00
30P18	0.60
30P19	1.00
30P1	2.50
30PL13	0.60
30PL14	1.75
31JS6C	5.50
33A/158M	19.50
35A3	3.95
35A5	4.50
35C5	4.50
35L6GT	2.00
35Z3	1.95
35Z5GT	3.50
38HE7	4.50
40KD6	5.50
42	6.95
47	6.00
50A5	1.50
50B5	1.95
50C5	0.95
50CD6G	1.95
50EH5	1.50
50JY6	2.95
53KU	4.50
75B1	3.50
75C1	4.50
80	4.50
83	8.50
82A1	7.50
85A1	6.50
85A2	2.95
90AV	15.00
90C1	3.50
90CG	13.50
90CV	12.50
91AG	9.00
92AG	19.50
92AV	15.00
95A1	6.50
100E1	10.00
108C1	2.50
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Droitwich frequency shift

From the first of February next year, the frequency of BBC long-wave (l.f.) transmitters, often used as frequency standards, is to change from 200kHz to 198kHz. This is in accordance with the requirements of the World Administrative Radio Conference of 1979 which set 9kHz as the standard frequency spacing for l.f. transmitters. Those wishing to receive Radio 4 on this frequency will need to retune slightly.

The Droitwich transmitter is often used as a reference source for the calibration of test equipment. According to Mike Sagin of Radiocode Clocks Ltd, specialist in off-air frequency standards, "80 to 90% of all calibration laboratories use Droitwich transmitter as a standard, despite the fact that it is switched off every night and that its range is limited to about 300miles (500km). The rubidium oscillator is adjusted monthly and is less accurate than, for example, the MSF transmissions from Rugby. Depending on the level of complexity of the equipment using the Droitwich standard, it may be possible to retune to the new frequency by changing a crystal but the majority of such test sets will need to be replaced."

The BBC claims that the new transmitter will be maintained to an accuracy of better than one part in 10^{11} by the National Physical Laboratories caesium standard.

Global satellite network for aviation

In addition to the Inmarsat use of satellites for aircraft communications, there is now a plan for a new global satellite network specifically for the aviation industry. Aviation Satellite Corporation (AvSat) has been set up to provide the system to be owned, designed and operated by the aviation industry jointly through AvSat. The system will offer complete global coverage for sending and receiving air-traffic control data and voice information. Aircraft operational control and administrative communications can be carried as well as surveillance and navigation data.

One facility to be added will contribute financially to the running of the others; a passenger telephone service. AvSat estimates that when the service becomes fully operational, 65 million calls will be made by in-flight passengers in a year.

At a recent meeting of over 50 international airlines and civil aviation authorities from 38 countries, a resolution was passed to support the retention of the 28MHz-wide band reserved for aeronautical mobile satellite service within the band 1235 to 1660.5MHz – the allocation came up for review at the mobile WARC in Geneva. They also resolved to bring the system to the attention of their respected administrations with the request that the recommendations of the International Civil Aviation Organisation and the AvSat conference should be supported.

Artificial intelligence and machine monitoring

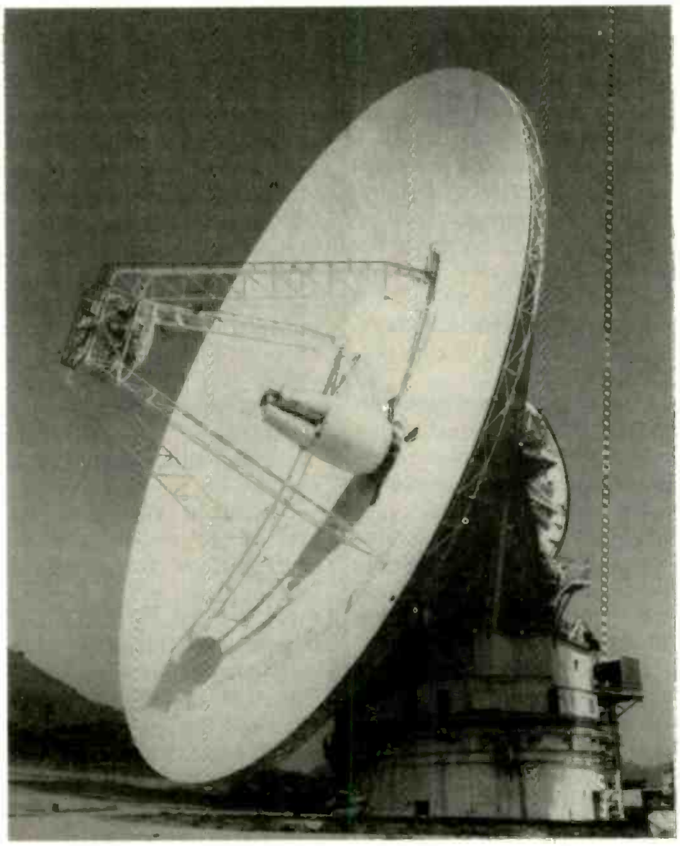
Careful monitoring of machinery can lead to improved maintenance. Automatic monitoring is especially useful and the addition of artificial intelligence enables a monitoring system to recognize trends and predict potential breakdowns in order to prevent them. An expert system can be programmed to recognize the various vibrations associated with a particular machine and also the specific parts of the machine that cause the vibrations. Any change in a vibration pattern as produced on a spectrum analyser can then be pinpointed to a specific part. Such a system, produced by Intelligent Applications, is called VIOLET, for 'vibration order listing expert.' Violet works in conjunction with a Solartron 1201 spectrum analyser and runs on an IBM PC-compatible computer.

Violet can read the signals from the analyser and compare them with a stored list. This identifies out-of-spec and new vibrations. Operators can input any relevant information in reply to questions posed by Violet which then indicates the most likely sources of trouble and even produces trend information to show accurately when breakdowns are likely to occur.

The software has been initially applied to a helicopter vibration monitoring system. However the system equally applies to the signature analysis of a range of devices and machinery including turbine, jet and diesel engines; and rolling stock in mills, conveyors, railways and the like. Each application requires initial expert programming to establish the rules but can then be operated by relatively inexpert personnel.

This NASA microwave receiver antenna dish has been extended from 64m to 70m in preparation for Voyager 2's encounter with Neptune in August 1989. Two other 70m dishes make up a network linking Canberra, Australia and California with this one near Madrid, Spain. All three are being tested and aligned by a British company, Eikontech Ltd of Sheffield, who are using microwave holography to generate images of the dish surface.

Analysis of the images is used in the adjustment of the 5000 screwjacks used to position the dish's 1272 individual panels. Further holographic tests show than the Madrid dish is within 0.65mm of the designed shape, and have produced data for improving accuracy still further.



Any views on the mobile spectrum?

Deregulation of the mobile radio spectrum could lead to problems and if so, a sub-group of the Civil Land Mobile Radio Committee of the radio regulatory division has been set up to look into them. Chairman of the sub-group Joe Whelan, says: "There must be many people in the mobile radio industry who have views on the issues of deregulation and pricing of the mobile spectrum and we would like to hear from them. By contributing now, they can help to shape the future of their industry."

Joe Whelan can be contacted *care of* the Radio communications division, DTI, Room 806, Waterloo Bridge House, Waterloo Road, London SE1 8UA.

Optical switch turns on

Imagine all the telephone conversations in progress in the world (about 700 million) passing through a single point. Plessey's new optical switch can handle them and yet is only the size of a chocolate bar.

The researchers who developed it at the Caswell Laboratories believe it to be years ahead of similar technology in America and Japan.

At present, optical-fibre networks are connected to electrical switching systems and the capacity of a fibre cannot be exploited because of the conversion. Optical switches can redirect the signals in fibres without the conversion and can operate much faster. It is expected to be of most use in high-capacity fibre-optic networks of the future which will link data networks, videophones, electronic mail and video newspapers, and high-definition tv. H.d.tv alone will require a device working 4000 times faster than the latest telephone switches.

Professor William Gosling, technical director at Plessey, said: "No one can predict with any certainty the final shape of these future networks. Electronic switching hasn't reached the limit of its development potential. However all major telecommunications suppliers for the period beyond the 1990s are looking at optical switching. The demonstration of a device of this complexity outside of the laboratory give Britain a significant position in this technology."

The switch is likely to find applications in current telephone networks, providing, for example, re-routing facilities in areas where there is already a concentration of optical fibre links.

● A means of tapping into an optical cable has been discovered by Plessey. By bending the cable around a small, precise diameter, a small fraction of the light signal (about 0.2%) can be scattered through the surface of the fibre where it can be picked up by a plastic light guide and directed to an optical receiver.

This tap removes the need to convert optical to electrical signals for distribution and will allow about 200 taps from one feeder fibre. Initial uses for the technique are likely to be in cable tv distribution.

The Plessey team, directed by Professor John Dakin, are now seeking to produce the ability to inject a signal *into* a fibre which could lead to a complex interactive network.

Engineering women

Inspiration for girl engineers can be gained from a book, "Tales of ten women." This gives profiles of ten winners or finalists in the Girl Technician of the Year Award organized annually by the IEEIE and the Caroline Haslett Memorial Trust. The book is written in a style appealing to teenagers and includes details of each woman's education, training and career as a vocational guide. The first printing of the book was a sell out; copies of the reprint are now available free from the Secretary, IEEIE, Savoy Hill House, London WC2R 0BS.

Robotic tasters

Another example of artificial intelligence using an expert system is being developed by Honeywell's micro switch division in the US to measure the subjective quality of food. Such a system will be able to tell sweetness, softness, creaminess, freshness and so on, and be used in the automatic production of foodstuffs. In order to do this the reactions of experienced tasters must be married to detailed chemical analysis.

Take orange juice for example; the intangible parameter, human choice, can be broken down into the tangible ingredients, water, sugar, ascorbic acid, salts and others. Of the many components, the most important ones are chosen and only these measured during the juice-makng process.

Once the system has been set up, it could prove to be more accurate than the human tasters as it would not be subject to the variations in taste suffered by humans; colds, depression, headaches, or hangovers.

Other factors in the quality of food may need different and highly sensitive transducers to test for such parameters as firmness, transluence, viscosity, or consistency of texture.

Such a sensor network system, combined with a knowledge-based system, could also be used in many other fields: process control lines and building automation, for example.

Electronic aid for higher education selection

An experimental system at the beginning of the academic year pointed a way to allocating courses to students in higher education. A pilot database system was updated daily to give information about available courses in universities, polytechnics and other institutions.

BBC's data broadcasting service, Datacast, was used to update the data held on a compact disc rom prepared by the Education Counselling and Credit Transfer Information Service (ECCTIS) The database was on display at four pilot sites; three careers offices and a large comprehensive school.

Special decoders were needed for the Datacasts and the system ran on IBM PC compatible computers, ECCTIS software engineers designed the system which demonstrated the possibility of combining the relatively large static database of the CD rom with the regular update provided by the broadcast signal. This can provide an up-to-date service at a relatively low cost, much cheaper and easier to use, claims the BBC, than other on-line telecommunications databases.

Datacast is the packet data broadcasting system developed by the BBC for commercial use. Like the public system, Ceefax, it uses spare capacity on the u.h.f. tv signal. Many financial institutions have or are planning information services on Datacast including the Stock Exchange, the Financial Times and Coral Racing. The technology has been exported to Germany for use by a major bank.

In Brief

New phonecards have a notch in one side so that blind users can identify which way to insert them into the call box. This has been welcomed by the Committee on Communications for the Disabled and Elderly (DIEL); but they further press for a means of identifying cards of different value and an earlier audible warning from the payphone when the card is running out of available units.

Roy Cousins, of DIEL commented: "We were not consulted when the Phonecard was originally launched. It has taken years of chivvying for DIEL to persuade BT to make the cards easier to use for blind people; the notch was just one of a number of suggestions that we recommended. In general British Telecom consults outside bodies; but the needs of the disabled are often an afterthought."

The Engineering Council wants school leavers to have a broader education and so is supporting a new examination for over-sixteen students; AS-level. Each AS-level examination is the equivalent of half an A-level and is designed so that it can complement the main subjects and contrast with them. The exams enable a student taking, say, maths and science or technology at A-Level to take English, another language or humanities at AS-level. The exams are supported by all the representative bodies of higher education as being a 'good thing' and a booklet; "AS Levels are important" is available from the Engineering Council, Tel: 01-240 7891 or from the Standing Conference on University Entrance, 01-387 9231.

A fourth company is offering to demonstrate 'fourth-generation' software as part of the DTI scheme to promote software engineering tools (see Update, September 1987). The company, Strategic Resource and Information, is developing marketing information databases with the "versatility to meet varied and changing customer demands." The development is being carried out using the Genesis V language. The company is in Queens Park, London.

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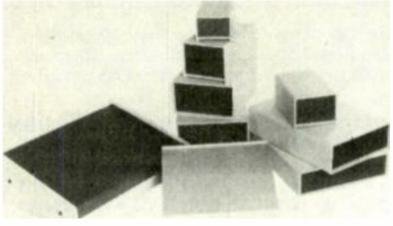

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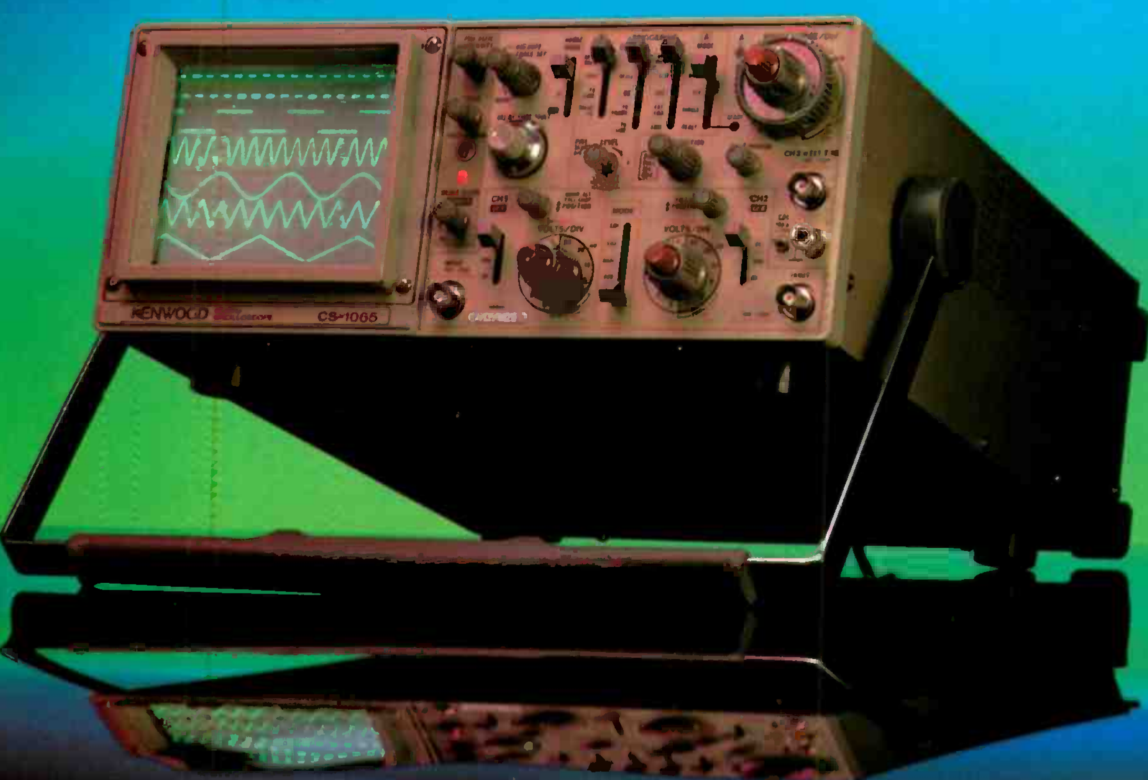

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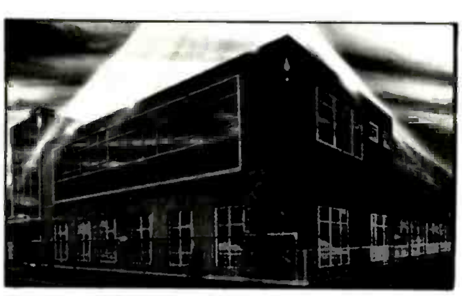

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