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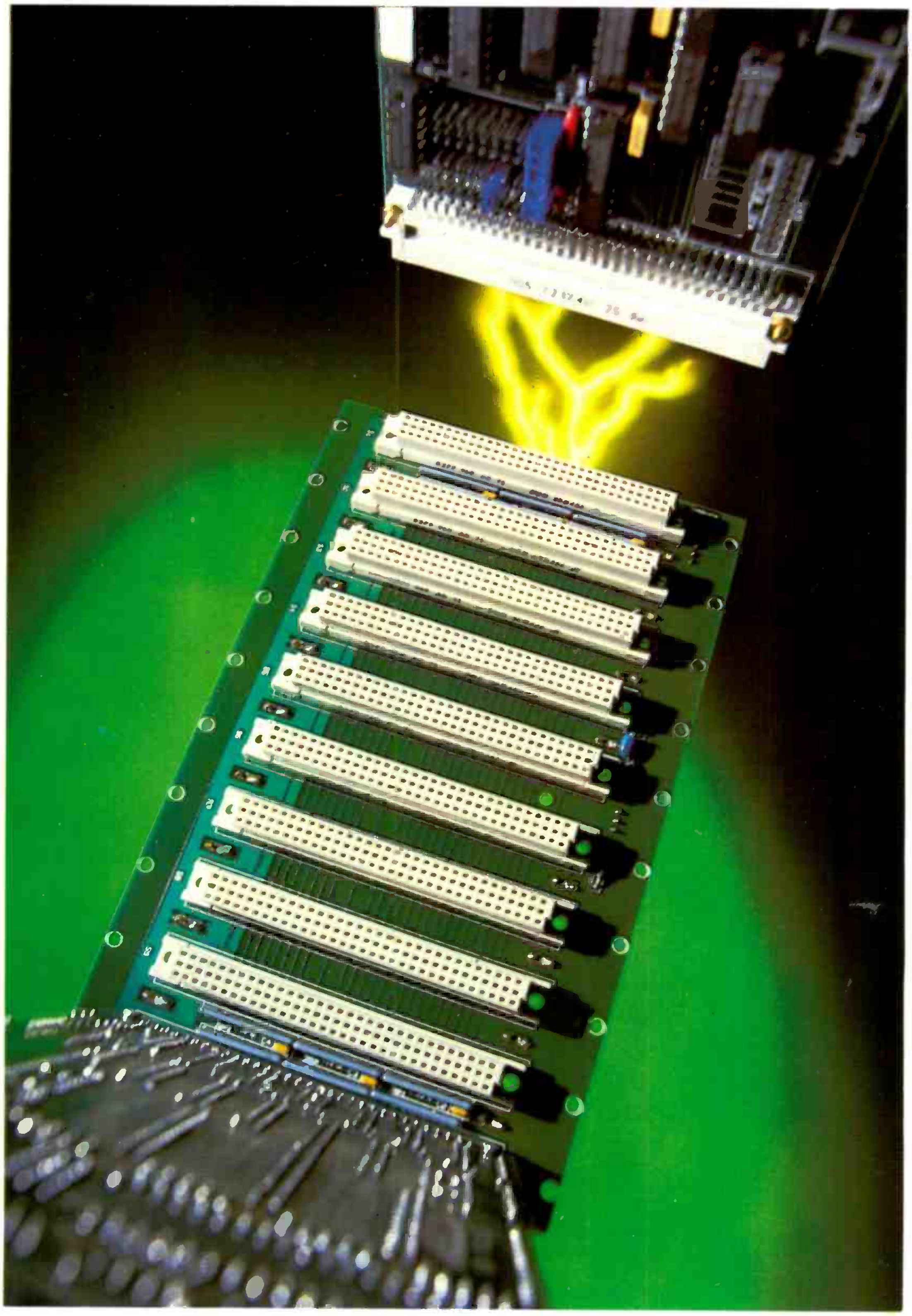

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COMMENT

Building for the future?

One result of the recent questionnaire, which readers were kind enough to respond to in their thousands, was an indication that a respectable number of professional engineers are still happy to continue their interest in electronics into their leisure time and to build equipment for their own use.

It is taking us rather longer than we had hoped to analyse the results and to hold a conference of all involved in running the journal to decide how to implement them. When that is all settled, the result will be published in these pages.

But, to go back to my opening point, I find it most encouraging that, at a time when many people are saying that it is no longer considered worthwhile to spend one's spare time in this way because most electronic requirements are well met by extremely well presented boxes from Japan, Taiwan or Korea, a visible proportion of engineeers do not agree.

Shortly after WWII, when thousands of people were back in civilian life after having become acquainted with military radio, radar and other manifestations of the electronic art, there was a truly remarkable surge of activity in the spare-time building of equipment. Television was new and the high-quality reproduction of sound was beginning to attract the attention of engineers. Components arrived on the market via the government surplus suppliers in profusion, allowing those who were determined to use their recently provided training to follow somewhat less warlike pursuits. Radar receivers became television receivers and the number of KT66 valves which were never called upon to amplify in anger must have run into the hundreds of thousands.

A large number of well known and respected figures in the electronics industry received a major incentive to make their careers in the subject in this way. University and technical-college courses were not plentiful and journals such as *Wireless World* helped in their education, often by the provision of designs for them to study and sometimes to build.

Now, of course, electronics is well catered for in the teaching institutions. Students are short of nothing and the level of education is such that the subject would be well-nigh unrecognizable to a graduate of 20 years ago. But, to judge from comments made by lecturers, there is very little evidence of any spark of fascination in the subject. Everything, it appears, is provided and the scope for any spirit of investigation and discovery – even if it exists before the youngsters reach university, and it seems that it rarely does – is limited by the need to get through the course and obtain a degree.

It is my view that part of this journal's job is to help in the education process. Indeed, when it was launched in 1911, the editor stated that he intended *The Wireless World* to "inform, instruct and entertain". *EWW* does, of course, just that, but the instruction, if it consists solely of theory, can be a little arid. Design principles need to be illustrated by practical application.

In the future, therefore, we will not feel quite so inhibited about publishing articles of a tutorial nature which culminate in a design for a piece of hardware. There is no substitute for practice, even when the theory is well understood.

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Multiprocessor systems

In this fourth article Alan Clements looks at the practical side of linking processors using VMEbus with the 68000 as an example.

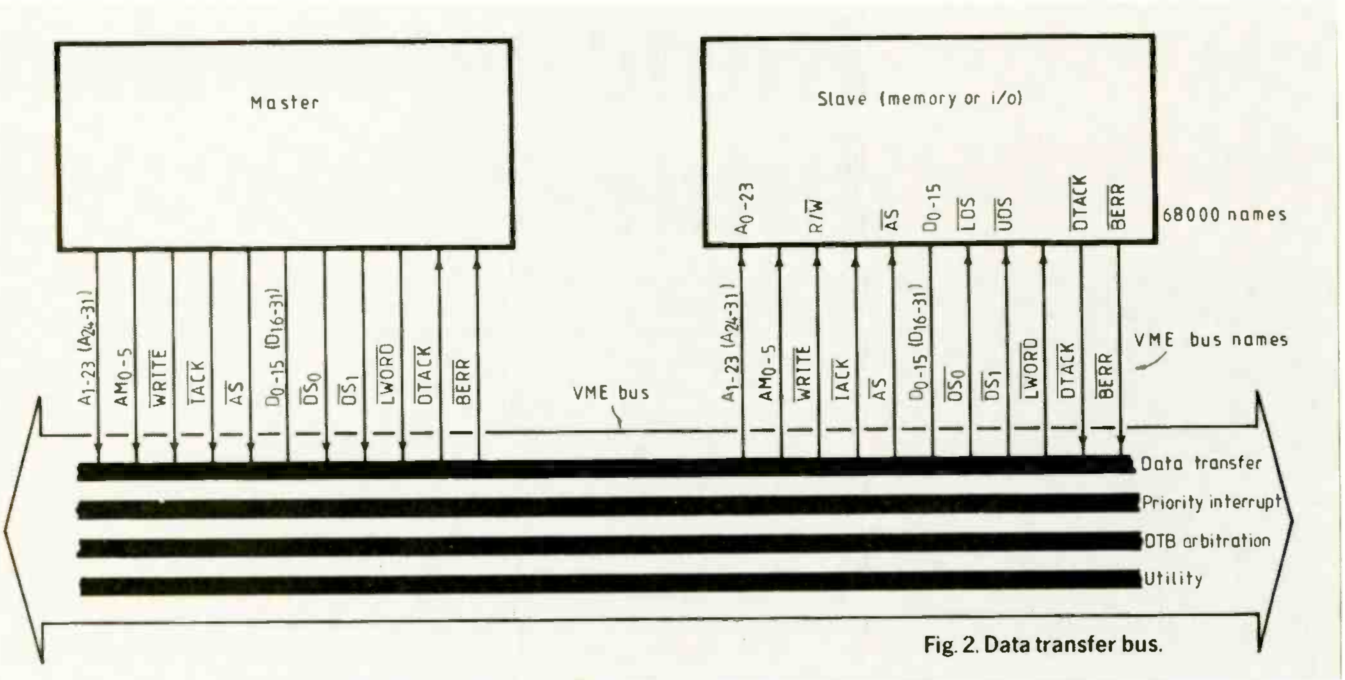


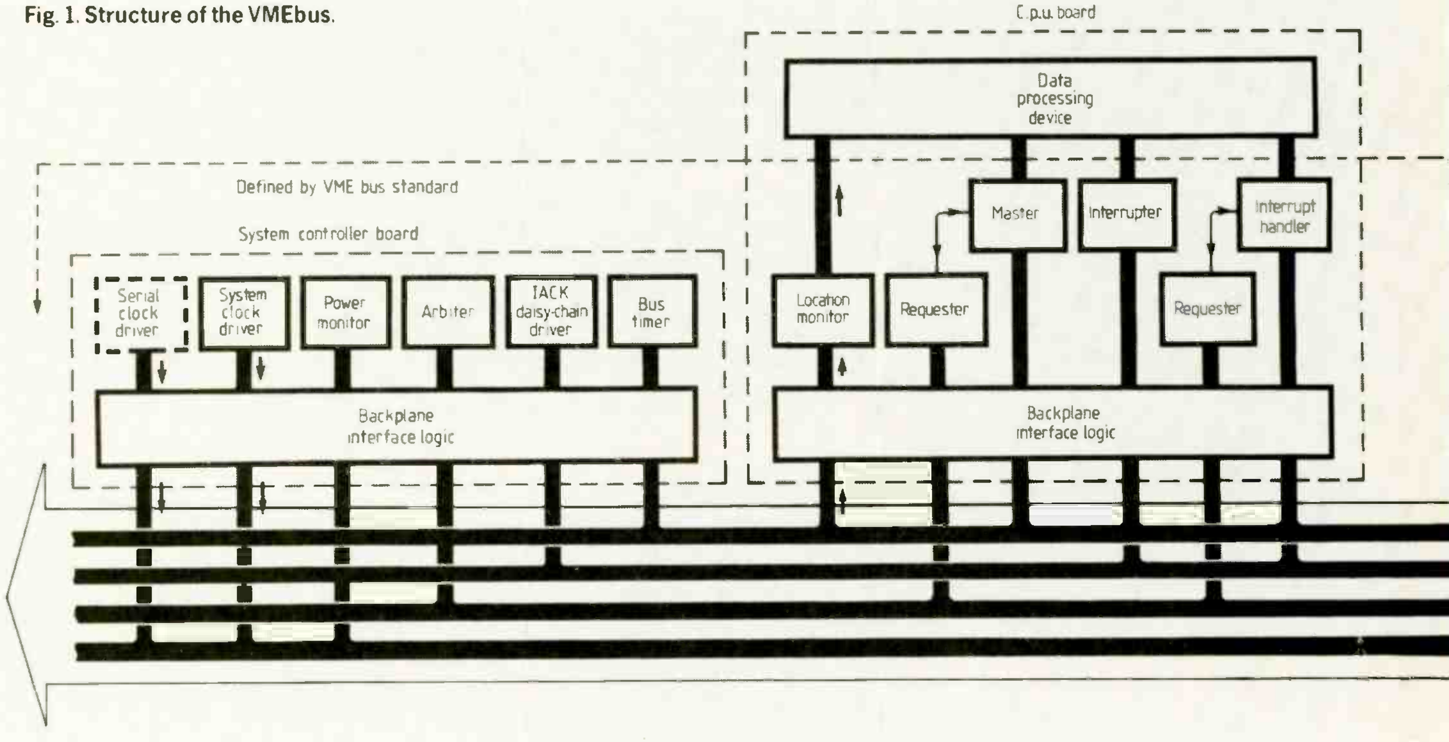
Fig. 2. Data transfer bus.

I have already indicated that the bus topology offers the simplest approach to multiprocessor design*. While this statement is true, it is not true that the design of a multiprocessor system based on a common bus is a trivial task. In fact, the design of any high-speed bus, be it a simple bus in a single-processor system or a contention bus, is much more complicated than it might appear. Many of the problems in bus design arise from the electrical effects associated with high-speed pulses on transmission lines.

Probably the best approach to designing a bus-based microcomputer is to choose one of the popular and standardized commercially available buses – unless, of course, the volume of production justifies the design, development and manufacture of a custom bus. This article looks at multiprocessor systems using a bus structure – namely the VMEbus that is now standard in many 68000-based microcomputers.

Originally, VMEbus was designed and

Fig. 1. Structure of the VMEbus.



supported by three major manufacturers; Motorola, Mostek and Signetics. Today it is supported by a wide range of manufacturers and is in the process of becoming an international standard (IEEE-1014 and IEC-821). Although primarily intended for 68000-based microcomputers, the VMEbus is suitable for other advanced 16 or 32bit microprocessors.

Physically, VMEbus is a typical backplane bus with plug-in cards of either 233.35 by 160mm or 100 by 160mm. These are so-called single-height 3U Eurocards and double-height 6U Eurocards. The cards connect to the VME bus by means of two-part 96 way DIN 41612 standard plugs and sockets which are relatively expensive but are highly reliable.

There are, in fact, two VMEbuses. In minimal systems a J1 bus with 96 lines provides all the facilities required to support a 16bit data bus and a 23bit address. A second bus, called J2, expands the J1 bus to cater for processors with 32bit data and 32bit address buses. Most of the tracks on the J2 bus are user-defined. Table 1 defines the VMEbus pinout.

Logically, VMEbus divides into four sub-buses; a data transfer bus (d.t.b.), an arbitration bus, an interrupt bus and a utilities bus. The data transfer bus is a conventional non-multiplexed address and data bus that provides several miscellaneous functions not catered for by the other buses such as a 16MHz clock and a system-failure line.

DATA-TRANSFER BUS

The data transfer bus of the VMEbus is based on the 68000's own address, data and control bus. Figure 2 illustrates the d.t.b. component of the VMEbus. Fig. 3 provides a protocol flow diagram for a VMEbus access and Fig. 4 provides the timing diagram of a read cycle.

Principal differences between the 68000's own bus and the VME data-transfer bus are the inclusion of a 6bit address modifier bus (AM_{0-5}), the addition of a long-word data strobe ($\overline{LWORD}$), the re-naming of $\overline{LDS}$ $\overline{UDS}$ ($\overline{LDS} = \overline{DS_0}$, $\overline{UDS} = \overline{DS_1}$) and the extension to 32 address and data bits. Signal $\overline{LWORD}$ is asserted active-low during a long-word (32bit) data transfer on D_{0-31}. In 68000 systems not using long-word transfers, $\overline{LWORD}$ is passively pulled up to V_{cc}.

Information on the address bus is verified by means of the address modifier bus AM_{0-5}. For example, the current bus master can use AM_{0-5} to indicate the type of the current access (short, standard or long address), memory-management information, or any other user-defined function.

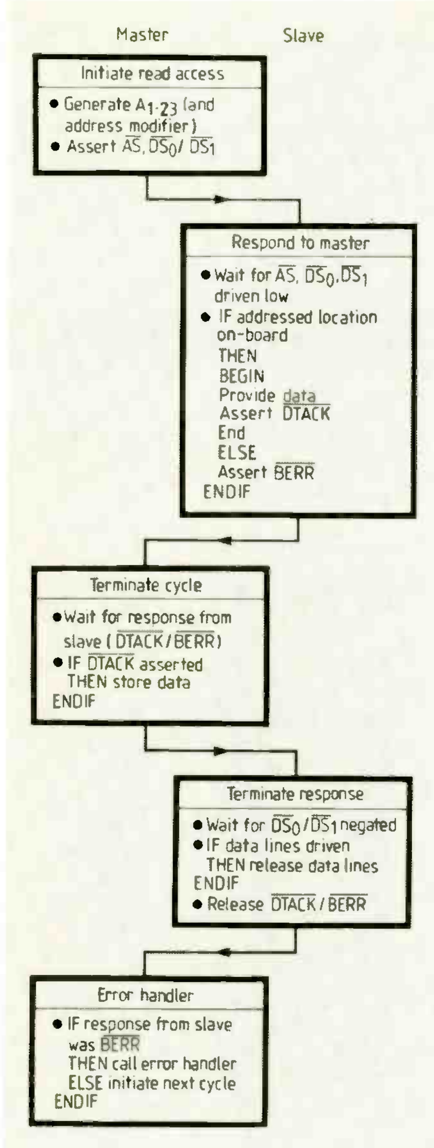


Fig. 3. Protocol flowchart for a VMEbus access.

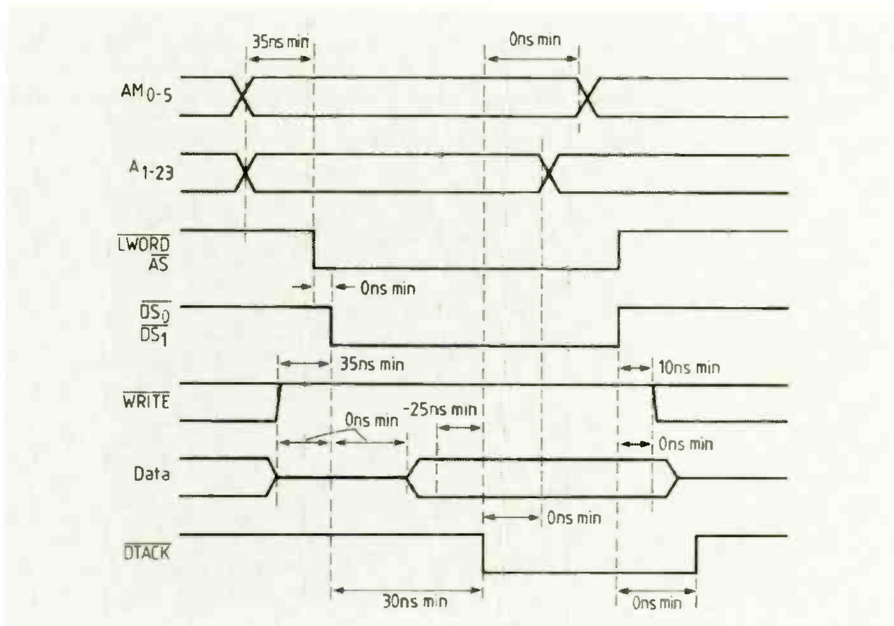
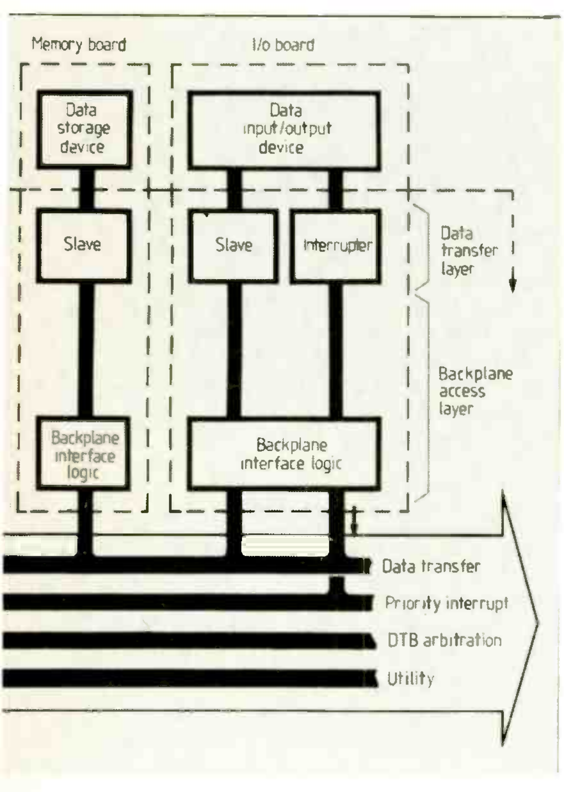


Fig. 4. Timing of a VMEbus read cycle.



enables information to be transferred between a bus master and a bus slave.

At this point it is worth noting that VMEbus operates in a master-slave mode so that at any instant only one device (e.g. 68000 microprocessor or direct memory access controller) may access a slave connected to the bus.

The arbitration bus provides the VMEbus with multiprocessor facilities by enabling control to be passed from one master to another in an orderly fashion. Interruptors signal their need for attention via the interrupt bus, which also allows an interrupt handler to deal with the interrupt request.

In Fig. 1, illustrating the VMEbus structure, you can see that the utilities bus

ARBITRATION BUS

It is the arbitration sub-bus of the VMEbus that makes it so suitable for multiprocessor systems. Two types of functional unit access the arbitration bus: the requester and the arbiter, Fig. 5. A requester is part of any module that may wish to request mastership of the VMEbus. An arbiter is part of the system controller board and must be located physically in slot 1 of the VMEbus system. Whenever the arbiter receives a request for the bus from a requester, the arbiter decides how the request is to be handled.

Figure 5 also illustrates the actual arrangement of the arbitration bus. A requester in any slot (apart from slot 1) may

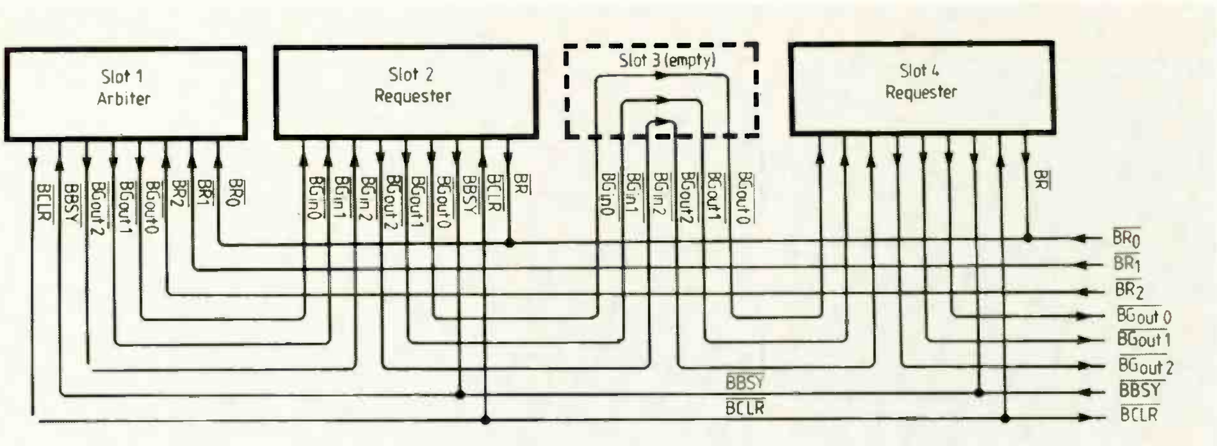


Fig. 5. VMEbus requester and arbiter.

request the data transfer bus by asserting one of the bus request lines, $\overline{BR_{0-2}}$. On detecting a request for the bus on $\overline{BR_{0-2}}$, the arbiter decides whether to grant the request or to ignore it (I will describe how this is done later). Figure 6 provides a protocol flow diagram for a typical VMEbus arbitration sequence.

If the arbiter grants the d.t.b. request, it asserts the corresponding active-low bus-grant output level (i.e. $\overline{BG_xOUT}$, where x = 0,1,2 or 3). For example, a request on $\overline{BR_2}$ would result in a bus grant signal on $\overline{BG_2OUT}$.

Bus-grant output lines are daisy-chained so that the $\overline{BG_xOUT}$ pin on module i is wired to the $\overline{BG_xIN}$ pin on module i+1. When a module receives $\overline{BG_xIN}$ asserted from its upstream neighbour, it either takes the bus-grant itself (and does not assert its $\overline{BG_xOUT}$ signal) or it passes the bus grant to its downstream neighbour by asserting its $\overline{BG_xOUT}$. Consequently, a level-x bus grant ripples down the daisy-chain until the first device requesting the bus at level x receives the bus grant and does not pass it on.

Of course, daisy chaining includes an implicit prioritization mechanism: a module nearer to the arbiter is always served before its neighbours further away from the aribter.

When a requester has been granted control of the data-transfer bus via the bus-grant daisy-chain, the requester takes control of the bus by driving $\overline{BBSY}$ (bus busy) low. Once $\overline{BBSY}$ has been asserted by the new bus master, the arbiter can once again begin to perform arbitration if any other potential master requests the bus. The requester is now the new bus master and will remain so until it negates $\overline{BBSY}$.

Interestingly, the VMEbus specification provides no mechanism for forcing a requester off the bus: $\overline{BBSY}$ can be negated only by the current bus master. However, a bus clear, $\overline{BCLR}$, signal is provided as an option. When a potential bus master with a request higher than the current level requests the VMEbus, the arbiter asserts $\overline{BCLR}$ to inform the current master that it should consider giving up the VMEbus. It is left to the system implementer to decide how $\overline{BCLR}$ should be used.

Fig. 6. Protocol flow for a VMEbus arbitration sequence.

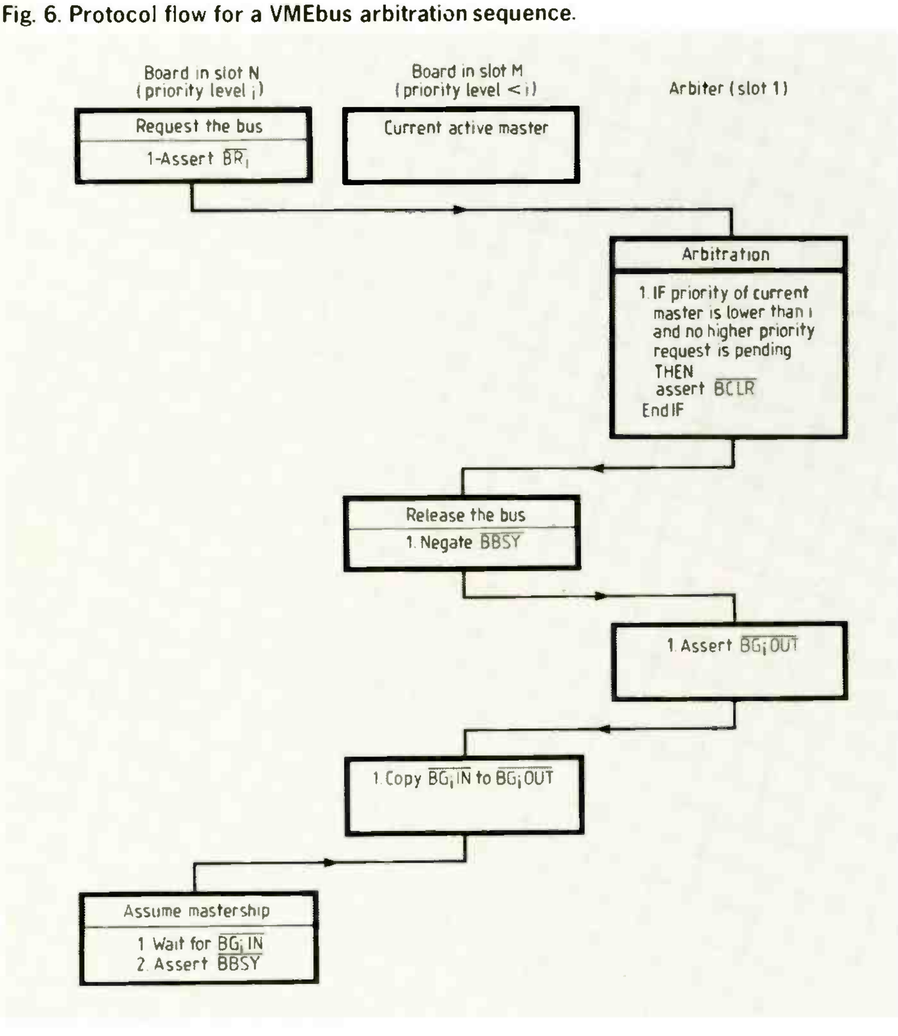


Table 1. VMEbus pin assignments. J1/P1

Pin	Signal mnemonic Row a	Row b	Row c
1	D_{00}	$\overline{BBSY}$	D_{08}
2	D_{01}	$\overline{BCLR}$	D_{09}
3	D_{02}	$\overline{ACFAIL}$	D_{10}
4	D_{03}	$\overline{BG_0IN}$	D_{11}
5	D_{04}	$\overline{BG_0OUT}$	D_{12}
6	D_{05}	$\overline{BG_1IN}$	D_{13}
7	D_{06}	$\overline{BG_1OUT}$	D_{14}
8	D_{07}	$\overline{BG_2IN}$	D_{15}
9	GND	$\overline{BG_2OUT}$	GND
10	SYSCLK	$\overline{BG_3IN}$	$\overline{SYSFAIL}$
11	GND	$\overline{BG_3OUT}$	$\overline{BERR}$
12	$\overline{DS_1}$	$\overline{BR_0}$	$\overline{SYSRESET}$
13	$\overline{DS_0}$	$\overline{BR_1}$	$\overline{LWORD}$
14	$\overline{WRITE}$	$\overline{BR_2}$	AM5
15	GND	$\overline{BR_3}$	A_{23}
16	$\overline{DTACK}$	AM_0	A_{22}
17	GND	AM_1	A_{21}
18	$\overline{AS}$	AM_2	A_{20}
19	GND	AM_3	A_{19}
20	$\overline{IACK}$	GND	A_{18}
21	$\overline{IACKIN}$	SERCLK	A_{17}
22	$\overline{IACKOUT}$	SERDAT	A_{16}
23	AM_4	GND	A_{15}
24	A_{07}	$\overline{IRQ_7}$	A_{14}
25	A_{06}	$\overline{IRQ_6}$	A_{13}
26	A_{05}	$\overline{IRQ_5}$	A_{12}
27	A_{04}	$\overline{IRQ_4}$	A_{11}
28	A_{03}	$\overline{IRQ_3}$	A_{10}
29	A_{02}	$\overline{IRQ_2}$	A_{09}
30	A_{01}	$\overline{IRQ_1}$	A_{08}
31	-12V	+5VSTDBY	+12V
32	+5V	+5V	+5V

ARBITRATION

An arbiter in VMEbus slot 1 may implement three basic types of arbitration: single level, priority, or round-robin select. The actual mode of arbitration (scheduling algorithm) used in any particular system is an option selected by the designer and the VMEbus specification does not exclude scheduling algorithms other than the three mentioned above.

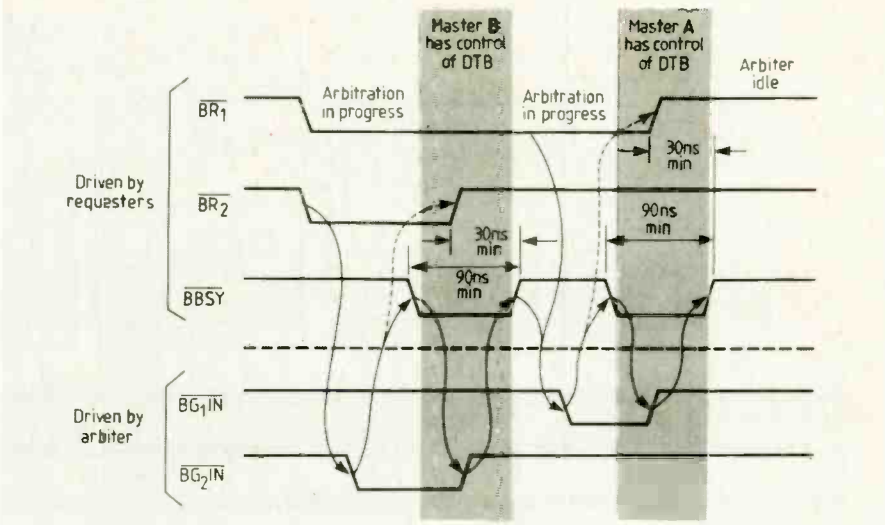
Single-level arbitration offers the simplest scheduling algorithm. Only requests for arbitration on $\overline{BR_3}$ are accepted by the arbiter in slot 1 (i.e. the bus-request lines, and bus-grant lines for levels 0, 1 and 2, are not used).

Prioritized arbitration makes use of all bus arbitration lines. Bus-request line $\overline{BR_0}$ has the lowest priority and $\overline{BR_3}$ has the highest. If more than one level of interrupt is pending, the arbiter always grants priority to the highest level of request.

Whenever a requester with a priority greater than that of the current bus master requests the d.t.b., the arbiter asserts the $\overline{BCLR}$ (bus clear) line. An active-low on $\overline{BCLR}$ indicates to the current master that it should relinquish the bus as soon as possible – but remember that it cannot be forced off the bus.

A round-robin select scheduling algorithm attempts to be fair to requesters by

Fig. 7. Timing of an arbitration sequence.



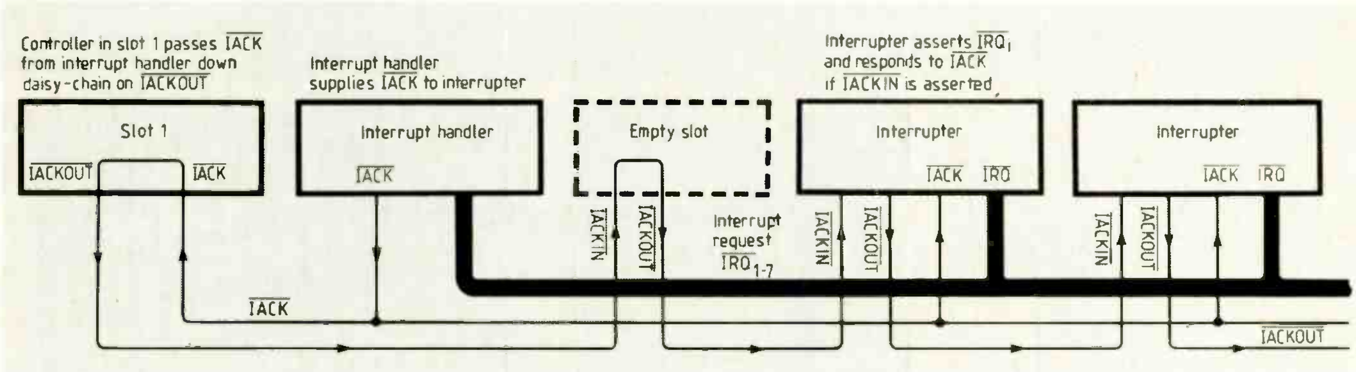
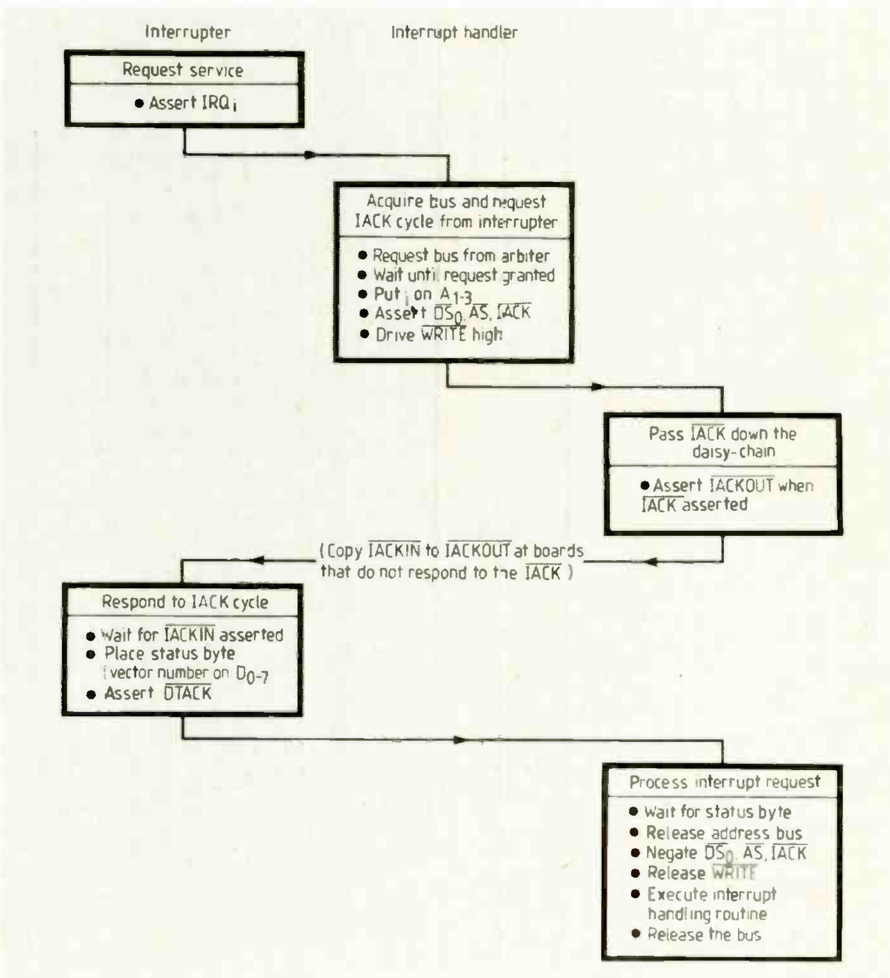


Fig. 8. The interrupt bus (above).
Fig. 9. Protocol flow for a VMEbus interrupt sequence.

rotating the current level of maximum priority. For example, if the current highest level of priority is 3, the highest priority in the next cycle of arbitration will be 0.

Figure 7 shows the timing diagram of a typical arbitration sequence. Initially, data-transfer bus requests are made on $\overline{BR_{1,2}}$ at approximately the same time. The arbiter in slot 1 detects both requests and gives priority to $\overline{BR_2}$ by asserting the $\overline{BG_2IN}$ line. When the requester that asserted $\overline{BR}$ detects $\overline{BG_2IN}$ asserted, it asserts $\overline{BBSY}$ to claim the data-bus transfer and negates its $\overline{BR_2}$ line.



J2/P2

Pin	Signal mnemonic Row b*	Pin	Signal mnemonic Row b*
1	+5V	17	D_{19}
2	GND	18	D_{20}
3	Reserved	19	D_{21}
4	A_{24}	20	D_{22}
5	A_{25}	21	D_{23}
6	A_{26}	22	GND
7	A_{27}	23	D_{24}
8	A_{28}	24	D_{25}
9	A_{29}	25	D_{26}
10	A_{30}	26	D_{27}
11	A_{31}	27	D_{28}
12	GND	28	D_{29}
13	+5V	29	D_{30}
14	D_{16}	30	D_{31}
15	D_{17}	31	GND
16	D_{18}	32	+5V

*All pins on rows a and c are user defined.

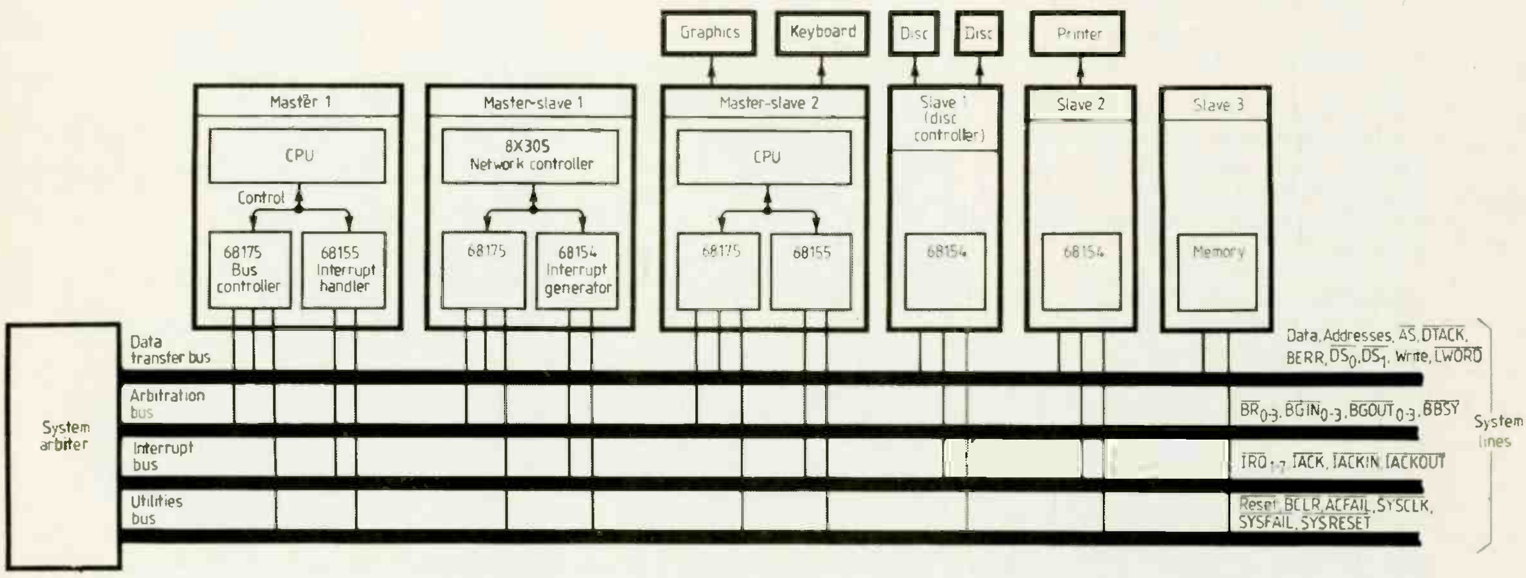


Fig. 10. The 68175, 68154, 68155 and VMEbus (above).

Once the current bus master has finished with the data-transfer bus it negates BBSY. The arbiter detects that the bus is once more free and there is still a request pending on level 1. Therefore, the arbiter asserts $\overline{BG_1IN}$ to pass control to the new bus master.

Later I will discuss interfaces to the priority arbitration bus.

INTERRUPT BUS

You have now seen that the VMEbus implements a data-transfer bus very much like the 68000's own data transfer bus and implements an arbitration bus that fits in well with the 68000's own arbitration control signals (BR, BG, BGACK). It should therefore not surprise you to discover that the VMEbus implements an interrupt handling structure in keeping with the 68000's own interrupt mechanism.

Three types of module are associated with the priority interrupt bus: the interrupter, the interrupt handler and the IACK (interrupt acknowledge) daisy-chain driver, Fig. 8.

An interrupter is a module capable of signalling an interrupt a request on one of the seven prioritized interrupt request lines, $\overline{IRQ_{1-7}}$. The IACK daisy-chain driver in slot 1 detects an interrupt request and transmits a falling edge down the IACKOUT-IACKIN daisy-chain. Figure 9 provides the protocol flow diagram of a VMEbus interrupt sequence.

An incoming interrupt acknowledgement is detected by the interrupt handler on its IACKIN pin. If this requester initiated the interrupt, it uses its on-board bus requester to request the d.t.b. and, when granted access to the d.t.b., initiates an interrupt-acknowledge cycle. By reading the STATUS/ID byte from the interrupter, the handler initiates the appropriate interrupt-servicing sequence. The actual servicing of an interrupt (i.e. how it is done and which device

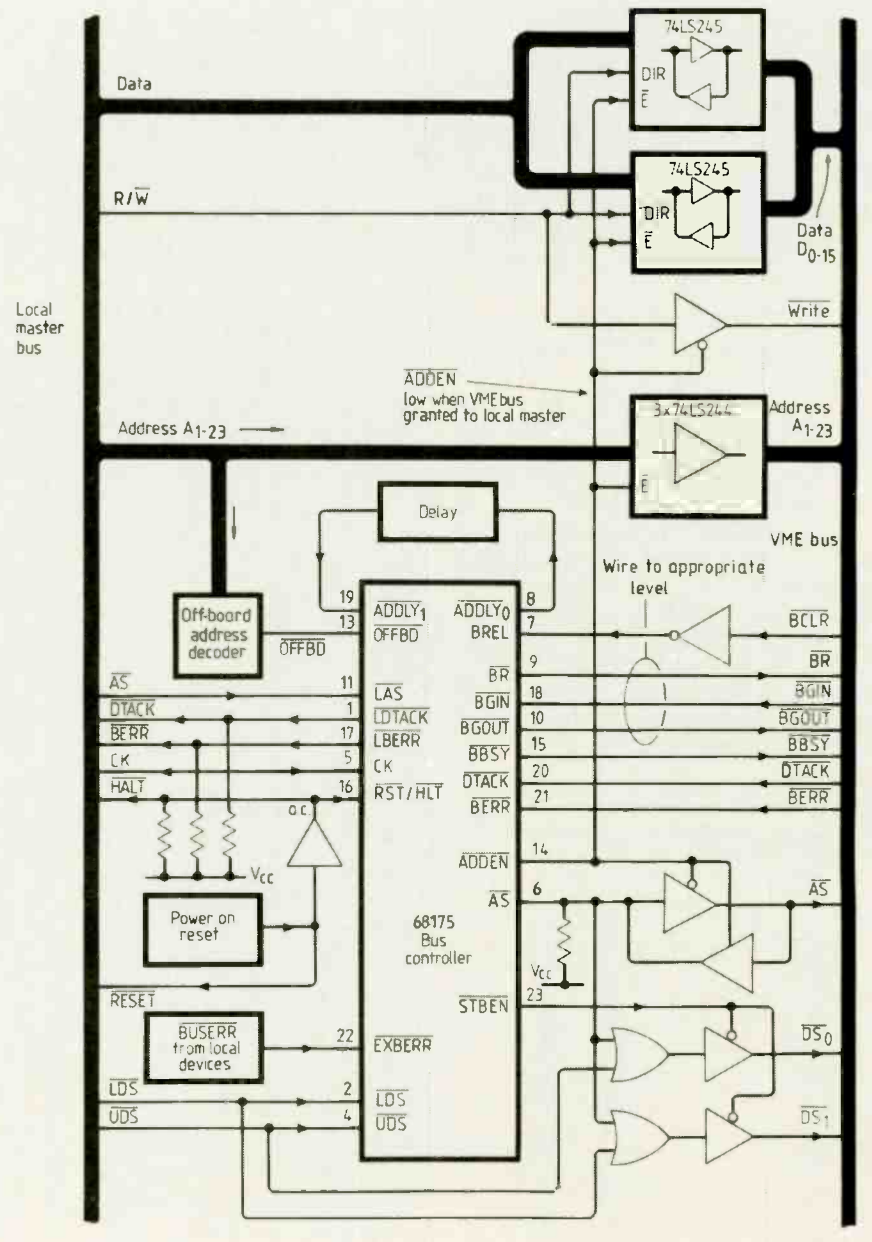
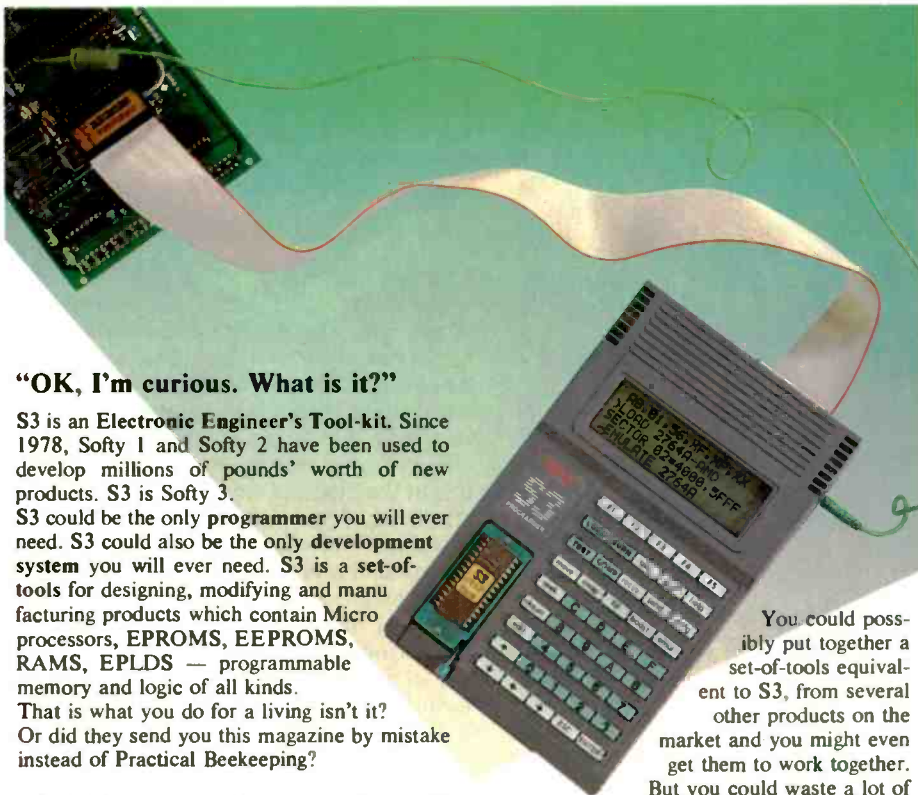


Fig. 11. The 68175 and its interface to the VMEbus and a local bus master.



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does it) is not part of the VMEbus specification.

VMEbus systems cater for two interrupt handling mechanisms: single interrupt handlers and distributed interrupt handlers. Distributed interrupt handlers are found in multiprocessor systems in which interrupt handling is shared among several bus masters.

INTERFACING TO VMEbus

There are three ways of interfacing a module to the VMEbus, each with a different degree of difficulty. The easiest way is to buy the appropriate module from a supplier of VMEbus modules. As long as they fully comply with the VMEbus specifications, there should be little or no difficulty. The most difficult way of interfacing to VMEbus is to design the interface entirely yourself using standard t.t.l. or programmable logic chips. A custom interface requires a detailed understanding of the VMEbus protocols and much design time.

As you might expect, the third way of interfacing, which lies between the other two in difficulty, is a compromise between buying a ready-made module and designing the interface entirely on your own. It involves designing the interface yourself using some of the special purpose VMEbus chips now available. Here I am going to look at three devices – the 68175 bus controller, the 68154 interrupt generator and the 68155 interrupt handler. Figure 10 shows how these three devices relate to the VMEbus.

68175 BUS CONTROLLER

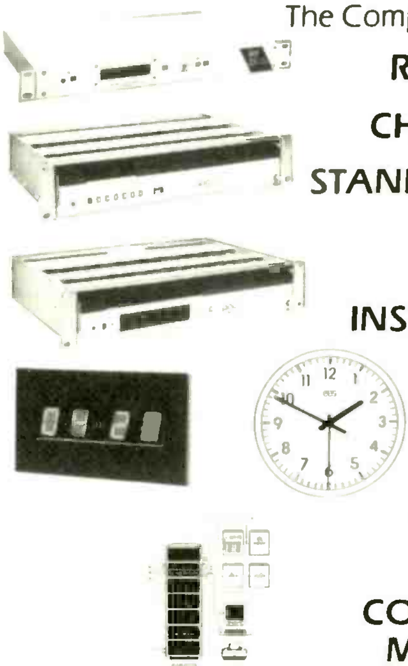
Arbitration between a local master on a module and the VMEbus itself is performed by the 68175 bus controller. As it is less instructive to describe the internal structure of the 68175 than to demonstrate how it is used, I will look at how the 68175 interfaces between a local master and the VMEbus.

Figure 11 shows how a 68175 sits between the local bus of a bus master (which we will assume is a 68000 processor) and the system VMEbus. In addition to the 68175 itself, address and data bus buffers and a few t.t.l. gates are needed.

In normal local-master operation, the local master accesses its own memory and peripherals via its local bus. Under these circumstances, the output of the address decoder, $\overline{\text{OFFBD}}$ (i.e. off board), is inactive high. Consequently, the 68175's address enable output, $\overline{\text{ADDEN}}$, is also inactive high and all devices capable of driving the VMEbus are disabled.

Suppose now that the local bus master wishes to access some resource from the VMEbus. A VMEbus access is initiated whenever the local master accesses address space that has been partitioned to the VMEbus. That is, when the local master accesses an address that forces the $\overline{\text{OFFBD}}$ output of the address decoder active-low.

When the bus controller detects that both $\overline{\text{OFFBD}}$ and $\overline{\text{LAS}}$ (local-address strobe = $\overline{\text{AS}}$ from the local master) are low, it asserts its bus request output, $\overline{\text{BR}}$ in an attempt to gain control of the VMEbus. Signal $\overline{\text{BR}}$ must be connected to one of the VMEbus's $\overline{\text{BR}}_i$ lines. Note that bus-request priority is assigned by



12
11
1
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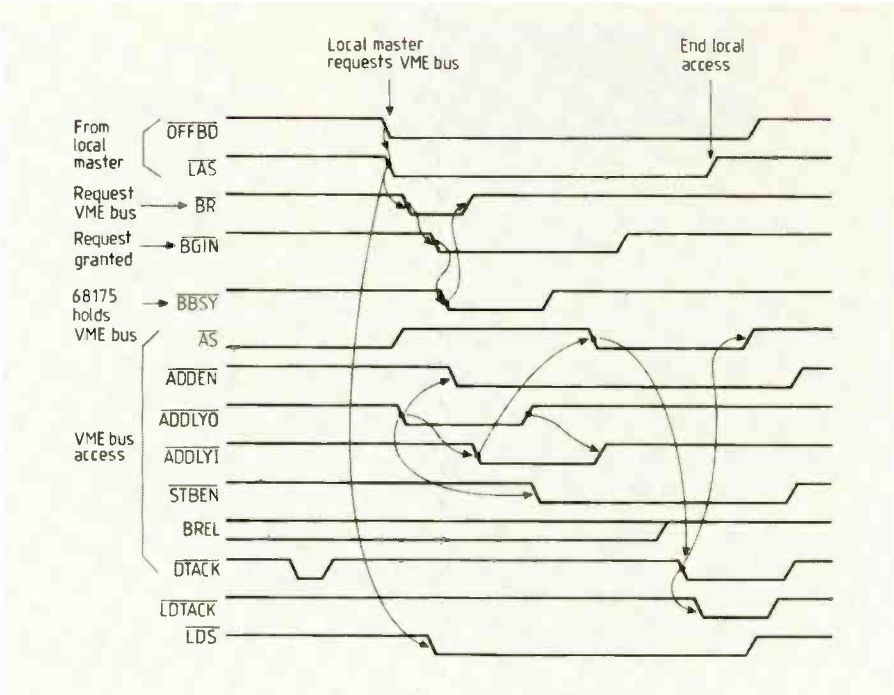
Fig. 12. Timing diagram for a local master access to the VMEbus.



a hardware link. If there were sufficient pins, the 68175 could have had a software-selectable bus-request priority level.

Eventually, the current VMEbus master responds to the 68175's request by passing a bus-grant signal down the $\overline{\mathrm{BGIN}}$-$\overline{\mathrm{BGOUT}}$ daisy-chain. If the 68175 receives $\overline{\mathrm{BGIN}}$ low before it asserted its own $\overline{\mathrm{BR}}$ output, it passes $\overline{\mathrm{BGIN}}$ down the daisy-chain by asserting its own $\overline{\mathrm{BGOUT}}$. That is, the 68175 is a polite device – if another potential bus master requested the bus before its own local bus master, it will not attempt to grab the bus at the first opportunity. If the 68175 receives $\overline{\mathrm{BGIN}}$ low after it asserts its $\overline{\mathrm{BR}}$ output, the 68175 will assert its $\overline{\mathrm{BBSY}}$ output to claim ownership of the VMEbus and negate its $\overline{\mathrm{BR}}$, as it is now new VMEbus master.

Actual VMEbus accesses do not begin until the old bus master has released the bus by negating $\overline{\mathrm{AS}}$, $\overline{\mathrm{DTACK}}$ and $\overline{\mathrm{BERR}}$. Once the local bus master has control of the VMEbus, it provides the necessary signals to control a VMEbus access. For each bus access, the 68175 asserts its $\overline{\mathrm{ADDEN}}$ (address and data enable), $\overline{\mathrm{STBEN}}$ (strobe enable) and $\overline{\mathrm{AS}}$ outputs active-low. $\overline{\mathrm{ADDEN}}$ is a totem pole output that is used to enable the module's address and data-bus drivers. The $\overline{\mathrm{STBEN}}$ output enables the two data strobes (i.e. $\overline{\mathrm{DS}}_{0,1}$).

Two pins of the 68175 bus controller are devoted to the generation of an appropriate delay between the point at which the VME-bus address is valid and the point at which the VMEbus $\overline{\mathrm{AS}}$ is asserted low. Whenever a VMEbus cycle is executed, the 68175 asserts its $\overline{\mathrm{ADDLYO}}$ pin (address-delay output). $\overline{\mathrm{ADDLYO}}$ is connected to the $\overline{\mathrm{ADDLYI}}$ (address-delay input) pin by a user-supplied delay line. This delay, typically 35ns, guarantees a minimum setup time between the assertion of $\overline{\mathrm{ADDEN}}$ and $\overline{\mathrm{AS}}$ Figure 12, 13.

As I have already said, the VMEbus has no explicit mechanism for forcing a current bus master off the VMEbus. That is, the control of the 68175's active-high BREL (bus release) input is left to the designer of the specific system using the 68175 bus controller.

In some applications, BREL can be permanently asserted by tying it to a logical one (i.e. V_{cc}). As BREL is always asserted, the 68175 will never control the VMEbus for more than a single bus cycle. In other words, the 68175 is configured to carry out one VMEbus cycle at a time and to release the VMEbus between successive cycles. This mode may result in a relatively high latency if there are many contending bus masters. It is, however, fair because it prevents the local bus master from hogging the VMEbus.

Alternatively, the BREL input to the 68175 can be connected to the VMEbus's $\overline{\mathrm{BCLR}}$ (bus clear) line via an inverter. Whenever the VMEbus arbiter in slot 1 requests the bus by asserting $\overline{\mathrm{BCLR}}$, the local bus master wil be forced off the VMEbus at the end of its current bus cycle by BREL being high.

Signal BREL can also be connected to one or more of the VMEbus's bus-request lines by means of suitable gating (BREL is the Nand of the appropriate bus requests). Note that a Nand gate is used to make BREL the logical Or (in negative logic) of the appropriate $\overline{\mathrm{BR}}_i$ inputs). In this mode, the 68175 implements a release on request (r.o.r.) strategy — as soon as the 68175 sees that another potential master is requesting the bus, it begins its release sequence. Note that the 68175 does not monitor its BREL input until the last leading edge of $\overline{\mathrm{BGIN}}$ or $\overline{\mathrm{ADDLYI}}$ is negated to prevent the 68175 relinquishing control of the VMEbus due to its own bus request.

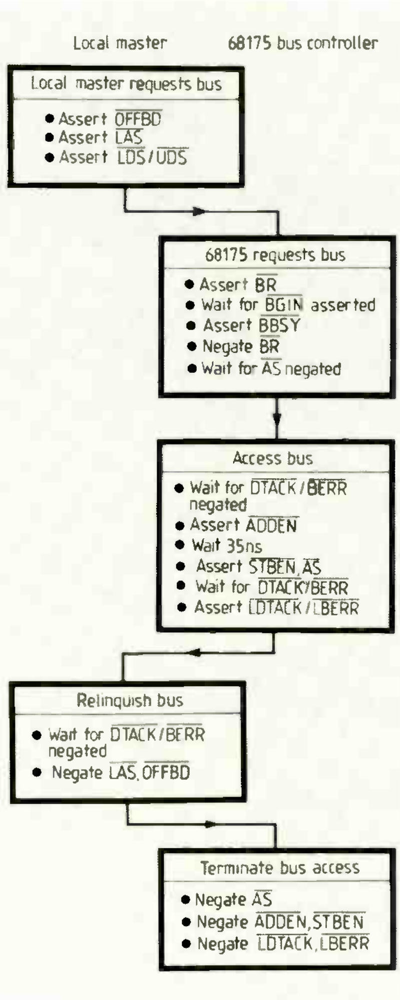


Fig. 13. Protocol flowchart for Fig. 12.

There is a mechanism on the 68000 for re-running faulty bus cycles, i.e. bus cycles terminated by the assertion of $\overline{\mathrm{BERR}}$ rather than $\overline{\mathrm{DTACK}}$. If $\overline{\mathrm{BERR}}$ and $\overline{\mathrm{HALT}}$ are asserted together, the 68000 attempts to re-run the current bus cycle using the same address and function codes. The bus cycle re-run, or retry mode, helps the 68000 recover from certain forms of soft errors.

A facility for the automatic re-running of bus cycles is included on the 68175 bus controller. If the controller receives either $\overline{\mathrm{BERR}}$ from the VMEbus or $\overline{\mathrm{LBERR}}$ (during a local bus cycle) it asserts both $\overline{\mathrm{LBERR}}$ and $\overline{\mathrm{RST/HLT}}$. Simultaneous assertion of both these signals allows the bus master to execute a re-run cycle. However, if the re-run cycle also leads to the assertion of $\overline{\mathrm{BERR}}$ or $\overline{\mathrm{LBERR}}$, the 68175 will assert only $\overline{\mathrm{LBERR}}$; the 68175 is designed to attempt one bus re-run cycle.

The 69175's external bus error input, $\overline{\mathrm{EXBERR}}$, is provided to enable local resources to initiate a bus cycle re-run sequence. For each access to the VMEbus, $\overline{\mathrm{ADDEN}}$, $\overline{\mathrm{STBEN}}$ and $\overline{\mathrm{AS}}$ are asserted low. If the 68000 accesses its local memory (i.e. $\overline{\mathrm{OFFBD}}$ goes high), $\overline{\mathrm{ADDEN}}$, $\overline{\mathrm{STBEN}}$ and $\overline{\mathrm{AS}}$ all remain inactive-high throughout the cycle.

As I said earlier, the 68000 is capable of executing an indivisible read-modify-write instruction called TAS (test and set). A read-modify-write cycle cannot be interrupted (i.e. by bus arbitration). The 68000 asserts $\overline{\mathrm{AS}}$ throughout or read-modify-write cycle and the 68175 is designed to retain control of the bus as long as $\overline{\mathrm{AS}}$ is low. Consequently, the 68175 bus controller automatically handles the 68000's read-modify-write cycle or, for that matter, any other indivisible bus cycle for which $\overline{\mathrm{AS}}$ remains low throughout (see Fig.4 on p876 of the September issue). Next month's final article discusses the 68154 interrupt requester and the 68155 interrupt handler.

A radiant century

Hertz's discovery of electromagnetic waves in 1888

K.L. SMITH

In the January 1988 issue of *E&WW*, W.A. Atherton gave us a brief glimpse of Heinrich Hertz's work. So far this year, very few parts of the media – much of it utterly indebted to Hertz – have shown any interest in celebrating his remarkable achievement. I am pleased to say that *E&WW* once again is an exception, and because this is the centenary year regarding Hertz's important observations and publications on the subject, another small contribution might record our continuing appreciation.

As well as that, I suspect many readers find absorbing interest in the depth and thoroughness of much pioneering work such as Hertz's. I am pleased to report, contrary to other claimed indications, that young people to whom I have re-enacted some of Hertz's experiments during lectures to them, are absolutely fascinated by what he achieved.

So I recommend Atherton's article, to which these supplementary notes might add a little more technical detail.

DYNAMICAL AND MECHANISTIC THOUGHT

When Helmholtz suggested an attempt on the problem of experimentally testing some of the claims made by Maxwell in his Electromagnetic Theory, Hertz held back from an early attack on this. A few years passed but, by the mid 1880s, Hertz gradually began to swing his researches towards experimental programmes. This seems to indicate that he probably mulled over the subject during the inactive years; no doubt, as he later stated[1], he found Maxwell's exposition difficult to understand.

Maxwell, although using systems of cogs and rollers[2] to help visualize the aether in his early work – a highly mechanistic way of thinking – nevertheless was a highly dynamical thinker; he soon dropped the 'cogs...' analogy in his later work. In fact, natural philosphers holding dynamical outlooks tend to use analogy, and Maxwell was no exception. He had been brought up in the Scottish dynamical philosophy tradition in education, and received major influences on his career from Whewell, who was steeped in that tradition. Maxwell also came under the influence of Hamilton and Tait, whose mathematics of quaternions – also dynamically biased – contained all the seeds of Vector Ana'ysis.

Through all this, Maxwell thought vectorially, as indeed he showed in his invention of the 'curl', 'convergence' (negative 'divergence') and 'gradient', together with the use of ∇^2 (ref.3). But this vital breakthrough was too much even for Maxwell and he presented his results in Cartesian form (triple components); the full vector method had to await the work of Oliver Heaviside and Willard Gibbs.

By the mid 1880s, Hertz was still "Cartesian". In effect, he had been nurtured through the Continental mechanistic tradition, and found all this 'vague dynamical field theory' and 'quaternion-vector' approach from the Scottish/English schools very baffling.

HERTZ BECOMES CONVINCED

Nevertheless, Hertz became convinced of the reality of electric and magnetic wave radiation, produced electrically. These should travel through space at the velocity of light, and not instantaneously as "action-at-a-distance".

Maxwell's contruction, which in true reductionist-mechanistic terms Hertz called "Maxwell's Theory is Maxwell's Equations", had succeeded handsomely in optics, so (risking a speculative assertion) in Helmholtz and Hertz's minds, "there must be a considerable content" in the theory.

Fig.1. The zinc spheres on Hertz's "long-wave apparatus" were 30cm diameter, connected by a 5mm thick wire 2.6 metres long with a spark gap in the centre. Hertz calculated the wavelength radiated by this apparatus as λ = 7.5 metres. This very reasonable result agrees with the "half-wave dipole" length of 2.6m, when you consider it was capacitively end loaded with the spheres.

We then assert that if Π is any function whatever of ρ, z, t, which satisfies the equation—

$$A^2 d^2\Pi/dt^2 = \Delta\Pi,$$

and if we put $Q = \rho d\Pi/d\rho$, then the system

$$\rho Z = dQ/d\rho, \qquad \rho P = A dQ/dt,$$
$$\rho R = -dQ/dz, \qquad N = 0$$

is a possible solution of our equations.

In order to prove this assertion, we observe that we have—

$$X = R\frac{d\rho}{dx} = -\frac{d^2\Pi}{dx\,dz}, \qquad L = P\frac{d\rho}{dy} = -A\frac{d^2\Pi}{dy\,dt},$$
$$Y = R\frac{d\rho}{dy} = -\frac{d^2\Pi}{dy\,dz}, \qquad M = -P\frac{d\rho}{dx} = -A\frac{d^2\Pi}{dx\,dt},$$
$$Z = \frac{1}{\rho}\frac{d}{d\rho}\left(\rho\frac{d\Pi}{d\rho}\right) = \frac{d^2\Pi}{dx^2} + \frac{d^2\Pi}{dy^2}, \qquad N = 0.$$

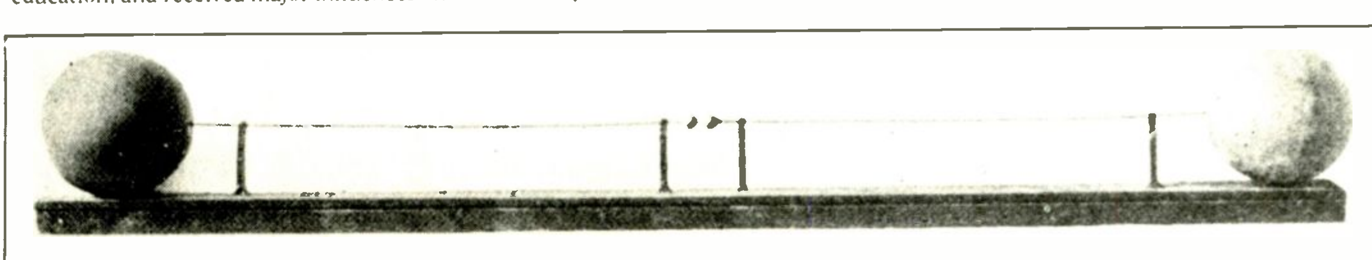
Fig.2. This extract[4] shows Hertz's introduction of the quantity Π, later known as the "Hertz vector".

Hertz then proceeded with an induction coil to produce high-intensity electric energy, which he stored in the capacitance of an oscillator consisting of spherical capacitors (C) coupled to the inductance of conducting rods (L), extended in space, see Fig.1. He knew perfectly well how this oscillator would perform and calculated its frequency, employing in modern notation, $f = 1/2\pi\sqrt{LC}$. He was averse to Maxwell's "vector potential A" and proceeded to invent a new quantity, which, when later placed into vector notation, became the Hertz vector in Fig.2.

With Π he analysed the radiation to be expected from the oscillating dipole he had set up, obtaining all the terms, (the 'static' field, the 'induction', or near field and the 'radiation', or far field). He went on to discuss the radiation resistance in terms of the damping effect to be expected in his oscillator, "even if the conductors themselves were resistanceless"[5].

During the course of the experiments, Hertz was fully aware of the need to employ *resonance* or, as he called it, *tuning* in the receiving apparatus. This he did by selecting the dimensions of the receiving loop aerial and by using a variable capacitor at its poles, as shown in Fig.3.

It is ironic that, many decades later, the magnetron using small Hertz resonators made a huge contribution to defeating the Nazis ruling his fatherland at the time of the World War II. Figure 4 shows them clearly.



HERTZ'S POWER OUTPUT

The quoted extract from Hertz's paper shows in a fascinating way how advanced and rigorous he was in the business of explaining what he had accomplished. Though he had no interest in the engineering applications of his results, nevertheless nearly all the design data was there for the development of a radio telegraphy system. As we know, Professor Righi at Padua was most interested in Hertz oscillators, and during his many demonstrations, the young Guglielmo Marconi often sat in the audience. Telegraphy to ships at sea and ultimately telegraphing the Morse Letter "S" across the Atlantic soon followed – although Hertz was never to see these results.

The power radiated from a Hertzian Dipole is[6],

$$W=\frac{\eta_0\beta^2\hat{I}^2 l^2}{12\pi}\text{ watts}$$

where $\eta_0=\sqrt{\mu_0/\epsilon_0}$ = 377Ω, the characteristic impedance of free space. β is the phase constant $2\pi/\lambda'$, with λ' equal to the wavelength in metres. (Hertz tended to use λ for the *half* wavelength in all his papers, which makes a preliminary reading of them quite difficult.) $\hat{I}$ is the peak current, and the l the dipole length.

The oscillating charge Q, relates to the peak current $\hat{I}$ via,

$$Q=\int_0^{\frac{1}{2}}\hat{I}\sin\omega t\,dt=\frac{\hat{I}}{\omega}$$

where ω as usual = $2\pi f$ with f the frequency in hertz. The time of one cycle is T/2 or 1/2f, so that:

"...we get for the energy which goes out through the whole sphere during a half-oscillation

$$\tfrac{1}{3}E^2l^2m^3nt = \pi^4E^2l^2/3\lambda^3.$$

Let us now try to deduce from this an approximate estimate of the quantities actually involved in our experiments. In these we charged two spheres of 15 cm. radius in opposite senses up to sparking distance of about 1 cm. If we estimate the difference of potential between the two spheres as 120 C.G.S. electrostatic units (gm.$^{1/2}$ cm.$^{1/2}$ sec.$^{-1}$), then each sphere was charged to a potential of ±60 C.G.S. units, and therefore its charge was E=15 × 60 = 900 C.G.S. units (gm.$^{1/2}$ cm.$^{3/2}$ sec.$^{-1}$). Hence the whole stock of energy which the oscillator possessed at the start amounted to 2 × ½ × 900 × 60 = 54,000 ergs, or about the energy which a gramme-weight would acquire in falling through 55 cm. The length l of the oscillator was about 100 cm., and the wave-length about 480 cm. Hence it follows that the loss of energy in the half-period of oscillation was about 2400 ergs. It is therefore evident that after eleven half-oscillations one-half of the energy will have been expended in radiation. The rapid damping of the oscillations, indicated by our experiments, was therefore necessarily determined by the radiation, and would still occur even if the resistance of the conductor and of the spark became negligible.

To furnish energy amounting to 2400 ergs in 1.5 hundred-millionths of a second is equivalent to working at the rate of 22 horse-power. The primary oscillator must be supplied with energy at fully this rate if its oscillations are to be kept up continuously and with constant intensity in spite of the radiation. During the first few oscillations the intensity of the radiation at a distance of about 12 metres from the primary conductor corresponds to the intensity of the sun's radiation at the surface of the earth."

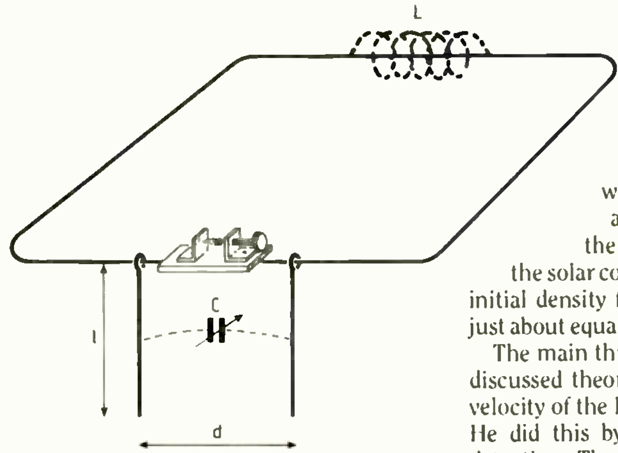


Fig.3. Hertz reports on his experiments with "tuning". "The easiest way of adjusting the capacity of the secondary circuit was by hanging over its two ends two parallel bits of wire and altering the length of these and their distance apart". "Exactly similar results followed when the poles of the secondary circuit were connected with the plates of a Kohlrausch condenser".

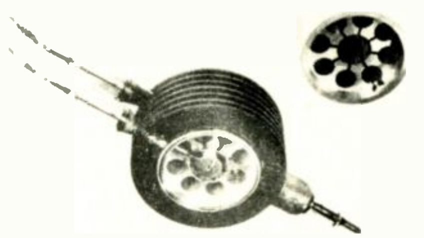


Fig.4. The cavity magnetron, devised by Randall and Boot, contains small, interconnected Hertz resonators, excited directly across the capacitive gaps.

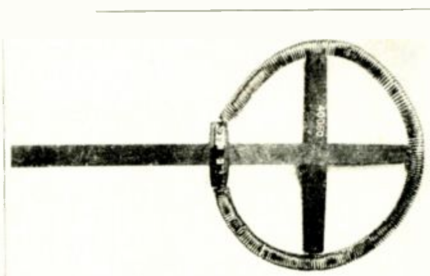


Fig.5. This interesting device shows that Hertz experimented with inductive loading, or (see text) possibly the slow-wave properties of spirals.

Hertz correctly states this would be the required power of a c.w. transmitter to maintain the radiation. Then he calculates the solar constant S, and claims that the initial density from his aerial at 12 metres just about equals S.

The main thrust of the experiment Hertz discussed theoretically was to measure the velocity of the EM waves he was generating. He did this by interference and antinode detection. The clear reporting of problems connected with working close to the oscillator were covered in his grasp of near and far field effects. Most of the techniques and principles he reported, still apply to anyone starting aerials research today.

In the same paper, Hertz discusses single-wire, waveguide-mode propagation, and perhaps slow-wave modes on spiral wires, which later enabled techniques of travelling-wave amplifiers to be developed. Alternative interpretations of his spiral wire pickup loops shown in Fig.5 include the obvious one that he had reduced the size of resonators by utilizing self-inductance.

There is a fascinating question Hertz did not directly answer. The magnetic axis of a single open loop is perpendicular to the plane of the loop, so Hertz would have held it so that the magnetic vector of the EM wave coupled a maximum changing flux through the loop. But in the case of his spiral-conductor loop, the magnetic axis runs along the centre line of the toroid so produced. The **E**, (and therefore **D**) vector would now require to be threaded through the loop, so that via curl$\mathbf{B}=\partial\mathbf{D}/\partial t$ the required coupling would have been maximized again – the integral of curl **B** now circulating a changing magnetic flux through the turns of the toroidal loop.

Thus was started the remarkable research school I reviewed some time ago[7], with all the paradoxes mentioned there. The "Hertzians" as this school became called, carried out most of the work to establish microwave optics. The results peaked, then the efforts fell away, deserted, because the long-wave "wireless telegraphers" began to achieve their spectacular success with waves three or four miles long. The importance of the "useless" short waves had to await the discoveries of radio amateurs decades later, and the microwave engineering revival brought on by the second world war.

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5. Ref. 1, page 150. See also the quoted extract.
6. See Ref. 5.
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The NEW ORYX PORTASOL PROFESSIONAL is a unique cordless soldering iron that fits comfortably and safely into the pocket. It offers up to 120 minutes of continuous operation with a choice of 7 tips including a HOT GAS TIP and a FLAME TIP
Butane-powered using standard gas lighter fuel and easily refillable, the PORTASOL PROFESSIONAL provides total portability free from trailing leads and the need for a power point.
ORYX PORTASOL 'ORIGINAL'
Similar in specification to the 'Portasol Professional' with a choice of 4 soldering tips and knife tip.
The unit is completely self-contained, featuring a lighter mechanism in the cap with which to ignite the tip.
Equally at home in the field or workshop environment, the PORTASOL PROFESSIONAL's gas energy source removes all risk of electrical damage to sensitive components.
THE PORTASOL KIT
Each 'PORTASOL PROFESSIONAL' Kit comprises:
Carrying box
Safety stand
A hot knife tip
A hot gas tip
A gas flame tip
Cleaning sponge
Portasol Professional gas iron with 2.4mm tip
The only truly pocket-portable gas iron
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For further details on both the Oryx Portasol Professional and Oryx Portasol Original, please contact:
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ENTER 26 ON REPLY CARD

Remotely controlled RC oscillators

Final design steps towards a precision Wien bridge oscillator

A.J.P. WILLIAMS

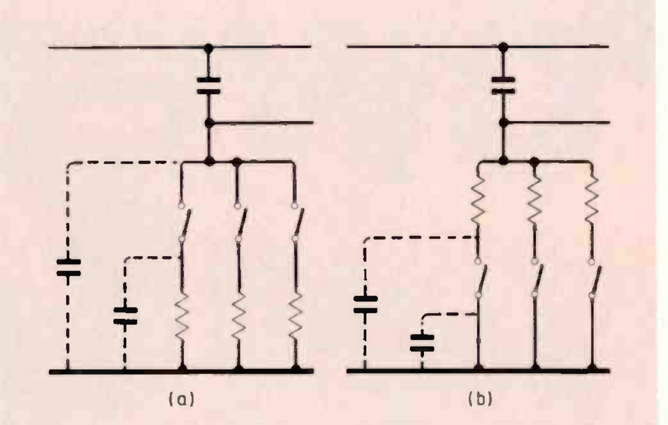


Fig.15. Switching capacitance effects for either switching method.

From past experience I knew that the capacitance of the analogue switches would give errors on the 100kHz to 1MHz range. The switch can be placed as in Fig.15(a) or as in Fig.15(b).

The bulk of the stray capacitance in the analogue switch is from either side of the switch to earth. Figure 15(a) gives maximum capacitance across the resistive arm when the switches are closed and minimum when they are open. The configuration in Fig.15(b) gives negligible capacitance effects when the switches are closed, but when they are open there is a series RC combination across the active resistors as in Fig.16. At the oscillation frequency, the stray series components C_1 and R_1 can be replaced by their parallel equivalents R_1' and C_1', as shown in Fig.17. C_1' will only have a small effect on the frequency, but R_1' will move the frequency significantly, especially at frequencies where the reactance of C_1 is equal to the resistance of R_1.

The above effects can be almost completely eliminated by using a two-way analogue switch and a boostrapping circuit, as shown in Fig.18. Providing $C_1 \gg C_s$ in Fig.18, where C_s is the stray switch capacitance, then the alternating voltage across any resistor switched to its right-hand contact is very small. This results in a negligible current drawn by any resistor that is switched out of circuit; hence, it has a negligible effect on frequency or amplitude.

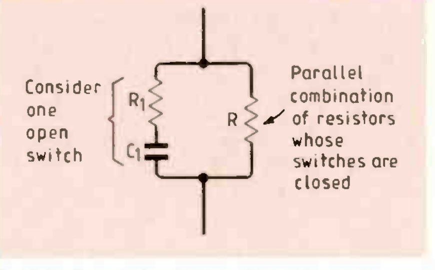


Fig.16. Equivalent circuit of "open" analogue switches.

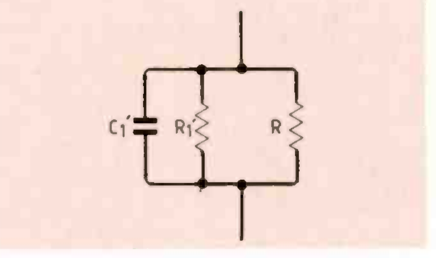


Fig.17. Parallel version Fig.16 circuit.

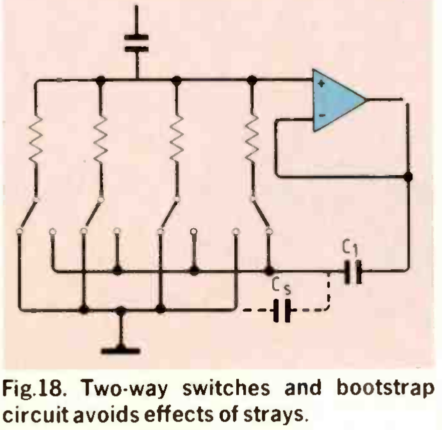


Fig.18. Two-way switches and bootstrap circuit avoids effects of strays.

THE FIRST COMPLETE CIRCUIT

The complete circuit based on Fig.5 (October, page 987) is shown in Fig.19. The circuit was constructed on a printed circuit board using LM6361N op-amps, which have a gain bandwidth product of 35MHz and a full-power bandwidth of 4.5MHz.

This time, the unwanted high-frequency oscillation was more persistent and occurred on all except the highest frequency range. Many methods were tried to introduce sufficient loss at the unwanted oscillation frequency (about 10MHz) but they all caused excessive phase shift and hence frequency shift at 1MHz. A 2nF capacitor connected between the output of amplifier A_3 and earth was sufficient to prevent unwanted h.f. oscillation on all ranges, causing excessive frequency error on range 5 only. Hence, diodes D_6 and D_7 were used to switch the capacitor out of circuit on range 5. This was achieved by switching point A to a +5V supply for ranges 1 to 4 and a −5V supply for range 5. The logic controlling S_1 and S_2 can be decoded to provide a signal suitable for switching D_6 and D_7 on the appropriate ranges. The analogue switches were operated with supply lines of ±5.1V obtained from 5.1V zener diodes, which provide suitable voltages for switching D_6 and D_7.

RC circuits C_{12}, R_1 and C_{13}, R_2 provide phase-advance networks to compensate for phase lag introduced by amplifiers A_1, A_2, A_3 and the stray capacitance in R_4 and R_5 at the high frequencies.

Amplitude control. R_4 is a cadmium sulphide photo-conductive cell, which has peak response at about 0.62μm and an active area of approximately 5.3×5.3mm. I used a high-brightness led (500 mcd at 20 mA) to illuminate R_4: the led has a peak output at 0.68μm and therefore is a good wavelength match for R_4.

The viewing angle for the led is 70°, so by mounting the led and R_4 inside an opaque tube a few millimetres apart, almost all the light output of the led illuminates all the active area of R_4. The combination is such that amplitude control can be achieved with less than 1mA of current flowing in the led.

Amplitude control proved to be more stable with full-wave rectification than half-wave and the use of A_7 as a differential amplifier enabled the full-wave bridge to be used on the unbalanced output of amplifier A_6. It is possible to use the led directly in the bridge circuit, but then the discharge time constant varies as the current through the led varies. In Fig.19, both charge and discharge time constants can be adjusted to achieve good stability. The gain of A_6 can be adjusted R_3 to set the output amplitude to a convenient level.

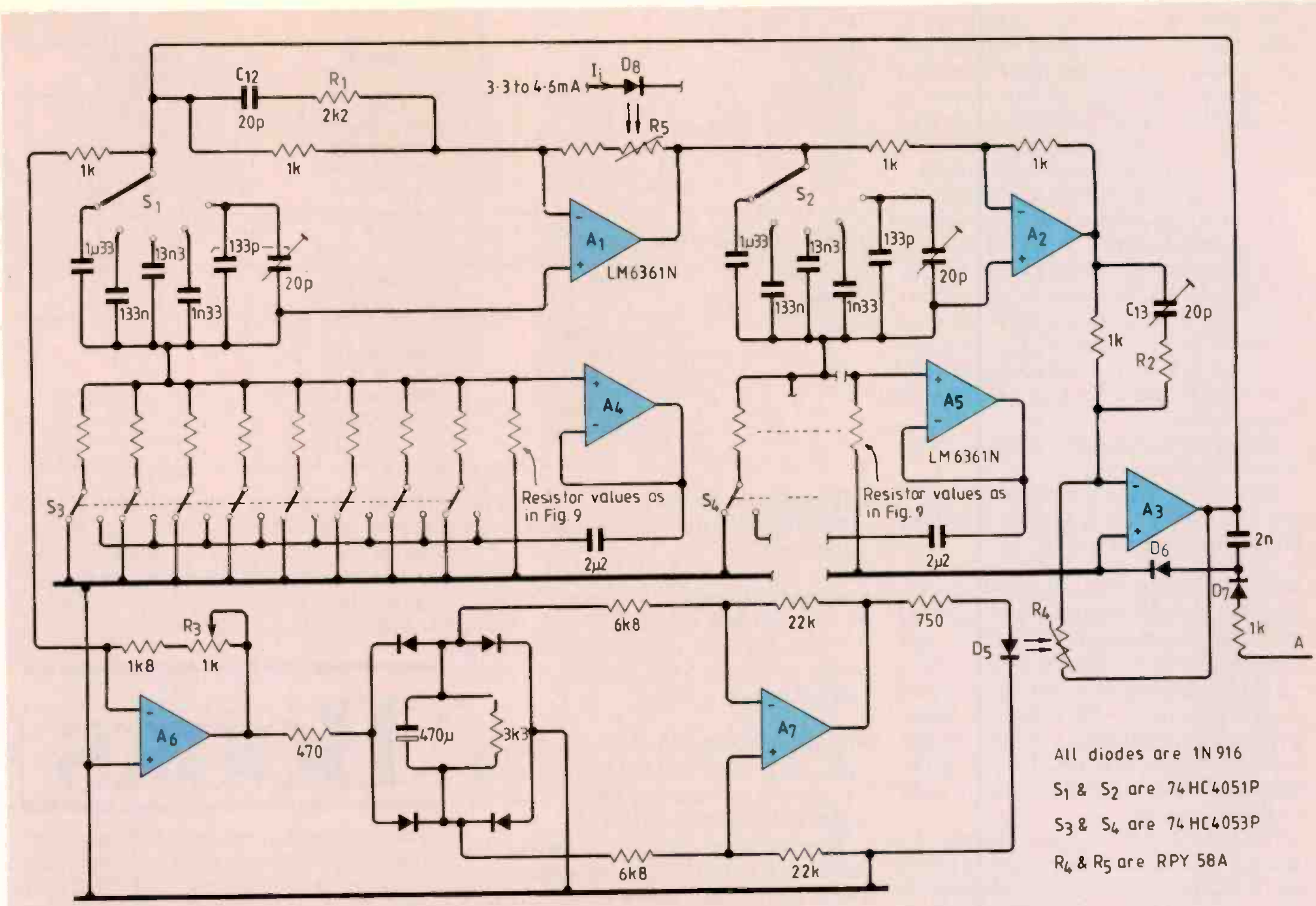
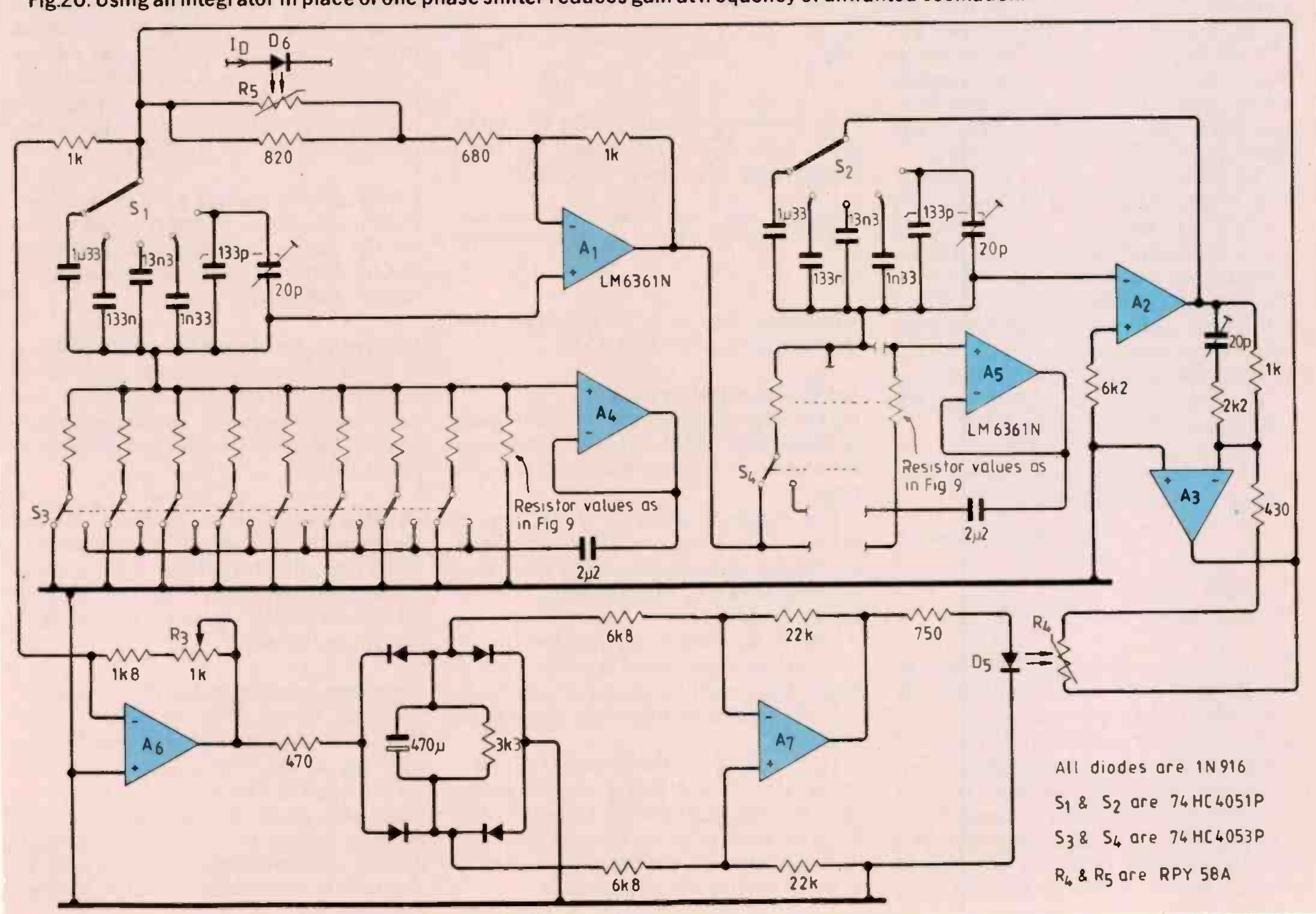


Fig.19. Final circuit, based on arrangement of Fig.5 (October issue, page 987).

Fig.20. Using an integrator in place of one phase shifter reduces gain at frequency of unwanted oscillation.



A resistor of 430 ohms was included in series with R_4 to force it to stabilize at a lower value, which reduces the effect of stray capacitance within R_4. If this resistor is increased to a higher value, the capacitance effects are reduced even further, but only at the expense of reduced amplitude control.

The D_8 and R_5 combination of led and cadmium sulphide cell is exactly the same as for D_5 and R_4. Current I_1 was set to about 4.2mA to make the resistance of R_5 such that the frequency is the nominal value determined by $f=1/2\pi CR$. Increasing the value of I_1 reduces the resistance of R_5, which reduces the gain of A_1 and hence lowers the frequency. Similarly decreasing I_1 increases the frequency.

The percentage change in frequency is the same for all frequencies.

Obviously, current I_1 must be very stable and free from noise to prevent frequency drift and frequency jitter.

Alternative circuit. The problem of preventing unwanted high-frequency oscillation led me to the circuit shown in Fig.20. In this circuit one of the 90° phase shifters has been replaced by an integrator, which gives 90° of phase shift over a wide frequency range. Switching the input resistors to the integrator is only necessary to keep the gain of the integrator close to unity and hence limit amplitude variation.

The gain of the integrator naturally reduces as the frequency is increased (providing the component values are not changed) and this makes the gain too low to sustain unwanted high-frequency oscillation.

As the circuit of Fig.20 has only one frequency-determining network compared with two networks for that of Fig.19, then its frequency stability must be approximately halved. However, the frequency stability is adequate for most purposes and the circuit does have a few advantages as listed below.

- The initial setting up is easy. For example, the larger capacitors such as C_1 are usually at best ±5% tolerance. In this circuit, C_1 only is trimmed to give the correct frequency, then separately C_6 can be trimmed to give the same amplitude to range 1 as for the other ranges where the component tolerance is closer.
- The gain of the integrator is $1/\omega CR$.
  The gain of the phase shifter with fine frequency control (Fig.13) is

  $\sqrt{(R_2/R_1+1)/(R_1/R_2+1)}$ at a frequency given by $f=\sqrt{R_2/R_1}/2\pi CR$.

  When the phase shifter and integrator are used together the gain is

  $\sqrt{(R_2/R_1+1)/(R_1/R_2+1)}\times 1/(\sqrt{R_2/R_1}/CR)=1$.

  As a result the adjustment of R_2 produces a change in frequency without producing any overall amplitude variation.
- The amplitude control is good throughout the frequency range and when the temperature is varied. The inclusion of R_1 in series with the main frequency-determining resistors compensates for a small frequency error due to analogue switch resistance in series with the integrating capacitors.

Table 1: performance of the circuit of Fig. 19.

Time after switch on	conditions	frequency	change in frequency
23 min	0.1V supply change	1MHz	≈ 10Hz
30 min	supply varied 12.5V to 16V	100kHz, range 5	<5Hz
35 min	supply constant at 15V	100kHz, range 5	±1Hz over > 10 min period
45 min	supply constant at 15V	100kHz, range 4	±3Hz over > 10 min period
60 min	supply constant at 15V	1MHz	distinct moving cycles for >4 min

Table 2: performance of the circuit of Fig.20.

Time after switch on	conditions	frequency	change in frequency
> 30 min	0.05V supply change	1MHz	≈ 10Hz
"	supply varied 15V to 16V	100kHz, range 5	< 5Hz
"	supply varied 14.2 to 14.6V	100kHz, R4	< 5Hz
"	supply constant at 15V	100kHz, range 5	± 5Hz over > 6 min period
"	supply constant at 15V	100kHz, range 4	± 5Hz over > 8 min period
"	supply constant at 15V	1MHz	distinct moving cycles for > 1 min

- If amplitude variation can be tolerated, then the integrator capacitors could be 5% tolerance.

Frequency accuracy. On a frequency counter, all switched frequencies were within +/−2%, about 90% of the frequencies being within +/−1% for both circuits over the full range of 10Hz to 1.3MHz.

Frequency stability. No buffer amplifier was used. The frequencies were checked against a temperature-controlled crystal oscillator using Lissajous figures (Table 1,2)

The circuit of Fig.20 was checked for harmonic distortion using a wave analyser at a time when R_5 was a conventional resistor.

Frequency	2nd	3rd	4th	5th	harmonic
100Hz	−54	−41	<−60	−57	
1kHz	−57	−41	<−60	−58	dB relative
10kHz	−50	−41	<−60	−56	to fundamental
100kHz	−51	−43			
450kHz	−41	−48			

By increasing the value of the resistor in series with R_4 to 730 ohms, the third harmonic was improved as shown below.

Frequency	2nd	3rd	4th	5th	harmonic
100kHz	−45.7	−47.2	−64	−69	dB relative to the fundamental

This change resulted in the amplitude control being reduced to about ±5%.

Amplitude control for Fig.20.
Initially, the amplitude was set to 2.0V peak at 5kHz. The upper and lower frequency amplitudes were then measured on each range.

The voltage amplitude of all frequencies measured lay within ±2.5% of the 5kHz amplitude. These results could have been improved with finer adjustment of the integrating capacitors.

The oscillator was then placed in a domestic refrigerator and cooled to +10°C. After 2 hours, the maximum change in amplitude was 1% relative to the room-temperature amplitude.

The oscillator was then removed from the refrigerator and a soldering iron held under the D_5/R_4 combination until the two components felt warm to touch. The amplitude had then only moved a maximum of 1% relative to the room temperature amplitude.

A further improvement in frequency accuracy, frequency stability, harmonic distortion and amplitude control can be expected for the circuits discussed in this article, when designed with mechanical rather than analogue switches, compared with the results quoted above.

BOOKS

Electronic engineering index. Technical Indexes Ltd (Willoughby Road, Bracknell, Berkshire RG12 4DW, tel. 0344-426311): a £60 subscription (£90 overseas) brings three issues, published in March, July and November. Product locator and address book, an index to a series of component catalogues on microfilm. Publisher offers a comprehensive range of index services both on-line and on fiche or film, covering British, European and American industry, documentation and technical standards.

CMOS circuits manual by R.M. Marston. Heinemann, £9.95. Beginner's book covering the various functional groups of cmos devices. At the back is a miscellany of useful circuits. Soft covers, 190 pages.

Electronics for electricians and engineers by Ian R. Sinclair. Heinemann, £9.95. Non-mathematical treatment of electrical and electronic theory and circuit operation, aimed at the newly-qualified technician. Soft covers, £9.95.

Oscilloscopes: how to use them, by Ian Hickman. Heinemann, £5.95. Extensively illustrated with photographs and diagrams. For sixth-formers, ONC/HNC students and others who require a practical introduction. Soft covers, 133 pages.

Transistor selector guide and **Power selector guide** by J.C.J. van de Ven. Bernard Babani, £4.95 each. Alphanumeric listings covering, in the two volumes, over 2400 Jedec, JIS, Pro-Electron and branded devices; plus selection tables and charts of package outlines and leadouts. The volume dealing with transistors includes a conversion table for decoding markings on surface-mounted devices. Pocket size, soft covers.

FEEDBACK

Underground radio

South Africa is undoubtably a leader in mining technology and Dr Austin's article *EWW*, September 1987 draws attention to work in the underground radio field in that country. In view of the political climate, this is laudable but he is guilty of the omissions and errors about which he complains in other publications.

The principles of Wadleys "invention", particularly the Tellurometer, were not sufficiently novel to allow worthwhile patents to be obtained. This prototype design submitted to us in Cape Town by the NITR (CSIR) was a disaster insamuch as the units were poorly designed and the principle used resulted in serious measurement errors. It was left to the undersigned to redesign the units and change the method of operation to obviate the serious errors and this work led to the present design of the Tellurometer, which is a very fine instrument.

With reference to underground radio and Dr Martin's letter in *EWW*, January 1988, his suggestion of "rediscovery" is relevant inasmuch as in 1961 at the request of the S A Chamber of Mines I designed a "transistorized" communication system using s.s.b. at around 70kHz. I was only advised recently that Messrs Blignaut and Vermeluen had made a valve unit using a.m. at around 300 MHz, although one of these gentlemen actually conducted the tests on my unit in extensive gold and coal mines in which we ran out of space. S.s.b. was used mainly because of the high power efficiency – an important point when batteries are used as power sources.

The low radio frequency was chosen because (i) the transmission loss through rocks is smaller at lower frequencies, (ii) the transmission loss is lower when conductors are present, e.g. railway lines, power cables, etc., (iii) the s.s.b. filter system is greatly simplified (I can see little point in using commercially available filters as this results in complications), (iv) I never believed the aerial inefficiency loading factors applied to Wadley's curves and (v) no clarifier (fine tuning) is required. The increased transmission loss at higher frequencies can be deducted from the lower peak-to-peak values of the standing waves shown in Dr Austin's article and I make the guess that if the flow of water he mentions was stopped or deflected the resulting curves would not be altered appreciably.

Mr Lord, *EWW*, May 1988, reminds us that the e.m. waves radiated from a loop aerial are of low level. However a multi-turn loop aerial is efficient in coupling to or from transmission lines comprising railway lines or other conductors as I demonstrated over 25 years ago.

Thus there is a good case for the use of lower radio frequencies and s.s.b. for underground radio particularly as, in large mines, railway lines, waterpipes electric conductors and compressed air pipes usually extend to the working faces and can assist in reducing the transmission loss. Nostalgic humour reminds us of a previous underground case in which to reduce transmission losses the frequency was lowered from 50Hz to 25Hz at Charing Cross.

In view of the foregoing perhaps I should state that I am in no way commercially involved in the Tellurometer or underground radios (any offers)?

F.G. Clifford
Wetton
South Africa

The Subjectivist Manifesto

Predictably, Doug. Self's article has provoked correspondence on this thorny topic. Great though my respect for John Linsley Hood is, I regret his letter in the September issue because he has unwittingly thrown crumbs of succour to the Subjectivist sparrows. They will peck eagerly at what he's said, as further evidence that The Engineers Don't Always Know What They Are Doing. John's generous evenhandedness is wholly admirable; but a tactical error, nevertheless.

Let me try and put it all in perspective. As I write, I have just dug out of my archives an article I was commissioned to write for *Wireless World* and published June 1969. It analysed the state of audio amplifier design at that time and covered comprehensively, so I thought, the matter of crossover distortion. It even included a cover picture in colour showing this objectionable artefact! It was also my impression that everyone by then was familiar with the concept, that any amplifier design using n.f.b. had to preserve the essential characteristics of such feedback under both static *as well as dynamic* conditions. Moreover, there were plenty of test techniques to ensure that obtained. It was my view at the time that most of the important problems of transistor audio amplifier design had been solved.

In any case, what hiccups did occur arose during the earlier transition into the semiconductor age. A new, younger generation of design engineers had emerged and were, 'tis true, fully *au fait* with the technology; but many were totally unfamiliar with the requirements of high-quality audio amplifier design. Some had never even heard of crossover distortion.

This, sir, was almost two decades ago!

With our disciplined engineer's approach, we run the risk of missing the real differences between us and the Subjectivist trendies, because we can furnish all the objective data we like and they still won't believe us. Why? Simple, because one of their tenets of faith is that There Are Phenomena We Don't Understand and Won't – Ever. Another tenet is one that real engineers will regard as fatally flawed – that the human ear must always be the final arbiter of whether the sound is acceptable or not. Note, I did *not* say faithful or otherwise and for good reason. Emotional content enters into it in a way that I, certainly, have never understood; perhaps a clinical psychologist can explain it. It is useless insisting that as a qualitative assessing instrument, the human ear/brain interface is insufficiently consistent; and as far as quantitative assessment goes, almost useless. Nevertheless, for purposes of argument, it may be regarded as a measuring instrument of sorts, so long as one observes the golden rule I drum into my students – if two measurements don't agree, then one or even both are certainly wrong. Again, a concept the Subjectivists will never understand, even if they wanted to.

As I said in my earlier letter, we can do nothing about the ex-shop assistants. Our target must be those who ought to know better; those who suggest, for example, that a minimum of n.f.b. is a Good Thing; or even obliquely, lend credence to all this cable and fancy capacitor rubbish. The latest lunacy is a passive preamplifier, a contradiction in terms if there ever was one and a real con. There is not one specialist hi-fi publication in this country that offers to its readers competent and reliable engineering expertise. Happily, this trend appears to be in reverse in the USA and at least two respected magazines are now firmly rejecting the irrational myths that are so avidly promoted in the UK by the less responsible sections of the industry and its sycophantic press friends.

Finally, in our attempts to eliminate this parasitic blight on the science and craft of audio, we need to preserve a sense of humour; and to this end, I must repeat my favourite true story. A well-known "professional reviewer" was lobbying a senior figure from a leading audio manufacturing company, seeking to evaluate their latest product – an audio amplifier. The senior figure, who had a somewhat jaundiced view of the reviewing profession, eventually responded – tongue well in cheek – with "Well, yes, you can – if you compare it with a piece of straight wire". Pause.... and came the apprehensive answer "What sort of wire?"

Reg. Williamson
Kidsgrove
Staffordshire

Firstly, I would like to say how pleased I was to see Douglas Self's article in the July edition of *E&WW*. One feels impelled to say that such a breath of sanity is long overdue in the now crazy world of audio criticism.

I do, however, take the point made by Reg. Williamson (September Feedback) that because this superlative article has appeared only in the pages of *E&WW*, Mr Self is preaching largely to the converted.

FEEDBACK

Notice that I use the term "largely", for in the very same letters column we are treated to the views of Mr J.L.Linsley-Hood, and it appears that Mr Linsley-Hood is far from being converted. I can only say, and I make this statement as an amateur electronics enthusiast, that I find the views expressed by JLH, almost unbelievably naive.

After re-iterating the oldest chestnut in the subjectivist litany – that steady-state measurements do not tell us enough about an amplifier's dynamic performance – Mr Linsley-Hood then invites us to contemplate the possibility that the humble capacitor may possess as yet unexplained manipulative properties when confronted with music signals.

What I find so unacceptable about the above arguments is that they are propounded without any reference to the tests outlined by Mr Self which demonstrably prove that these 'effects' do not in reality exist. I refer of course to the Baxandall cancellation technique and the Hafler 'staight wire' differential test. Perhaps Mr Linsley-Hood would like to comment on this.

Steve Price
Bethel
Caernarfon
Gwynedd

I too read Douglas Self's excellent article (July 1988), as well as the subsequent correspondence, with great interest; but it was forcibly brought home to me last week just how far the spreading of pseudotechnical misinformation has gone when I was in the local branch of a nationwide firm specialising in p.a. equipment. I had to wait to be served while the resident expert demonstrated a range of speaker systems to a would-be purchaser (who, I think, was a disco or night club operator); this was done at sound levels well over 100dB, making comparison impossible (to my ears) – but that's beside the point.

While the bemused customer pondered the choice, the following pearls of wisdom were offered by our friendly man behind the counter. One particular design of h.f./l.f. enclosure has the bass unit set a couple of inches forward of the tweeter "because high-frequency sound travels slightly faster than low-frequency". (I felt it would be rude to butt in and suggest that the same compensation might have been made more cheaply by using a longer cable to the treble unit.)

Another design of combined enclosure, employing the familiar vertically split h.f. horn above a sealed (infinite baffle) bass cabinet, was designed this way "to economise on bass amplifier power, sealed cabinets being much higher in efficiency than horns".

Needless to say, the customer appeared perfectly satisfied with these explanations; I was only thankful that I had gone into that shop knowing exactly what I wanted, and why. It does seem at times that the world has gone completely mad.

F.J.P. Crampton
Carlton
Nottingham

An audio system is "linear" in the mathematical sense if, given any two input waveforms $I_1(t)$ and $I_2(t)$ from which separately it generates the output waveforms $O_1(t)$ and $O_2(t)$, it generates from the sum of the two input waveforms the sum of the two output waveforms. The input and output waveforms need not show any obvious similarities. The transient response of a linear system can be deduced from its frequency/phase response, so that if both types of measurement are made on a system which is linear they must yield compatible results. From J. Linsley-Hood's September letter it is not clear whether he is asserting that different linear audio systems may have different transient responses, which noone denies, or instead that for many audio systems the measured transient response fails to agree with the transient response predicted from the frequency response for a linear system. In the latter case the system *must be nonlinear*, and if capacitors are the components responsible then measurements such as those carried out by D. Self (July letters) can be expected to show non-zero t.h.d.

B. Duncan's series of articles on capacitors[1] in *HiFi News* describes how the behaviour of real capacitors of various types departs from that of ideal capacitors. Some of these deficiencies, dielectric absorption for example, may be consistent with the mathematical definition of linear behaviour. In general, his conclusion that capacitor types for particular applications must be selected with their limitations in mind seems inescapable. However I would want to see clear evidence for his assertion that occasional bursts of noise with a d.c component applied to a conditioned electrolytic capacitor can change its behaviour for an appreciable period.

In an article in the same journal [2], M. Hawksford pointed out that in coaxial cables the skin effect is beginning to become appreciable at the upper audio frequencies. He interpreted the particular solution he used for the radial variation of current in a linear conductor as representing a wave travelling inward from the surface of the conductor at a speed which for a fifty cycle signal in copper is as low as 3 m/s, and on this basis claimed that, if the driving signal were cut off, the currents instantaneously present in the conductor would collapse outward through the skin depth at speeds of this order, providing a worst-case 'memory' for a 1mm diameter wire of a few hundred microseconds. The much more direct time-domain calculation for a 1mm diameter copper wire with a resistance of about 2×10^{-4} ohm per cm and an inductance of about 1 nH per centimetre makes the time constant for rearrangement of local current irregularities a mere 5 microseconds. Thus those who "cite conductor and interconnect performance as a limiting factor within an audio system" do so without any physical justification for their views.

C.F. Coleman
Grove
Oxfordshire

References

1. B. Duncan, Series 'With a Strange Device', *Hi-Fi News*, 1986.
2. M. Hawkford, *Hi-Fi News* 30 (1985) 27-33.

Flow charts

Attention all digital hardware engineers; Mr Pratt (June Feedback) has revealed that all those 7400 Nand gates you have been using are a fiction; they are "inherently impossible and...cannot exist". Apparently the words he uses in his computer programs are what reality is all about.

I suspect that it is something to do with the stigma attached to blue-collar work (using soldering irons, etc.) that leads programmers (white-collar workers) to believe that their programs are more real than the machines they run on. The difference between hardware and software, Mr Pratt, is that software (as is is done now) is a pathetically inefficient representation of what the hardware will do when it is switched on.

D. Celano (also June Feedback) says that circuit diagrams "show all the physical information about a circuit with the exception of the actual p.c.b. layout...whereas flow charts in no way show all the program details". Turning that very page I saw a circuit diagram showing an integrated circuit as a blank rectangle; no physical information there.

Sometimes a circuit diagram reduces to a block diagram as simple as microphone-amplifier-speaker. Or else it can be very detailed, even showing the p.c.b. tracks (very important at higher frequencies). Circuit diagrams, flow charts and computer programs are simply convenient forms for representing and thinking about real machines. The detail they are drawn in depends on their intended use, all can be either very simple block diagrams, or else very detailed showing the "cogs" of the machinery. When doing detailed work it is best that the representation is close to the real thing. So when developing a new product it is bread-boarded (i.e., represented in the three dimensions of space and the changeability of time) so that any unforeseen bugs in the paper design can be seen in the round.

Programming languages are about as far from the real thing as is possible, being one dimensional "wavy lines". Circuit diagrams and flow charts are more than half way there, being two and a half dimensional (the

FEEDBACK

"half" dimension being the convention for crossing lines that are not connected). But with available technology we can do even better.

Imagine programming your latest version of a flight simulator. You are unhappy with the operation of one of the cockpit instruments appearing on the screen, so you take your programming tools, lift the lid off the instrument, find that it consists of a number of integrated circuits ("subroutines"), lift the lid off the offending circuit, RUN THE CIRCUIT to determine its operation and timing, move a few wires and transistors around (alter the "machine code"), put the lids back on, and you have an instrument that does just what you want. Just like working with the real thing, only much easier.

Try doing that with your wavy lines, Mr Pratt. And Celano, if you do not wish to dirty your hands on the "cogs...hidden from the programmer" then you will have to make do with what others give you.

The absymally slow von Neumann architectures of current computers would not do justice to the above program; a more flexible arrangement of wires and switches would be better. But that is another story.

A. Medes
D.Y.
Australia

Dimensions and definitions

Mr S.K. Chatterjee in his interesting article "A Dimensional Approach to Unified Theory" in the September issue of *E&WW*, on the one hand makes it clear that he is rejecting all but one definition of the word 'dimension', whilst on the other hand he fails to give us the definition he has selected. Hence, as in all cases, in all walks of life where one or more words are left undefined, confusion results.

If he has taken as the definition 'a degree of freedom' which is sometimes done implicitly, how than are we to interpret the various ratios such as L/T and $L^3/L = L^2$?

This failure to define words is extremely common in the writings of theoretical physicists. Mass, energy, time, and dimension have no definition. (This is despite the 'definitions' given in science dictionaries, which fail because they define all the key words in terms of each other.) It should be realised that for progress to be made in understanding, almost a dirty word in physics these days, definitions must be agreed upon, even though they may at a later time be changed for other agreed definitions. In other words, it is vital to have definitions right or wrong, otherwise chaos results: witness the current state of quantum mechanics etc.

David A. Chalmers
Finchley
London N1

I see the argument on dimensions advanced by Chatterjee in the September 1988 issue of *EWW* as another attempt to step away from reality and into a world of abstraction.

Einstein has done enough damage in trying to explain physical phenomena in terms of a dimensional distortion of space L^3 and time T.

If G is to be dimensionless and mass has the dimensions L^3/T^2, may I ask how the mass of a brick is to be quantified? Given that both L and T are measured in terms of the size and rate of rotation of the Earth, are we to suppose that the mass of a brick can be defined without reference to a unit of mass such as Earth mass?

Chatterjee's substitution $m = L^3/T^2$ is purely arbitrary. In physics it needs three *physical* equations to eliminate M, P and E from five quantities P, E, M, L and T and leave two unknowns L and T. Chatterjee uses two physical equations (Newton's force law for P and Einstein's energy law for E) and one that has no physical foundation at all.

Surely the energy crisis is not so bad that we have to eliminate it and its mass equivalent from the dimensions of physics. I am all for making changes to improve science, but this is one change that is not feasible.

H. Aspden
Department of Electrical Engineering
Southampton University

Smith charts

In his August article on Smith charts, Joules Watt makes a welcome plea for the geometrical tradition, because it harnesses the sense of sight so effectively to the process of learning. The Smith chart exploits inversion. The geometrical definition of the inverse of a point with respect to a circle makes it the point on the same radius vector which is such that the radius of the circle is the geometric mean of the radial distances to the two points. The inverse of a curve is just the locus of the inverses of the points which make it up. The inverse curves of circles and lines are circles and lines.

If now one looks in the complex plane at a set of complex numbers which trace out any particular curve, the points representing the reciprocals of the set of numbers trace out another curve, which is closely related to the inverse of the original curve with respect to the circle of radius unity centred at the origin, being the *reflection* of the inverse curve in the X-axis.

The phasors which represent currents and voltages varying sinusoidally at a particular frequency are two-dimensional vectors. Despite Joules Watt's Figs A1 to A4, they do not have reciprocals. The Smith chart, however, is concerned with impedances, which are two-dimensional vector operators, and do have reciprocals and products. Though phasors and impedances can both be modelled by complex numbers, only impedances show behaviour corresponding to the multiplication and division of these numbers.

In the November 1987 Letters, I pointed out that, although in three dimensions there is a traditional definition of vector multiplication, *c.f.* the Poynting vector **cExH**, there is no associated definition of vector division. There are in fact two distinct types of 3-D vector. The vector product of a force **F** and the radius vector **r** from a point on its line of action to a fulcrum represents the torque **T** which the force exerts about the fulcrum. **F** and **r** are 'polar vectors' having 'negative parity', i.e when viewed in a mirror their components perpendicular to it change sign (*c.f* the behaviour of two-dimensional vectors reflected in a line). **T**, however, like **H**, is an 'axial vector' with 'positive parity', i.e when viewed in a mirror its component perpendicular to the mirror does *not* change sign. Axial vectors are really anti-symmetric tensors, but in three dimensions they happen to behave in almost the same way as true, i.e polar, vectors (just as in two dimensions vector operators add in the same way as vectors), while the 3-D co-called 'vector' product is a tensor product.

C.F. Coleman
Grove
Oxfordshire

Computers, language and logic

A.Medes (*EWW*, February 87, August 88) seems set to banish logic and mathematics from electronic engineering. He hasn't succeeded so far.

Mr Medes's all-important point of departure is that an electronic oscillator, as used in clocks, for example, is a logical contradiction, yet exists and is put to good use by engineers. To Mr Medes, this proves that logic is wrong. It is clear, however, that the operation of the oscillator is based on propagation delays. If both the output and the input of an inverter happen to be at the same logic level, this just means that propagation is in progress. It is NOT a contradiction, and it doesn't prove anything about logic. We would have a contradiction if we had a point on a wire with two logic voltage levels at the same time, but engineering hasn't progressed to that piont yet, has it?

But Mr Medes doesn't stop at logic. He cites the view that mathematics is a model of nature, and as he has just presented a contradiction in nature, namely, the electronic oscillator, he concludes the contradictions should be allowed and useful in mathematics, too. But, as I pointed out above, his contradiction isn't there, and so Mr Medes's criticism of mathematics fails.

Sakuri Aaltonen
Helsinki
Finland

FEEDBACK

A.Medes has produced a neat intuitive shorthand for logic cicuit design (August) but his theoretical speculations about sequential analysis and the liar paradox are based upon a misconception that *anything* in the universe can be truly static.

All theoreticians and engineers please understand this point: absolutely nothing is static if you analyse the interactions in sufficient detail – at the microscopic level of causal interactions, propagating *information* on changing stimuli.

Absolutely everything is iteratively updated from moment to moment at the speed of light (or faster but finite) to take into account fluctuating conditions for the interaction to converge to some equilibrium.

For example, bonding between atoms by electro-'static' fields; atoms in a steel bridge are under continual stress, and superimposed upon this apparent constancy ('bias') is the noise of fluctuating traffic load that leads to metal fatigue and structural failure.

The interaction becomes a non-convergent power series when the system is loaded beyond its elastic limit, manifesting as oscillation or catastrophe depending on the 'signal' phasing. This is the continuation of the classical equilibrium theories into the theory of so-called 'chaotic' behaviour (eg. squegging, turbulence, critical opalescence, critical-point amplifiers, super-regenerative amplifiers in electronics or nuclear physics – an atom bomb is merely a super-regenerative neutron amplifier, as a pulsed laser is a super-regenerative photon amplifier, etc.).

Chaotic behaviour occurs for any system biased beyond its 'radius of convergence' for stability of self-referential interactions to produce self-consistency on each iterative update.

Apologies to the memory of Hume, as much as I admire the style of his writings he is simply wrong when he tries to reduce causality to mere constant conjunction. Causality is causality. Asymptotic convergence of a causal chain of interactions to a self-consistent limit is where causality only *apparently* reduces to 'mere constant conjunction'. But it is continually being iteratively updated from picosecond to picosecond to take into account changing conditions.

The interactions to-and-fro in an apparently 'constant' (static) electric field means that continuous change is an illusion of negligible delay times where the differential calculus becomes valid as a useful tool – but it is not physical reality. Physical reality is fundamentally digital with a continuously variable sampling rate dependent upon the propagation delay times. From this concept of the sampling rate of reality we can *derive* the Planck constant in terms of classical physics and geometry. And in orbital mechanics the propagation time delay for gravitational interactions produces the observed advance of perihelion of orbital motions. That is the physical mechanism – the mathematics of time-retarded forces is so complicated that we still have to use the Einsteinian shortcut of a curved geometry for natural (unforced) motions. *That* is merely a calculation device, not reality.

So, returning to the logical problem of the liar paradox, it is not a paradox between alternate co-existential equilibrium states but it is a *real* non convergence that can never be resolved into asymptotic consistency as it swings from one 'decision' to the other upon each consideration of the facts.

As a theoretical speculation I often wonder if there is an upper frequency limit to the electromagnetic spectrum defining an indivisible unit of time (Leibnitz' Monads) so fantastically small that is the 'spool of thread' which passes through every microscopic point of the universe to effect change and 'weave the tapestry' of our 3-dimensional existence. Remember the Greek anthropomorphic myth of the tapestry woven by the Olympian gods. But it seems an unnecessary extravagance to have that 'point of change' continually defining the laws of physics from moment to moment at every point in the Universe. How else can the laws of physics be defined and *derived* in a causal theory as the asymptotic limit of a causal chain of interactions!

P.J. Ratcliffe
Stevenage
Hertfordshire

Relativity

The arguments about STR, over the last 75 years or so, are distinguished by their repetitiousness, if not their adherence to logic. Viewed from somewhere towards the sidelines, one of the interesting things about all this is that there is one good argument against the theory that is very carefully avoided. Einstein himself made no bones about it. Writing in his book[1] in 1916, he says:

> "The special theory of relativity cannot claim an unlimited domain of validity; its results hold only so long as we are able to disregard the influence of gravitational fields on the phenomena (e.g. light)."

As we are being constantly reminded, the time is long past when the consequences of these influences are detectable, if not always accurately measured, within the solar system and particularly within the Earth's field. It seems more than just odd that everyone should studiously avoid using this argument and concentrate so hard on attempts, so far abortive, to destroy the theory completely.

The reason is not far to seek. It is perhaps easiest to understand the theory if we can clear our minds of misconceptions arising from the use of the somewhat vague term "velocity effects" and realise that it really concerns itself with energy, and the consequences upon the measurements of time, length and mass of changes in the total energy level of the body being observed. In his first paper[2], Einstein considers alterations in energy levels due to variations of kinetic energy resulting from relative motion. The game is given away by the appearance of v^2 and not just v in the transform ($\frac{1}{2}v^2$ in its approximate expansion). In his third paper[3] it is changes in potential energy due to alterations of position in a gravitational field which give rise to the effects. In this case gh appears in the approximate transform in place of $\frac{1}{2}v^2$. Both gh and $\frac{1}{2}v^2$ are measures of energy per unit mass. In this latter paper he only considers the effect on time and mass, but by analogy length is also changed. It is this that leads him to the mathematical description of gravitation via the curvature of space. In his book[4] he considers the effects of rotation and demonstrates this distortion of space, concluding:

> "This proves that the propositions of Euclidean geometry cannot hold exactly on the rotating disc, nor in general in a gravitational field... Hence the idea of a straight line also loses its meaning."

STR thus disqualifies itself by showing that the Galilean inertial reference system, upon whose validity the theory depends and which demands Euclidean space and 'straight' lines, has no meaning in the presence of gravity. But the whole of classical Newtonian mechanics is also only valid for Galilean inertial reference systems.

The uncomfortable truth is that neither classical theory nor STR can claim an unlimited domain of validity, the former less than the latter. This does not mean that within their limitations they are not superb approximations, their use usually resulting in errors which are well inside our capability to detect, unless we use them outside those limitations. We should be more than foolish not to use either theory where it is the best for our purpose, that is to say "where it works", but it is equally foolish to waste time and brainpower trying to obliterate the really important lesson which arises from the first real attempt to develop a theory of relativity – that the real step forward is to move to a more generalised theory.

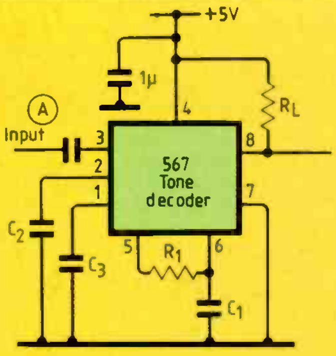
To the best of my knowledge, the only candidate so far is the General Theory of Relativity, and that is the theory that we really ought to be arguing about.

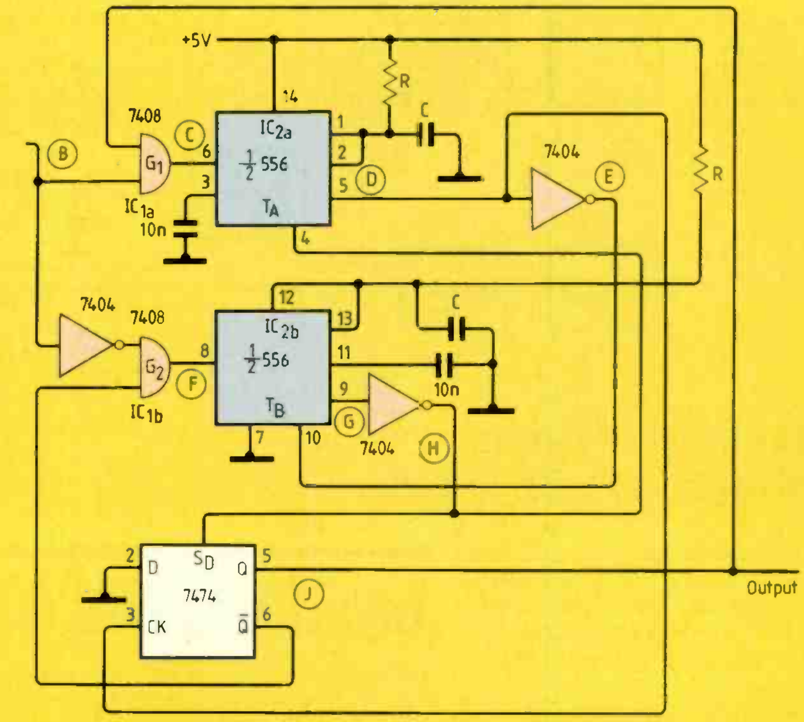
Alan Watson
Mallorca
Spain

References:

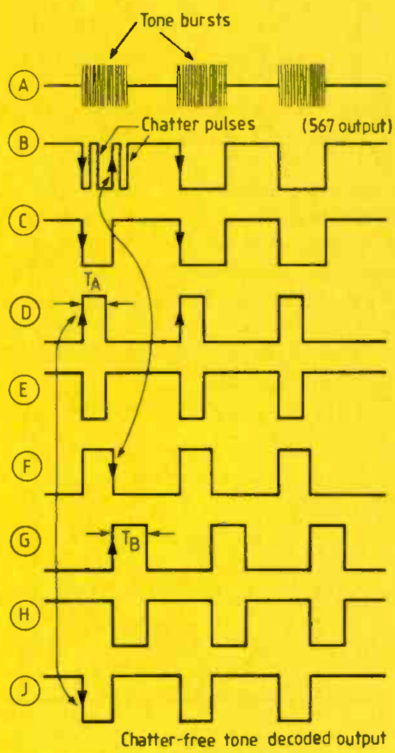
1. Relativity, the Special and the General Theory. A.Einstein. Methuen. First published in English translation 1920. 15th edition reprinted 1962. p.76.
2. On the Electrodynamics of Moving Bodies. A.Einstein. *Annalen der Physik* 17. 1905.
3. On the Influence of Gravitation on the Propagation of Light. A.Einstein. *Annalen der Physik* 35. 1911.
4. Reference 1.p.82

CIRCUIT IDEAS





Tone decoder with noise-chatter immunity



Phase-locked-loop decoders like the 567 are frequently used for tone detection. They can be over-sensitive and give spurious chatter when a noise spike or out-of-band signal of amplitude greater than the detection threshold appears at the input.

Common methods of solving such problems, such as feeding back part of the output or inserting a band-pass filter are of little use since no filter can have an infinitely sharp characteristic and noise is by definition random.

Normally, shaping the tone decoder output to average out the effects of noise pulses does not give immunity to spurious response as far as the logic circuit driven by the tone decoder is concerned. But noise pulses are nulled by the logic interface shown here.

Output of the 567 is high in the absence of a tone and becomes low when a tone is detected. Trace A on the timing diagram shows correctly decoded tone bursts and trace B is decoder output with spurious noise pulses on the correctly decoded tone information.

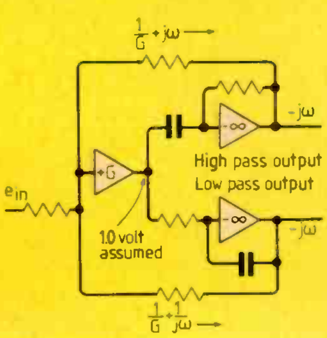
When tone-decoder output goes low in the presence of a tone, the monostable circuit is triggered and its output remains high for timing period T_A. Until IC_{2a} times out, further transitions at the input due to noise, etc., cannot cause any output change.

After period T_A the inverted positive input edge triggers monostable circuit IC_{2b}. Since both gates are disabled, spurious transitions at the tone-decoder output cannot give a false output at bistable i.c. output (point J).

Monostable circuit timing periods T_A and T_B should be chosen so that $T_A<T$, $T_B<T$ and $T_A+T_B>T$, where T is the tone 'on' duration (i.e. the time during which decoder output is low).

V. Lakshminarayanan
Centre for the Development of Telematics
Bangalore
India

Crossover filter



This diagram and its equations should have appeared with the crossover network on page 650 of the July issue. We apolgize for these omissions.

$$e_{in}=\frac{1}{G}+\frac{1}{G}j\omega+\frac{1}{G}+\frac{1}{j\omega}=\frac{3}{G}+j\left(\omega-\frac{1}{\omega}\right)$$

$$T_{LP}=\frac{-\frac{1}{j\omega}}{\frac{3}{G}+j\left(\omega-\frac{1}{\omega}\right)}$$

$$|T_{LP}|=\frac{1}{\sqrt{\left(\frac{3\omega}{G}\right)^2+(\omega^2-1)^2}}$$

If,

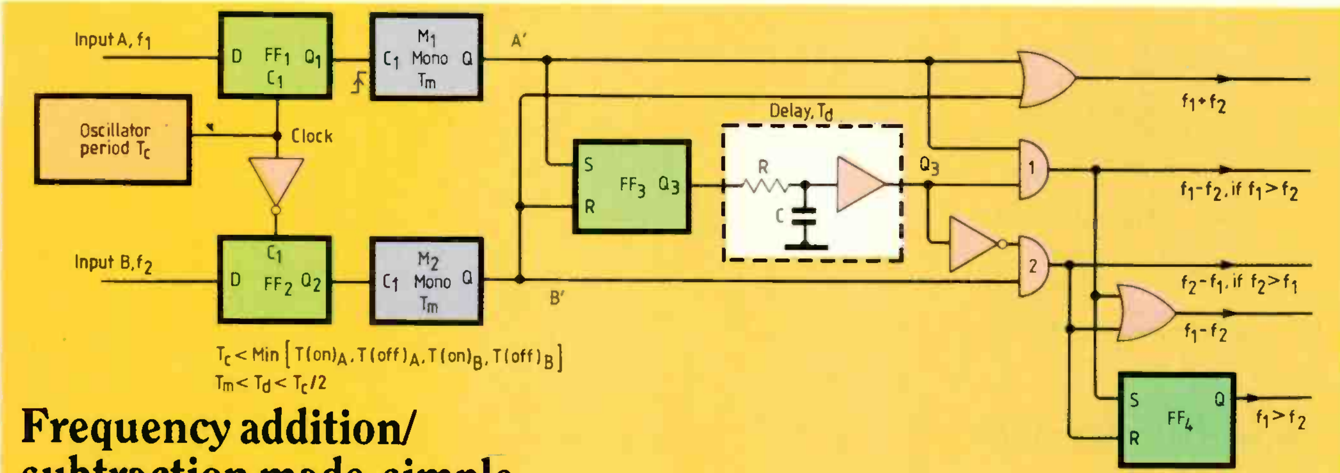
$$G=\frac{3}{\sqrt{2}},$$

$$|T_{LP}|=\frac{1}{\sqrt{\omega^4+1}},$$

the maximally-flat case, and,

$$|T_{HP}|=\frac{1}{\sqrt{\frac{1}{\omega^4}+1}}$$

McKenny W. Egerton
Owings Mills,
Maryland.



Frequency addition/ subtraction made simple

Pulse-cancellation is applied in this design to produce a simple sum and difference circuit that operates over a wide range of frequencies. From input frequencies f_1 and f_2 it produces signals of f_1-f_2 and f_1+f_2 and detects $f_1>f_2$.

Input signals A and B are latched by two D-type bistable devices on both leading and trailing clock edges. The clock is nearly symmetrical and its period, T_c, is less than the minimum on or off durations of signals A or B.

Although the inputs might have coincident transitions, the transitions at outputs $Q_{1,2}$ are separated by at least $T_c/2$ since the bistable devices are triggered at different clock edges. Also, ouputs $Q_{1,2}$ have the same frequency as their respective inputs A and B.

Two monostable i.cs, triggered on leading edges, produce sharp pulses A′ and B′ of duration T_m. After passing through Or gating, these pulses form a signal with an average frequency of f_1+f_2; this represents the sum of the input frequencies since A′ and B′ do not overlap.

A third bistable device is set by A and reset by B; its output, Q_3, is delayed by $T_d(T_m<T_d<T_c/2)$. When f_1 is greater than f_2, the first And gate produces a signal with an average frequency of f_1-f_2 by cancelling (inhibiting) a pulse of A′ for each pulse of B′.

Pulse cancellation takes place since pulse duration T_m is less than T_d. Output Q_3' goes to zero after delay T_d from the occurrence of a pulse at B′ and remains at zero until T_d after the occurrence of the next A′ pulse. Subsequent A′ pulses pass through the first And gate since Q_3' remains at logical one until another B pulse appears. Output of the second And gate, however, remains at zero.

Similarly when f_2 is greater than f_1, frequency of the second And gate is f_2-f_1 and output of the second And gate is zero. After passing through an Or gate, outputs of the two And gates have a frequency of $|f_1-f_2|$ and output of the fourth bistable device gives the polarity of the frequency difference; it is logical one only when $f_1>f_2$.

S. Murugesan
ISRO Satellite Centre
Bangalore India

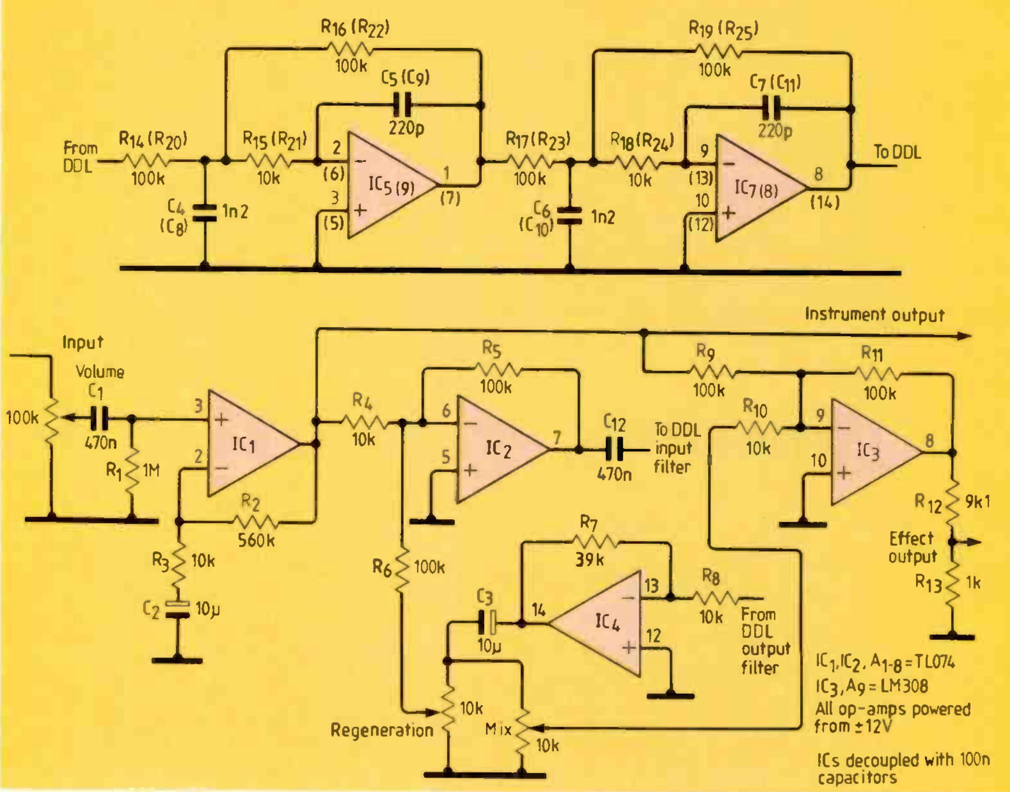
Digital-delay echo

Delays from 20ms to 250ms for the generation of echo and reverberation effects are produced by this digital delay line. An 8K×8 static ram, an 8bit digital-to-analogue converter and an 8bit analogue-to-digital converter form the digital delay line; analogue signals are recirculated to provide the required audio effects. Minimum sampling rate is about 33kHz and bandwidth is 10kHz.

The audio signal is amplified and filtered and fed into the a-to-d converter. An sc pulse of approximately 1μs initiates conversion of an analogue sample; this forces EOC low together with the LE input of the d-to-a converter and loads data from the current ram address into the converter. Recovered analogue output passes through IC_9 to the output filter and mixer circuits.

When conversion is complete EOC goes high, freezing the d-to-a converter latch contents and triggering the right-hand monostable multivibrator. The $\bar{Q}$ output of this multivibrator enables the data from the a-to-d converter to be placed on the data bus. At the same time the ram is set to read the new data. When the right-hand multivibrator times out, the left-hand one is triggered, producing an sc pulse and incrementing the ram address counters.

The sequence is, read-write-increment.

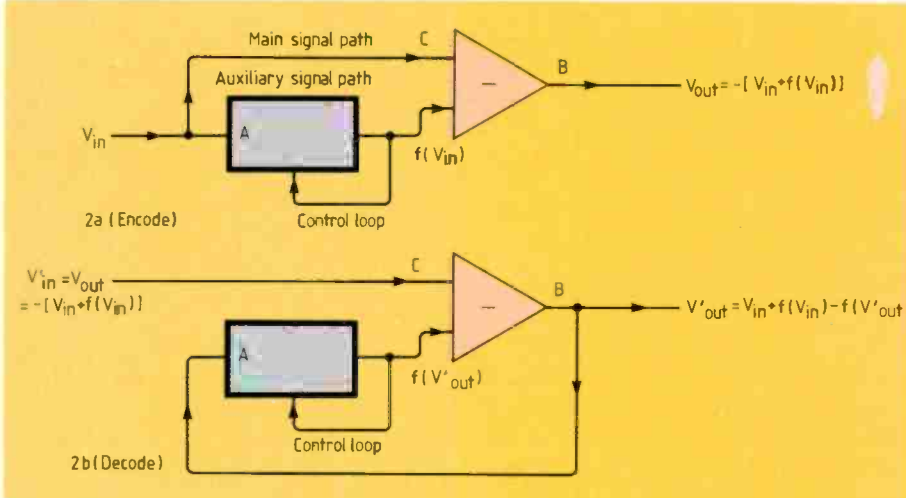


20dB noise reducer

Two signals paths are involved in this 20dB noise-reducer – an auxiliary path which selectively processes the higher frequencies, and a broadband main signal path. Outputs of the respective paths are added and the resultant inverted at the processor output; the signal applied to the auxiliary input determines whether the circuit encodes or decodes (as shown).

In encode mode, (a), auxiliary-block input A is connected to processor input C and if the input singal is V_{in}, the auxiliary block output is then $f(V_{in})$ and the output of the entire processor B is,

$$V_{out} = -[V_{in}+f(V_{in})].$$



This effectively turns the ram into an 8K×8 shift register. Delay time is varied in two ways; the clock of the a-to-d converter is variable from 290kHz to 1MHz, and the ram address range is adjusted by inhibiting address lines $A_{11,12}$. The clock is controlled by a potentiometer and the address range by S_1. Delay time is given by

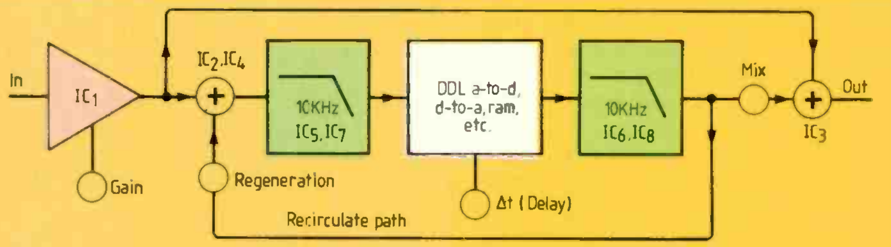
$$\Delta t = \frac{9}{f_{ck}} \times N$$

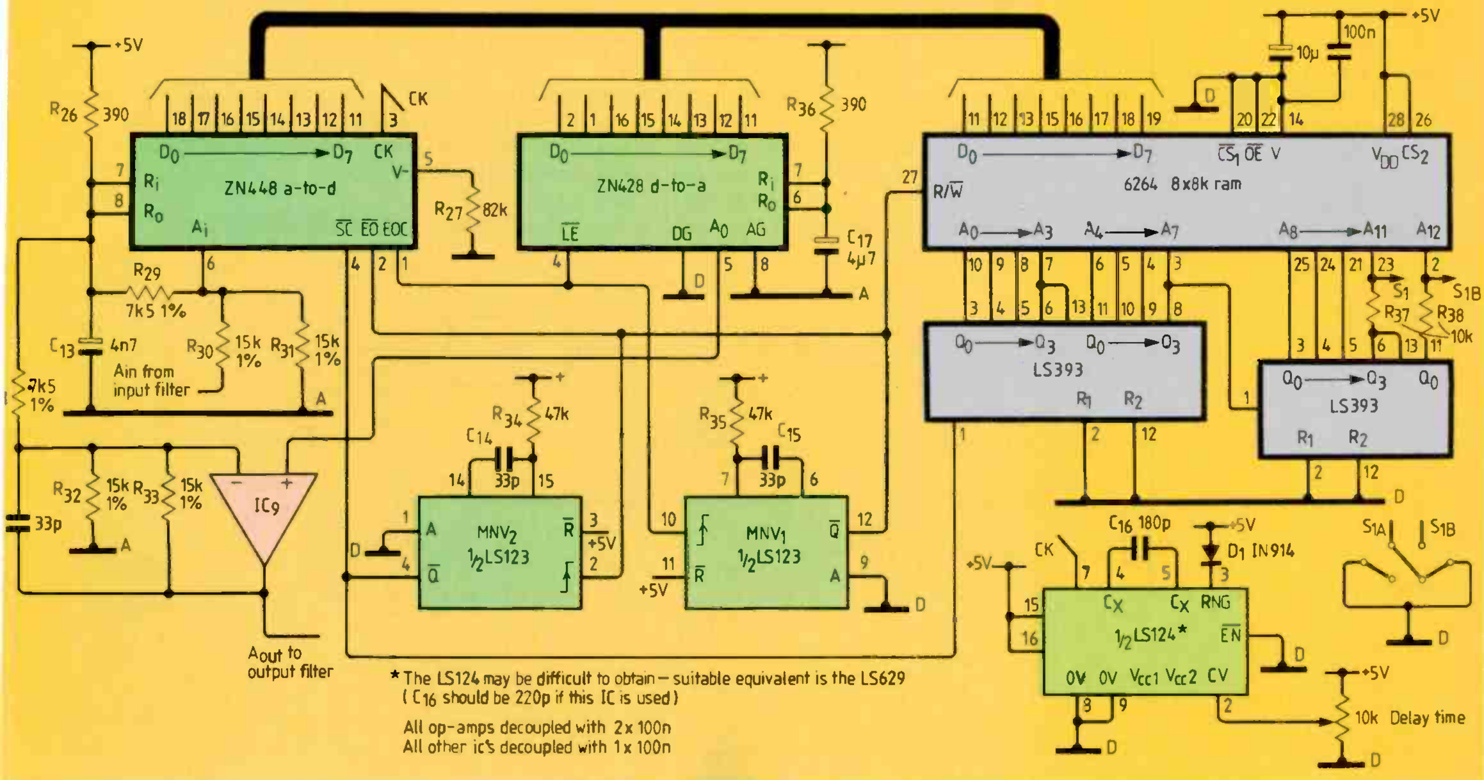
where N is the address range of 8192, 2048 or 4096. Clock frequency is 295kHz to 1MHz so Δ_t is 0.25s to 18ms at a minimum sample rate of 32.8kHz. To prevent aliasing the input bandwidth is limited to about 10.7kHz by a four pole low-pass filter $IC_{5,7}$.

Output from the delay line is also passed through an identical filter to remove the quantitization step noise. Recovered audio is recirculated through mixer amps $IC_{1,4}$ to give a variable reverberation time.

Treated audio and the original signal are mixed in IC_3 to provide control over the depth of echo. In spite of there being no companding and no sample-and-hold circuit the audio output is remarkably good.

A G Birkett, London.





CIRCUIT IDEAS

In decode mode, **(b)** auxiliary path input A is connected to the processor output B and if the processor input C is V_{in}, the processor output is,

$$V'_{out}=-[V'_{in}+f(V_{out})].$$

If now,

$$V'_{in}=V_{out}=-[V_{in}+f(V_{in})]$$

then

$$V'_{out}=-[-[V_{in}+f(V_{in})]+f(V'_{out})]$$

or

$$V'_{out}+f(V'_{out})=V_{in}+f(V_{in})$$

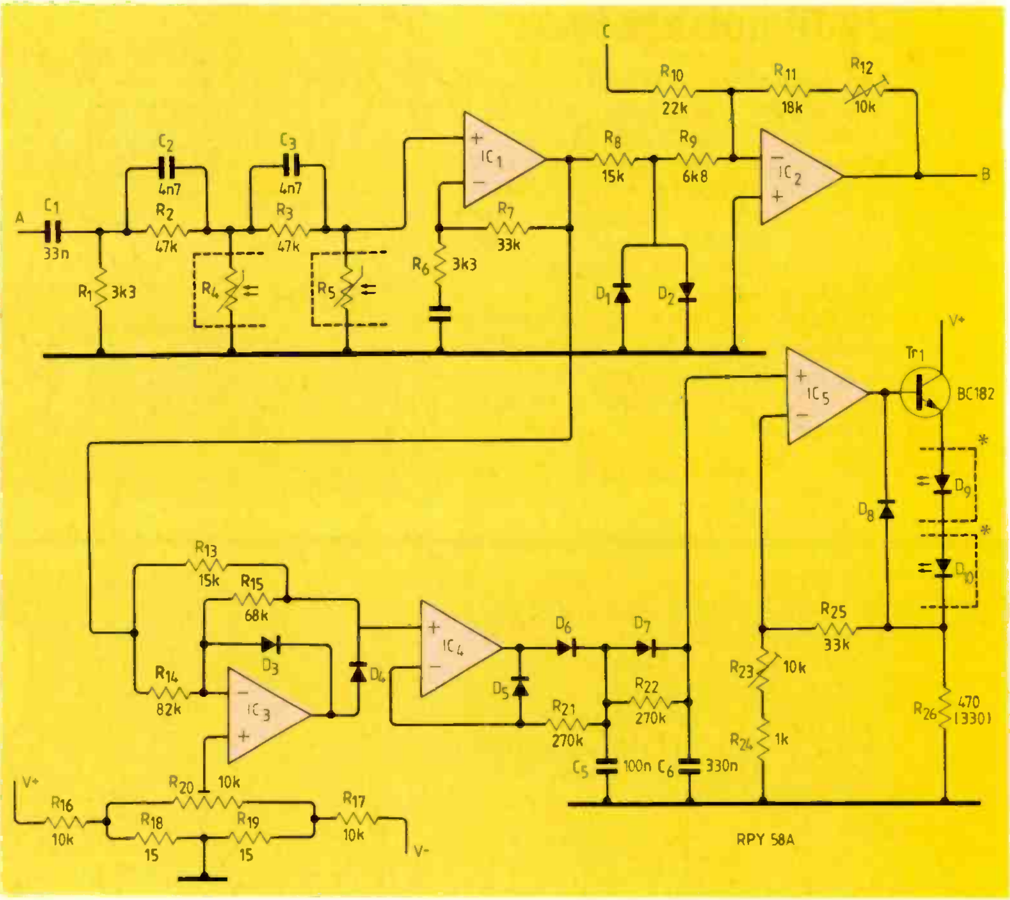
and evidently $V'_{out}=V_{in}$, i.e. the processor input in encode mode is identical to the processor output in decode mode irrespective of the form f(V) which the processing takes.

In the circuit of the auxiliary block and adder/inverter, IC_1 amplifies the auxiliary signal by 20dB and the two high-pass filters R_1C_1 and R_6C_4 provide for the 40dB/decade roll-off below 1.5kHz to prevent noise modulation by low-frequency signal components.

Light-dependent resistors were chosen as the variable-gain element on account of their ease of use compared to fets which require a.c. biasing to avoid even-harmonic distortion.

The attenuator pass band slides upward in frequency with increasing attenuation as in Dolby B to avoid modulation by high-level signals close in frequency to the filter cut off. Clipping diodes $D_{1,2}$ suppress spikes due to transients which are too fast to be handled by the control loop.

Suppression level may be set by varying the ratio of resistors R_8 and R_9. Values shown have been chosen to give a suppression threshold of roughly −3dBVU. Op-amp IC_2 recombines the main and auxiliary signals and inverts the resultant. Resistor R_{12} sets the overall gain. Op-amp IC_3 and its associated circuitry form a full-wave detector which monitors the output of the auxiliary path, while IC_4 drives the control-loop time constant.

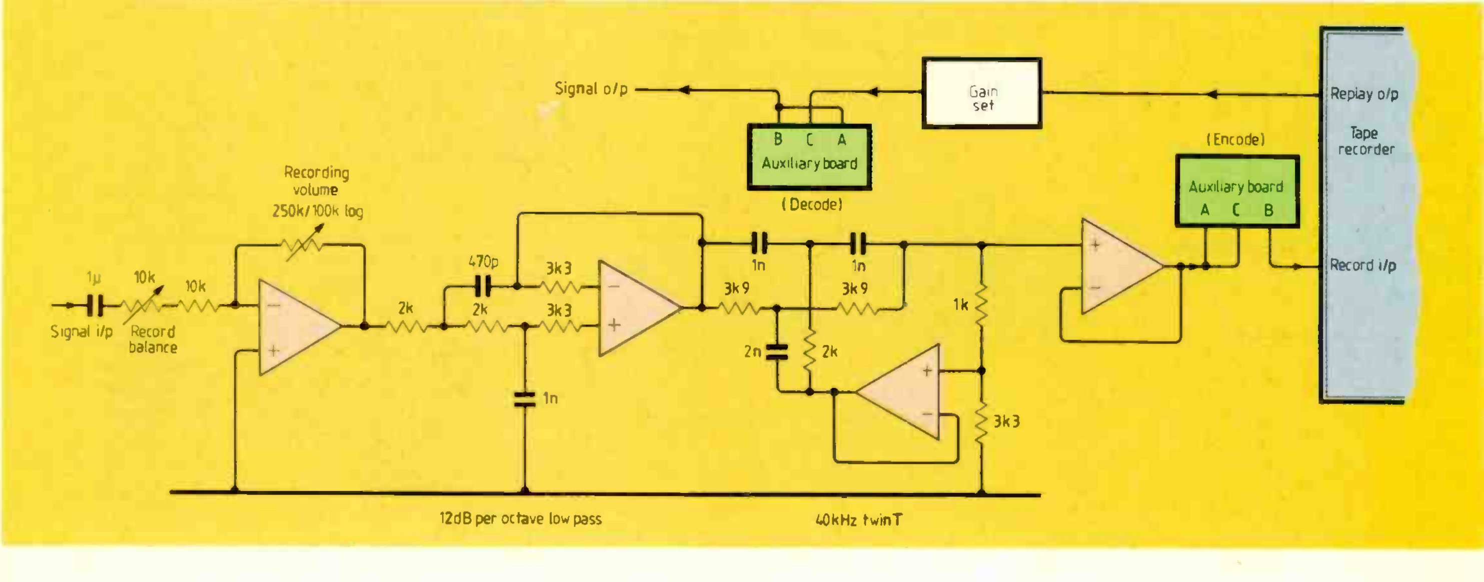


In the main circuit a low-pass filter is incorporated before the encode processor to eliminate trouble from sources with strong ultrasonic components; it prevents tracking errors by ensuring that the processor handles similar signal bandwidths on encode and decode.

A signal amplitude of 6V pk-to-pk at the processor output in encode mode was chosen to correspond to 0VU for the tape recorder. The processing threshold is defined as the level of a pure 10kHz tone at the processor input which causes the total processor gain to be 6dB in encode mode.

In the prototype circuit the processing threshold was set at 300mV pk-to-pk which corresponds to a processor output of −20dBVU and a noise reduction of 6dB. With this setting the noise reduction at −40dBVU and 10kHz is in excess of 17dB and the full 20dB of noise reduction is realized at about −50VU.

J. F. Gregg
The Clarendon Laboratory, Oxford.



Microcomputer as transient analyser

This computer interface provides the basic facilities of a digital storage oscilloscope, but at a much lower cost – and with more flexibility.

J. F. VAN DER WALLE

In many fields of research and production there often arises the need to analyse signals representing a single event or recurring phenomena. The most economical way to do this is to feed these signals to an analogue-to-digital converter and store them in a digital memory; the next step is, by using the appropriate timing circuits, to clock the data from memory via a digital-to-analogue converter, and to display the resulting analogue signals on an oscilloscope. The advantage of this method is that the entire signal can now be examined at leisure, time after time, without any loss of detail. A digital storage oscilloscope can do this, but the price is often out of reach for small research and/or production groups. Substituting a computer for a d.s.o. gives the distinct advantage that the user is now able to write his own program, or add extra modules to an existing program, to suit his own requirements best.

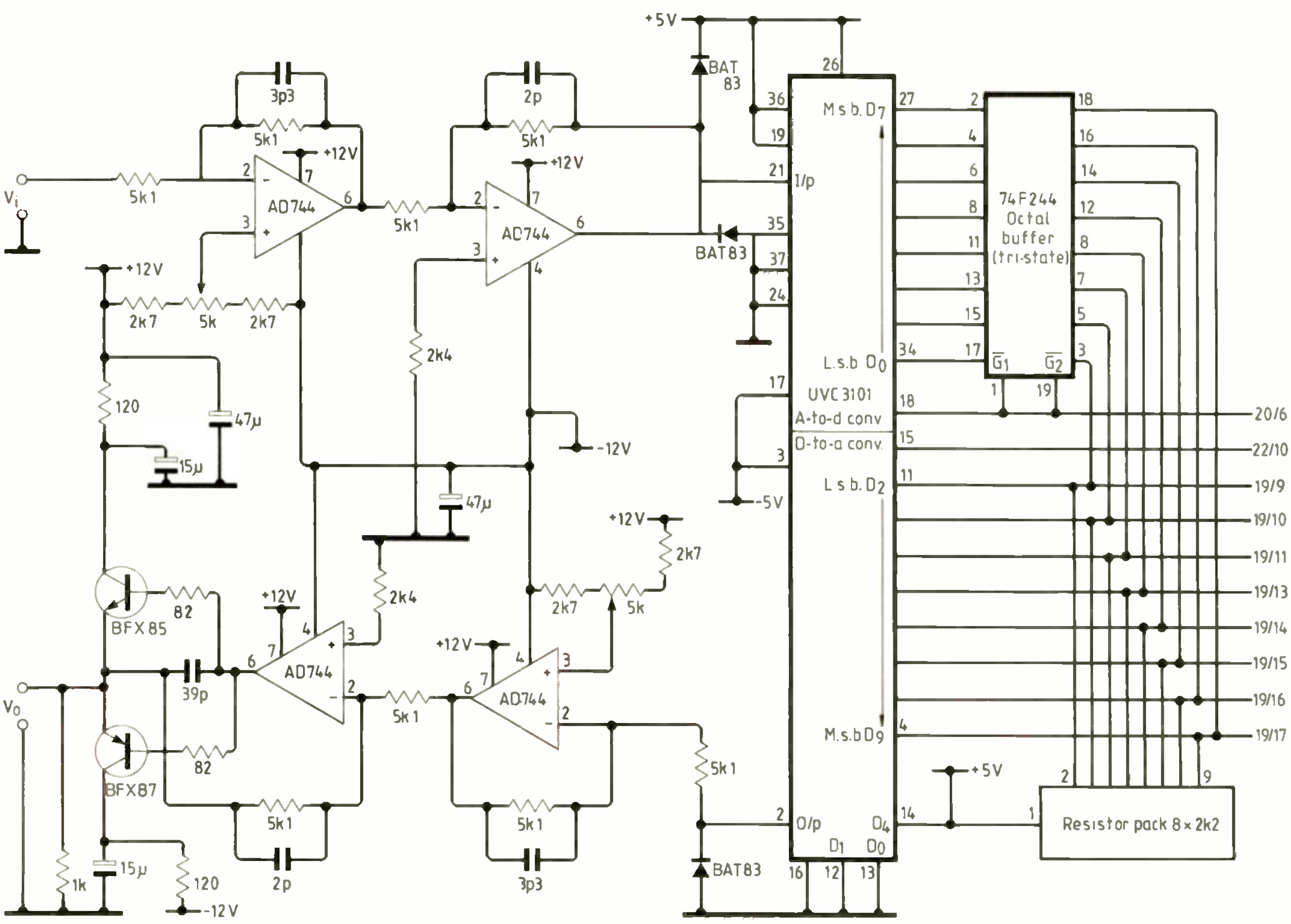
Two programs have been written for this particular analyser, both to run on a BBC model B computer. The first, called TRTD, drives the transient analyser and stores the data on a floppy disc. The second program, TRFD, brings data from the disc back to the computer and includes facilities for detailed analysis of the signal under study.

The t.a. can digitize analogue signals lasting from a few microseconds to several seconds. This particular t.a. has been used to study signals from both charge-coupled devices and very low frequency sources. The interface from the t.a. to the BBC computer has been kept as simple as possible and is incorporated into the design itself: all it needs is a cable to connect it to the 1MHz bus of the computer.

Another interesting feature is that the i.c. which digitizes the analogue signal (IC_{37}) also contains a d-to-a. This makes it possible to check the output of the a-to-d by connecting it the input of the d-to-a, which in turn is connected to an amplifier and driver.

After being digitized, the signal under study is stored in a 2048 word, eight-bit memory. Under program control the data is

Fig.1. Preamplifier and conversion stage: the combined a-to-d and d-to-a is an STC device. The digitized output can be looped back to the analogue driver for comparison with the original signal.



This program in BBC Basic sets up the interface for operation. Functions of individual modules within the program are indicated by Rem statements. Fuller information is available from the editorial office: send a stamped, self-addressed envelope or two international reply coupons, marking your covering envelope "Transient analyser".

```
10 REM MODULE 1(SET UP INTERFACE)
20 REM:PROGRAM NAME IS TRTD
30 REM:DATA FROM TRAN.ANAL.TO DISC
40 CLS:MODE4
50 ?&FD12=&FF:REM DIR.RG(B)=O/P FD10
60 ?&FD10=&00:REM LOAD 00 ON BUS B
70 ?&FD1C=&EC:REM IC10/9=L.BREAK
80 ?&FD10=&08:REM LOAD 08 ON BUS B
90 ?&FD1C=&EE:REM IC6/15=L.RST.INTF.
100 ?&FD13=&00:REM DIR.RG(A)=I/P FD11
110 X%=?&FD11 :REM RESET BUS B FLAG
120 PRINTTAB(20,0)"                  "
130 INPUTTAB(20,0)"TIMEBASE(ms)="U
140 IF U>6710.8864 THEN 240
150 PRINTTAB(20,1)"                  "
160 INPUTTAB(20,1)"SAMPLE F(mms)="B
170 IF B<.05 OR B>3276.8 THEN 260
180 N%=(U/B)*1000.1:N=N%:REM N=MEM.LC
190 PRINTTAB(20,3)"                  "
200 PRINTTAB(20,3)"MEM.LOCATIONS=";N
210 IF N>2048 THEN 280
220 DIM A(N):REM DATA INTO ARRAY
230 GOTO 300
240 PRINTTAB(20,1)"MAX.TB.=6710.8864"
250 GOTO 120
260 PRINTTAB(20,2)".05=<SF<=3276.8"
270 GOTO 150
280 PRINTTAB(20,4)"MAX.MEM.LOCS=2048"
290 GOTO 150
300 PRINTTAB(20,4)"
310 INPUTTAB(20,4)"PRETRIG(%)=",F
320 IF F>=100 THEN 300
330 F%=F:I=F%/100:REM ROUNDING
340 R=250-((N DIV 8)*(1-I)):R%=R
350 Z=((256-R%)*8*B)/1000
360 PRINTTAB(20,4)"                  "
370 PRINTTAB(20,4)"POSTTR(ms)=";Z
380 S%=(B*20)-1:S=S%:REM(I/P)IC11/14
390 PRINTTAB(20,2)"FREQ.DIVISION=";S
400 V=S DIV 256:REM V IS MSB OF S
410 W=S MOD 256:REM W IS LSB OF S
420 REM MODULE 2(LOAD IC3,4 AND 5)
430 ?&FD10=R% :REM LOAD R% ON BUS B
440 ?&FD1C=&CC:REM IC10/15=L.CLC IC3
450 ?&FD1C=&EE:REM IC10/12=L.BREAK
460 ?&FD10=W :REM LOAD W ON BUS B
470 ?&FD1C=&CE:REM IC10/14=L.CLC IC4
480 ?&FD1C=&EE:REM IC10/12=L.BREAK
490 ?&FD10=V :REM LOAD V ON BUS B
500 ?&FD1C=&EC:REM IC10/13=L.CLC IC5
510 finishtime=TIME+(U*.1)+100:REPEAT
520 UNTIL TIME>=finishtime:REM DELAY
530 REM:MODULE 3(READ FLAG REGISTER)
540 ?&FD1C=&EC:REM IC10/9=L.BREAK
550 ?&FD10=&0F:REM LOAD OF ON BUS B
560 ?&FD1C=&EE:REM IC10/7=L.RESTART I
570 ?&FD10=&00:REM LOAD 00 ON BUS B
580 F%=?&FD1D :REM READ FLAG REG(CA1)
590 PRINTTAB(0,0)"FLAG RG(RD.1)=";F%
600 IF F%=0 THEN 540:REM F%=0 NO FLAG
610 REM:MODULE 4(READ TRAP ADD.)
620 ?&FD10=&0A:REM IC6/13=L.ENA.IC16
630 X%=?&FD11 :REM READ MEM.ADD.LSB
640 ?&FD10=&0B:REM IC6/12=L.ENA.IC17
650 Y%=?&FD11 :REM READ MEM.ADD.MSB
660 ?&FD1C=&EC:REM IC10/9=L.BREAK
670 T=X%+(256*Y%):REM T=TRIGGER ADDR.
680 PRINTTAB(0,1)"MEM.ADD(TRIG)=";T
690 REM:MODULE 5(LOAD PRETRIG.ADD.)
700 P%=T-(N*I)
710 IF P%<0 THEN P%=(2048+T)-(N*I)
720 P=P%:REM P=PRETR.ADD.
730 J=P DIV 256:REM J IS MSB OF P
740 K=P MOD 256:REM K IS LSB OF P
750 ?&FD10=&0D: REM LOAD OD ON BUS B
760 ?&FD1C=&EE:REM IC6/10=L(IC23/6=L)
770 ?&FD1C=&EC:REM IC10/9=L.BREAK
780 ?&FD10=K :REM LOAD K ON BUS B
790 ?&FD1C=&CC:REM IC10/11=L.LD.IC7+8
800 ?&FD10=&0D:REM LOAD OD ON BUS B
810 ?&FD1C=&EE:REM IC6/10=L(IC23/6=L)
820 ?&FD1C=&EC:REM IC10/9=L,BREAK
830 ?&FD10=J :REM LOAD J ON BUS B
840 ?&FD1C=&CE:REM IC10/10=L,LD.IC9
850 REM:MODULE 6(READ PRETRIG.ADD.)
860 ?&FD10=&0E:REM LOAD OE ON BUS B
870 ?&FD1C=&EE:REM IC6/9=L*CLCIC16/17
880 ?&FD10=&0A:REM IC6/13=L,ENA.IC16
890 X%=?&FD11 :REM READ MEM.ADD.LSB
900 ?&FD10=&0B:REM IC6/12=L,ENA.IC17
910 Y%=?&FD11 :REM READ MEM.ADD.MSB
920 Q=X%+(256*Y%):REM Q=READ PRETRIG.
930 PRINTTAB(0,2)"START=";Q
940 IF Q=P THEN 960
950 REM:MODULE 7(STEP ADD.COUNTER)
960 C=Q:REM ADD.STEPCOUNTER IS C
970 FOR I=0 TO (N-1):REM N ELEMENTS
980 ?&FD10=&0C:REM LOAD OC ONTO BUS B
990 ?&FD1C=&EE:REM IC10/7=IC18/1=L
1000 A(I)=?&FD11:REM DATA MEMORY(IC19)
1010 PRINTTAB(0,3)"MEM.ADD(STEP)=";C
1020 PRINTTAB(0,4)"MEMORY DATA=";A(I)
1030 ?&FD10=&0D:REM LD.0D,IC6/10=L
1040 ?&FD1C=&EC:REM IC10/9=L,BREAK
1050 C=C+1:IF C=2048 THEN C=0
1060 NEXT I
1070 PRINTTAB(0,3)"                  "
1080 PRINTTAB(0,4)"                  "
1090 REM:MODULE 8(READ END ADDRESS)
1100 ?&FD10=&0E:REM LOAD OE ON BUS B
1110 ?&FD1C=&EE:REM IC6/9=L.CLCIC16/17
1120 ?&FD10=&0A:REM IC6/13=L,ENA.IC16
1130 X%=?&FD11 :REM READ MEM.ADD.LSB
1140 ?&FD10=&0B:REM IC6/12=L,ENA.IC17
1150 Y%=?&FD11 :REM READ MEM.ADD.MSB
1160 ?&FD1C=&EC:REM IC10/9=L,BREAK
1170 E=X%+(256*Y%):REM E=END ADD.
1180 PRINTTAB(0,2)"START=";Q;"END=";E
1190 IF E=C-1 THEN 1210
1200 REM:MODULE 9(READ FLAG REGISTER)
1210 F%=?&FD1D :REM READ FLAG REG(CA1)
1220 PRINTTAB(0,0)"FLAG RG(RD.2)=";F%
1230 REM:MODULE 10(PLOT GRAPH)
1240 INPUTTAB(0,3)"PLOT MULTP.=";G
1250 X=(1279/(N-1))
1260 PLOT 4,X,(A(0)*G)+40
1270 FOR I=0 TO (N-1)
1280 PLOT 5,X*I,(A(I)*G)+40:NEXT I
1290 Y=T-Q:IF Y<0 THEN Y=T-Q+2048
1300 PLOT 4,X*Y,0:REM TRIGGER MARKER
1310 PLOT 5,X*Y,(A(Y)*G)+20
1320 ?&FD10=&08:REM LOAD 08 ON BUS B
1330 ?&FD1C=&EE:REM IC6/15=L,RST.INTF.
1340 REM:MODULE 11(DATA TO DISC)
1350 INPUTTAB(0,5)"NAME FILE",A$
1360 AB=OPENOUT A$
1370 PRINTTAB(0,3)"LOADING DATA=";N
1380 PRINT#AB,U:PRINT#AB,B
1390 PRINT#AB,N:PRINT#AB,F
1400 PRINT#AB,T:PRINT#AB,Q:PRINT#AB,E
1410 FOR I=0 TO N-1:REM DATA TO DISC
1420 PRINTTAB(14,4);I
1430 PRINT#AB,A(I):NEXT I
1440 CLOSE#AB
1450 PRINTTAB(14,4);I
1460 PRINTTAB(0,3)"                  "
1470 PRINTTAB(0,3)"DATA NOW ON DISC"
1480 PRINTTAB(0,4)"END OF PROGRAM"
1490 VDU 23,1,0;0;0;0;:REM CURSOR OFF
1500 END
```

transferred to the computer and displayed on the monitor.

TECHNICAL DESCRIPTION

The transient analyser consists of four parts: a d.c. coupled analogue amplifier; an interface bus system; the register system; the interrupt system.

Direct coupling of the pre-amplifier (Fig. 1) has the advantage that very low frequency signals, or even the output fluctuations of a d.c. power supply, can be directly coupled to the flash a-to-d (IC_{37}); this prevents zero-line shift by applying a non-symmetrical waveform via a capacitor-coupled input.

The differential input stage makes it possible to raise or lower the input threshold of the amplifier. If an input signal is applied which has a positive or negative bias, one can set the associated potentiometer to such a value that the bias is cancelled and the input signal itself occupies the a-to-d's full conversion range of 0 to 2V.

The input stage is followed by an inverter, and so the input signal is fed to the a-to-d (pin 21 of IC_{37}) as a non-inverted signal. The amplification factor A of the amplifier is governed by the feedback resistors R_x and R_y, and the input resistors R_1 and R_2:

$$a=\left(\frac{R_x}{R_1}\right)\cdot\left(\frac{R_y}{R_2}\right)$$

If all resistors are 5.1kΩ, then $A = 1$. For a gain greater than unity, change the input resistors R_1 and R_2 and let $R_x = R_y = 5.1$kΩ. If both R_x and R_y are 5.1kΩ and the feedback capacitors across R_x and R_y are carefully selected, a rise-time of approximately 90ns can be achieved at the output, pin 6. With unity gains the pre-amplifier is fast enough to be used for studying the output of a video camera. If the amplifier is to be used for low frequency work, R_1 and R_2 can be decreased to give a much higher amplification with a restricted frequency response. By using op-amps with a much faster slewing performance, the rise-time can be improved, but at a greater cost.

A similar amplifier is connected to the output of the d-to-a. The analogue output of the line driver BFX 85/87 can be raised or lowered, with reference to ground, by means of a second potentiometer. The design of the t.a. is such that if a video signal is digitized, the analogue output via the line driver will generate the same picture on the monitor.

The bi-fet op-amp AD744 (Analog Devices) was chosen as the best compromise between price and rise-time.

BUS SYSTEM

The interface between the bus system of the transient analyser (Fig. 2) and the computer consists of the peripheral interface adapter IC_1 with IC_2, for full decoding of the 1MHz bus circuit of the BBC computer.

As can be seen from Fig. 2, there are two internal bus systems, one for data to the computer, port A of the 6522, and a second for data from the computer, Port B. Under software control, port A is used as an input port and port B as an output. This is set up in the first part of the program (see software for the t.a.) and is not changed during the

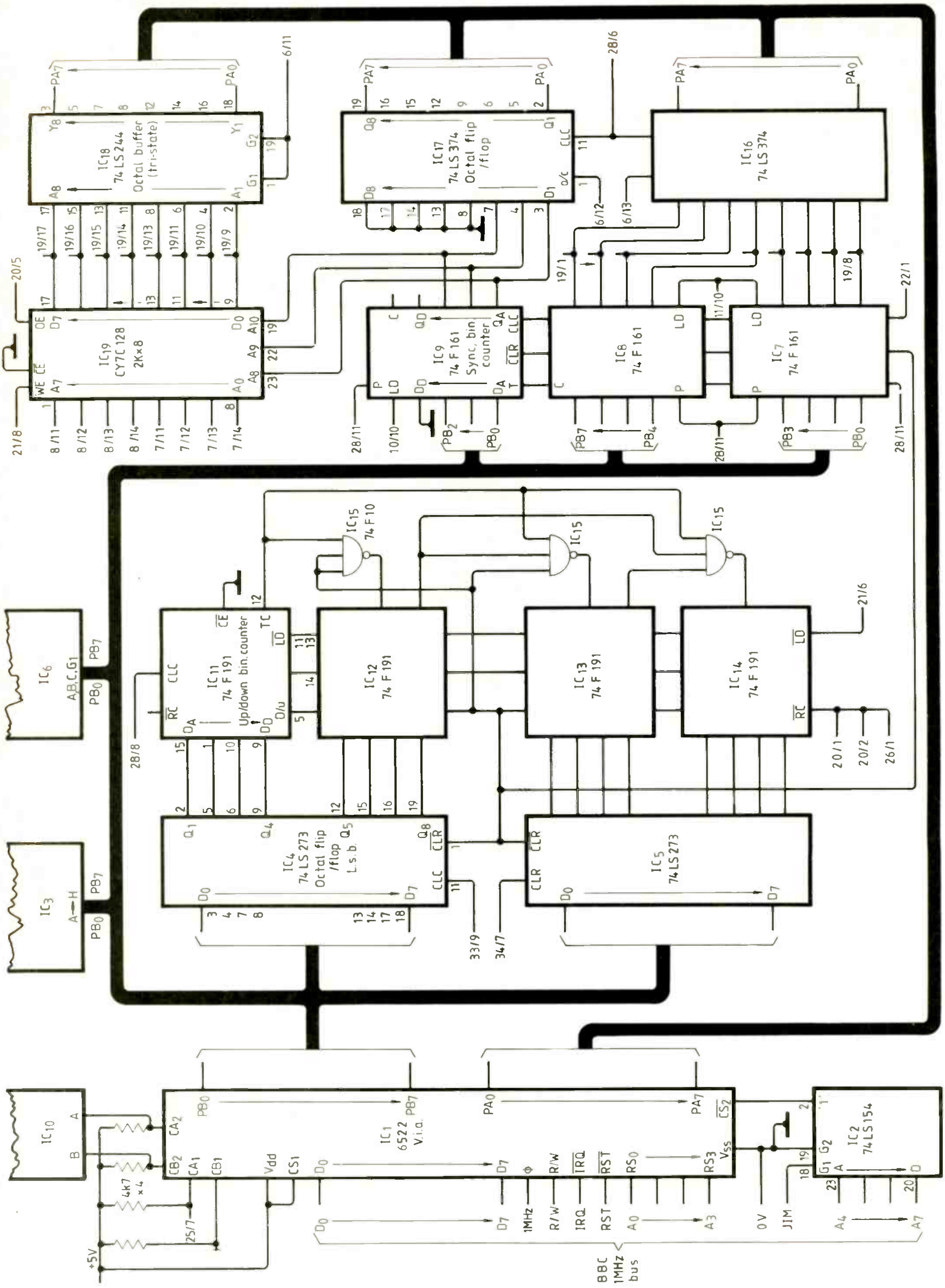

IC18 74 LS 244 Octal buffer (tri-state)
IC17 74 LS 374 Octal flip /flop
IC16 74 LS 374
IC19 CY7C 128 2K×8
IC9 74 F 161 Sync. bin counter
IC8 74 F 161
IC7 74 F 161
IC15 74 F 10
IC15
IC15
IC11 74 F 191 Up/down bin. counter
IC12 74 F 191
IC13 74 F 191
IC14 74 F 191
IC4 74 LS 273 Octal flip /flop L.s.b.
IC5 74 LS 273
IC6
IC3
IC10
IC1 6522 V.i.a.
IC2 74 LS 154
4k7 ×4
+5V
BBC 1MHz bus

Fig.2. Bus system. The transient analyser connects directly to the 1MHz bus port of a BBC microcomputer.

running of the program.

Data collected by the t.a. is placed on the PA bus by the octal buffer IC_{18} and the memory (IC_{19}) address via edge-triggered octal latches IC_{16} and IC_{17}. Data for the t.a. from the computer is handled by the PB bus and consists of 16-bit data to the octal flip-flops IC_4 and IC_5; 11 bits of data to preset the four-bit synchronous counters $IC_{7,8,9}$; eight bits to the input registers IC_3 (Fig. 3); four bits of data for the three-to-eight decoder IC_6.

REGISTERS

The registers receive the computer data via the eight-bit bus connected to port B of the 6522. To make sure that the correct data reaches the registers ($IC_{3,4,5}$) a strobing system is employed. The register system (Fig. 4) consists of $IC_{6,10,29,33,34}$ and generates the three clock signals for the registers after the data has been placed on the port B bus. These clock signals are generated by connecting control signals CA_2 and CB_2 from the 6522 to the three-to-eight decoder IC_{10}. Note that pin 10/3 (i.e. pin 3 of IC_{10}) is low after the reset signal on pin 34/5. The sequence is CA_2 and CB_2 low, then 10/15 low; CA_2 high and CB_2 low, then 10/14 low; CA_2 low and CB_2 high, then 10/13 low.

The three signals 10/15, 10/14, and 10/13 are all Ored and trigger the two monostables of IC_{29}. The first monostable triggers, giving an output at pin 13, the second one after about 420μs. The second monostable's output at pin 12 is connected to all three clock inputs of the flip-flops IC_{33} and IC_{34}. If CA_2 and CB_2 are both low, then 10/15 will keep 33/3(K) low and the clock pulse on 33/4 will make 33/7 (Q) go high (33/7, after the reset signal on 33/5, was low). The positive signal on 33/7 clocks data in the port B bus, into the register IC_3 and triggers the monostable IC_{35} so the output pulse of 35/4 loads the data from the internal registers into the eight bit binary counter IC_3. If IC_{29} is triggered by a false pulse, e.g. noise, then 33/3 will be high and 33/7 stays low. In the same way, the outputs of the flip-flops 33/9 (CA_2 high, CB_2 low) and 34/7 (CB_2 low, CB_2 high) clock the data from the port B bus into registers IC_4 and IC_5.

The same strobing system generates the reset signal (32/3) for the t.a., the clock signal for the binary counters $IC_{7,8,9}$ from 32/6, the output from 32/8 to clock the memory address on to the port A bus via IC_{16}, 17 and furthermore, negative-going and positive-going trigger signals from 32/11 and 30/13 respectively. This trigger signal makes it possible to start or stop any external signal source under software control. The four output signals from IC_{32} are derived from the four-bit word from the port B bus, which is connected via the three-to-eight decoder IC6.

A further strobing system is used to move data from the port B bus into the counters, $IC_{7,8,9}$. This is accomplished by IC_{27} and IC_{30}. This data makes it possible to load any address into the memory (IC_{19}).

INTERRUPTS

Let us first look what happens before an input signal reaches the a-to-d (IC_{37}). The 20 MHz oscillator IC_{24} drives a frequency division chain IC_{11-14}. The output of this chain, pin 14/13, goes to the clock input of IC_{20} (pin 1). Inputs J and K of IC_{20} are both high, because pin 25/7 is high after the general reset pulse from pin 32/3 to pin 25/14. The output of IC_{20}, pin 5, drives the output enable ($\overline{OE}$ of the memory (IC_{19}). When $\overline{OE}$ is high, the write enable $\overline{WE}$ goes low and so any data appearing on the input, D_0 to D_7, is written into memory. This means the memory circuitry (IC_{18} and IC_{36}) continuously updates the memory contents. The output from the a-to-d is fed through an octal buffer (IC_{36}) to the input of the d-to-a, so that the input signal on pin 37/21 can be monitored on pin 37/2. Memory updating can be stopped by applying a positive-going pulse on pin 23/12. Pin 23/10 goes high and enables the J input of flip-flop IC_{25}. The output of IC_{25}, pin 5, goes high after a negative-going transition on the clock input of IC_{25}. When pin 25/5 goes high, it will, via pin 28/6, clock the memory address into the octal latches IC_{16} and IC_{17}. This is called the trigger address. Simultaneously pin 25/6 goes low, enabling the divide-by-eight counter IC_{26}. For every eight output pulses of the divider chain IC_{11-14}, one 30ns pulse will appear on pin 3/13.

Each clock pulse on pin 13 increments the counter IC_3 until an overflow (i.e. a count of FF_{16}) occurs on pin 11. The output of IC_{25} (pin 7) goes low, inhibiting IC_{20}, stopping any further data intake into the memory and setting an interrupt flag on the 6522 (pin 40). The program will first read the trigger address and then load an address into the three counters $IC_{7,8,9}$ (a pre-triggered address), and will start transferring data from memory on to the port A bus and into computer memory.

This new pre-trigger address is transferred via port B bus, as two bytes. The lower byte is loaded into $IC_{7,8}$ when pin 10/11 goes low (CA_2, CB_2 low); the high byte is loaded into IC_9 when pin 10/10 goes low (CA_2 high, CB_2 low).

Note that when loading the four-bit counter 74F161 the clock input must go high when LD, pin 9, is low. The program now steps the counters by loading the same four-bit word into IC_6 via the port B bus. When pin 6/10 goes low (PB_0, PB_2, PB_3, high; PB_1 low) then a counting pulse will appear on pin 32/6 if after 400μs, the output of monostable IC_{29} goes low while pin 6/10 is

Features of the transient analyser

Analogue input range: +10V to −10V.
Preamplifier bandwidth: about 3MHz (can be increased).
Output (from monitor d-to-a): 2V via 50Ω driver.
Resolving power: 50ns−3276.8μs steps (eight bits).
Usable time base range: 10μs−6.7s (on computer monitor).
Pre-trigger facility.
Data storage on floppy disc.
Memory size: 2K-byte or more.

still low. For each memory address a unique word is transferred via the buffer IC_{18} on to the port A bus. Strobing of this data is done by a second four-bit word from the port B bus to IC_6. When pin 6/11 is low (PB_0, PB_1 low, PB_2, PB_3 high) the data is strobed via IC_{13} into the bus system.

SAMPLING FREQUENCY

The sampling frequency depends on the output of the frequency divider, IC_{11-14}. If this divider is set to zero, i.e. the 16 outputs of $IC_{4,5}$ are all low, then the output frequency, pin 14/13, will be the same as the oscillator frequency, 20MHz. Hence sampling will be in steps of 50ns. If pin 4/2 is high and the other fifteen outputs are low, sampling will be in steps of 100ns. If all sixteen outputs are high, sampling will occur in 3276.8μs steps. This gives this particular t.a. a wide range. By using a 2048 × 8 memory (IC_{19}) the minimum timebase will be 2048 × 50ns, or 102.4μs, and the maximum 6.7108864s. Both values can be doubled by using a 4096 × 8 memory by connecting pin 9/11 to the m.s.b. memory address line.

ACTION OF THE T.A.

1. Memory counters $IC_{7,8,9}$ continuously step the memory address lines. These counters are clocked by the same signal as the write-enable of the memory, via 22/5 and 22/1.
2. Any analogue signal between 0 and 2V is converted by IC_{37} and stored in memory. This digital signal is fed back to the d-to-a part of IC_{37}; hence on pin 37/2 there appears the same signal as on pin 37/21. Data in memory is continuously overwritten as long as $IC_{7,8,9}$ are enabled.
3. This carries on as long as pin 25/7 is high. But if a trigger pulse is applied on pin 23/12, the memory will be disabled after the overflow pulse on pin 3/11. Note that pin 21/8 is high ($\overline{WE}$ of the memory, pin 19/21, is disabled) and pin 20/5 is low ($\overline{OE}$ of memory, pin 19/20 is enabled). The time that passes between the trigger pulse on pin 23/12 and the overflow pulse on pin 3/11 is proportional to that amount of data in memory one is interested in.
4. If the trigger pulse applied to pin 23/12 occurs at the same time as the rising edge of the signal under study, one needs a facility to display the signal in such a way that the rising edge is also clearly visible. This is done by loading a pre-trigger address into the memory address counters (see Interrupts above).
5. After a pre-trigger address has been loaded into $IC_{7,8,9}$, program control takes over the stepping of the memory-address counter by loading a four-bit word on the port B bus. A stepping pulse is generated via IC_6, pin 10. For each memory address a unique data word is transferred via the octal buffer IC_{18} into the port A bus.

TRIGGER SOURCES

Several triggering modes are available:

1. A positive-going pulse from an external source can be applied to pin 23/12.

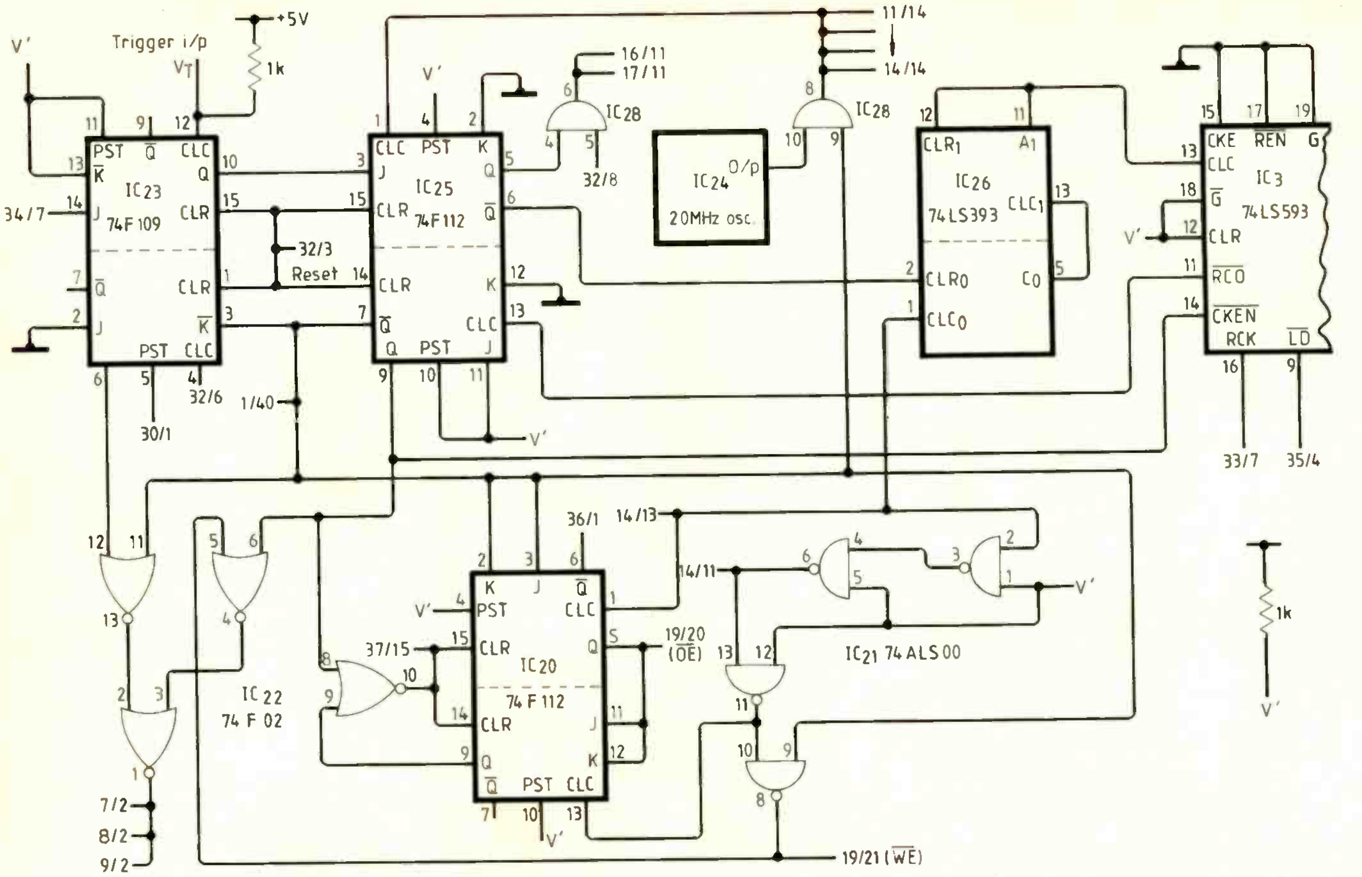


Fig.3. Oscillator and trigger circuitry.

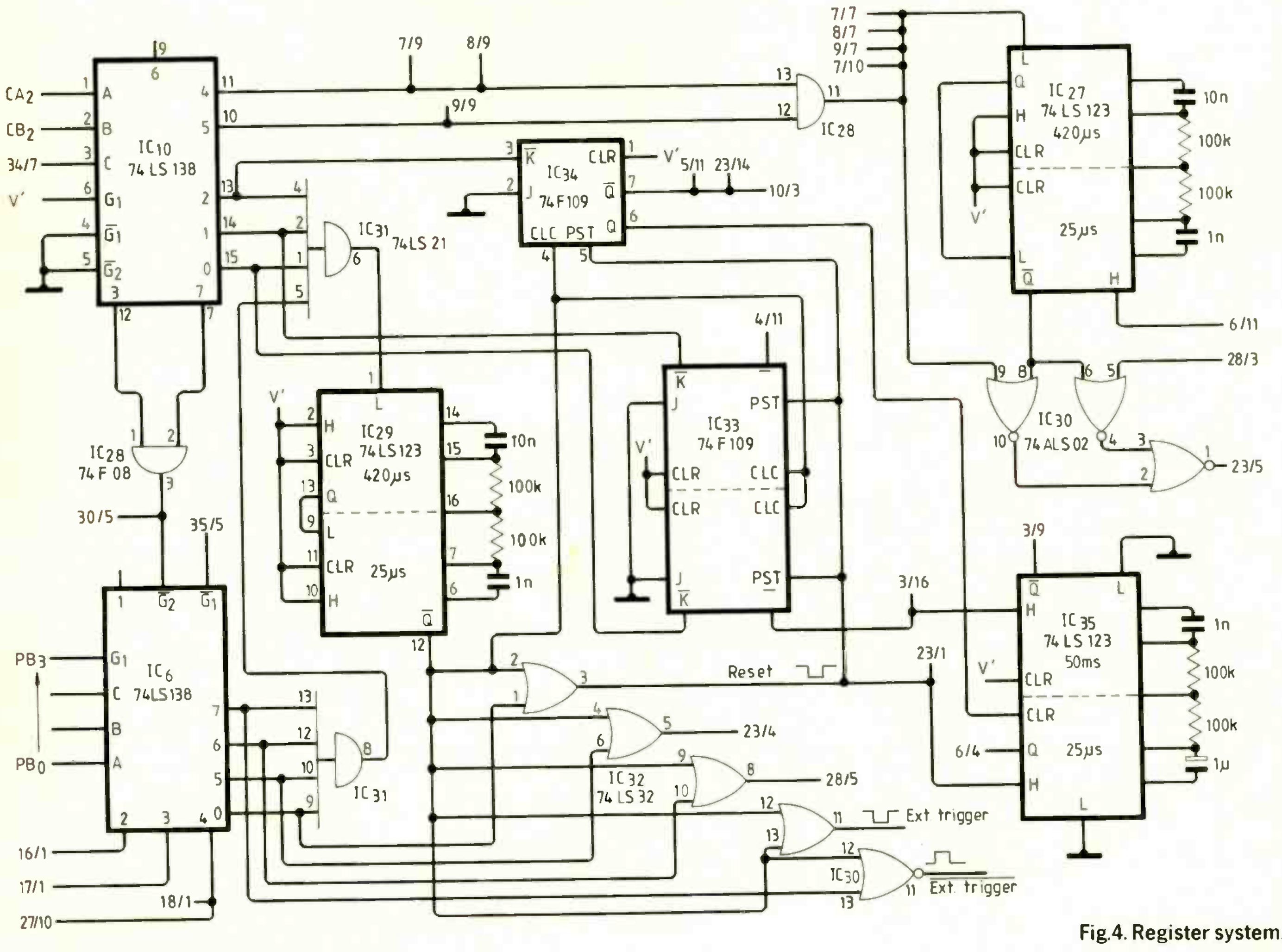


Fig.4. Register system.

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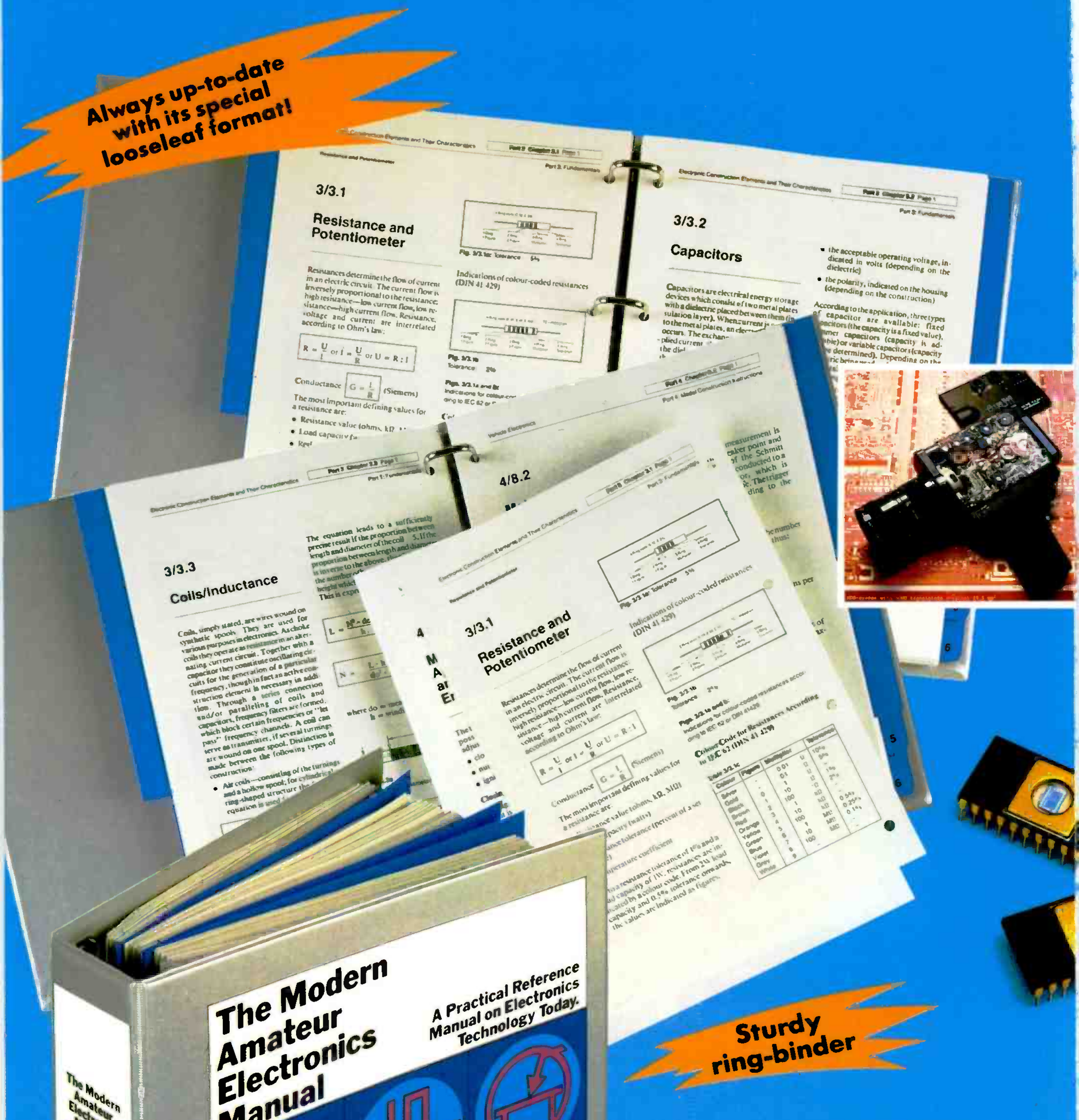

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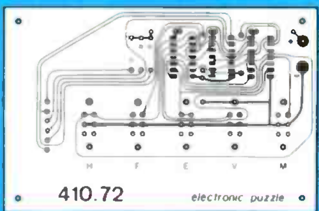

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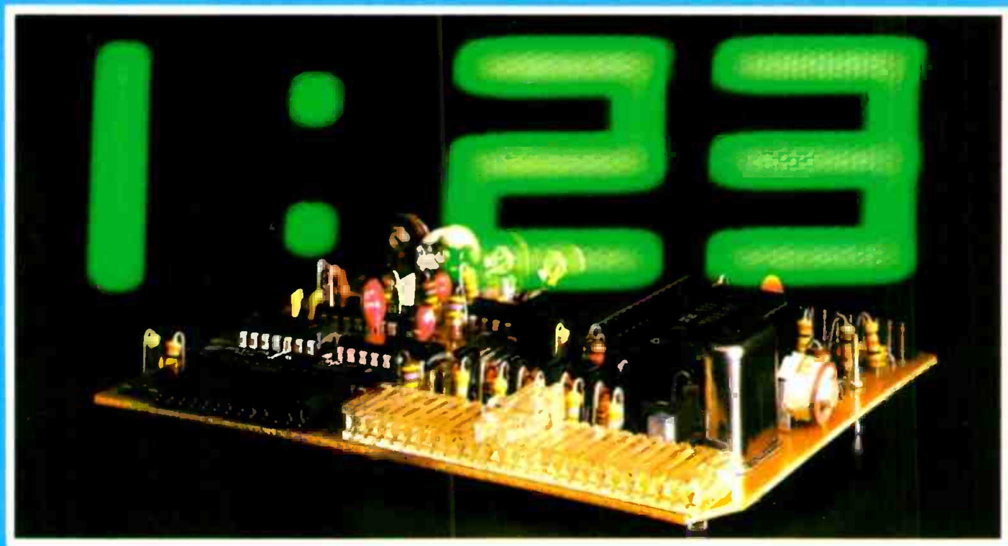

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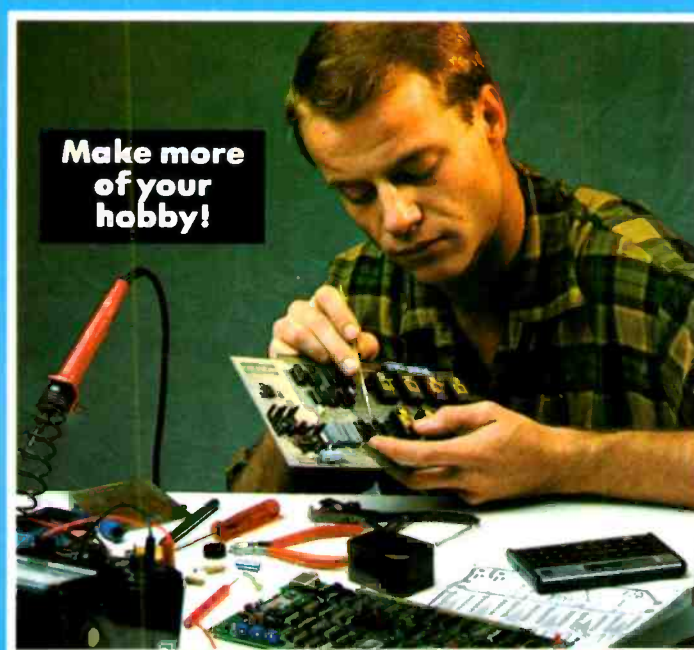

2. The input signal to the a-to-d can be started or stopped by a timing pulse generated under program control and appearing on pin 32/11 (negative-going) and on pin 30/13 (positive-going) simultaneously.

3. If a free-running or intermittent input signal is applied to the a-to-d, it is better to use the a-to-d's output data lines. Use is made of two 74F125, of which all eight three-state outputs are connected to pin 23/12 and via a pull-up register to the 5V rail. Each gate input of the buffers is connected to an outpin pin of IC_{37}. With the three-state control input one can enable or disable a particular buffer. With all control inputs high, then the eight common outputs are all high, and there is no trigger pulse. If the buffer connected to the m.s.b. (pin 37/27) is enabled (its control input low), then only when pin 37/27 goes high will the common output go high and trigger IC_{23}. With 256 possible combinations, one can set the trigger pulse at pin 23/12 at a very precise level.

A PRACTICAL EXAMPLE

Let the signal under study be a pulse with a width of 10μs and an amplitude of 2V. Because we are working here with short-duration phenomena, we select a 50 nanosecond step and for the display on the monitor a timebase of 20μs. To give a clear view of the rising edge of the pulse, a pre-trigger address is chosen to give a 20% clearance between the start of the sweep and the pulse under study. For a timebase of 20μs, this calls for 400 memory locations, because the memory counter steps at 20 locations per microsecond; 20% of 400 is 80 memory locations. Let the trigger pulse applied to pin 23/12 be derived from the (fast) rising edge of the pulse under study. After the trigger pulse has been applied to pin 23/12, the memory address will be latched into $IC_{16,17}$ and a flag set on pin 1/40. This flag will be acknowledged by the p.i.a. 6522 and program control will take over.

If the memory address latched into $IC_{16,17}$ is 1666, the pre-trigger address is then 1666 − 80 = 1586, which is the start address now in $IC_{7,8,9}$. Program control steps the memory counters a total of 399 times until the address 1985 has been reached. This means that the horizontal line in the monitor (the timebase) starts at address 1586 and ends at 1985, a total of 400 memory locations. Using the program TRFD the user can find the minimum and maximum value of the signal under study and also the value corresponding to addresses 1586 up to 1985. Three markers are included in the display, for the trigger address and minimum and maximum value addresses.

PRACTICAL NOTES

It is not advisable to build the two amplifiers together on one single p.c.b. board, because the t.t.l.-e.c.l. converters of IC_{37} tend to produce noise which is picked up by the input of the first amplifier. The supply lines leading to the combined a-to-d/d-to-a ought to be very well decoupled. Connect the analogue ground pins (pins 24 and 37) directly to the amplifier's ground.

For IC_{19}, use SSM 6116, 25 nanosecond (Saratoga), and for IC_{37}, UVC 3101 (STC).

This program retrieves stored data from the disc and generates the basic functions of a transient analyser.

```
10 REM MODULE 1 (DATA FROM DISC)
20 REM:PROGRAM NAME IS TRFD
30 REM:DATA(TRANS.ANALYSER)FROM DISC
40 CLS:MODE 4
50 PRINTTAB(0,0)"DATA FROM DISC"
60 INPUTTAB(0,1)"NAME FILE=",A$
70 PRINTTAB(0,2)"
80 CD=OPENIN A$
90 IF CD=0 THEN 200
100 INPUT#CD,U:INPUT#CD,B
110 INPUT#CD,N:INPUT#CD,F
120 INPUT#CD,T:INPUT#CD,Q:INPUT#CD,E
130 PRINTTAB(0,2)"LOADING DATA=";N
140 DIM A(N):REM DATA INTO ARRAY
150 FOR I=0 TO N-1
160 PRINTTAB(21,2);I
170 INPUT#CD,A(I):NEXT I
180 CLOSE#CD:CLS
190 IF CD<>0 THEN 220
200 PRINTTAB(0,2)"FILE NOT FOUND"
210 IF CD=0 THEN 60
220 REM   MODULE 2(PRINT,PLOT GRAPH)
230 GCOL 0,3:REM WHITE
240 PRINTTAB(0,0)"TIME BASE(ms)=";U
250 PRINTTAB(0,1)"SAMPLE FR(mms)=";B
260 PRINTTAB(0,2)"MEM.LOCATIONS=";N
270 PRINTTAB(0,3)"PRETRIGGER(%)=";F
280 PRINTTAB(21,0)"ADD.TRIGGER=";T
290 PRINTTAB(21,1)"START ADDRESS=";Q
300 PRINTTAB(21,2)"END ADDRESS=";E
310 INPUTTAB(21,4)"PLOT MULTP.=",G
320 X=(1279/(N-1)):REM GRAPH
330 PLOT 4,X,(A(0)*G)+40
340 FOR I=0 TO (N-1)
350 PLOT 5,X*I,(A(I)*G)+40:NEXT I
360 Y=T-Q:IF Y<0 THEN Y=T-Q+2048
370 PLOT 4,X*Y,20:REM TRIGG.MARKER
380 PLOT 5,X*Y,(A(Y)*G)+20
390 REM      MODULE 3(EXPAND)
400 I=0:P=0:J=0:L=-99:REM SPACEBAR
410 PRINTTAB(21,4)"HIT SPACEBAR=STOP"
420 INPUTTAB(21,3)"MARKER STEP=",D
430 D=D+N DIV 200:IF D=0 THEN D=5
440 GCOL 0,3:REM WHITE
450 PLOT 4,X*1,0:PLOT 5,X*I,A(I)*G
460 C=Q+I:IF C<=2047 THEN 490
470 C=Q+I:IF C>2047 THEN C=Q+I-2048
480 PRINTTAB(21,5)"
490 PRINTTAB(21,5)"CH.COUNTER=";C
500 H=20:iF I=0 THEN H=150
510 keynumber=INKEY(H):M=INKEY(L)
520 IF M=-1 AND P=0 THEN P=1:GOTO 600
530 IF M=-1 AND P=1 THEN 670
540 GCOL 0,0:REM BLACK
550 PLOT 4,X*I,0:PLOT 5,X*I,A(I)*G
560 I=I+D:REM CHANNEL COUNTER
570 IF I>=N AND P=0 THEN CLS:GOTO 230
580 IF I>=N AND P=1 THENI=N-1:GOT0670
590 GOTO 440
600 J=I:R=Q+J:IFR>2047THEN R=Q+J-2048
610 PRINTTAB(0,4)"CHANNEL(L)=";R
620 PRINTTAB(0,5)"CH(L)VALUE=";A(J)
630 PRINTTAB(21,3)"
640 INPUTTAB(21,3)"MARKER STEP=",D
650 D=D+N DIV 200:IF D=0 THEN D=5
660 GOTO 560
670 K=I:S=Q+I:IFS>2047THEN S=Q+I-2048
680 PRINTTAB(0,6)"CHANNEL(R)=";S
690 PRINTTAB(0,7)"CH(R)VALUE=";A(K)
700 W=S-R:IF W<0 THEN W=S-R+2048
710 V=(S-R)+1:IF V<0 THEN V=S-R+2049
720 IF W<=0 THEN 230
730 PRINTTAB(21,5)"(START-END)CHS=";V
740 finishtime=TIME+200:REPEAT
750 UNTIL TIME>=finishtime:REM DELAY
760 REM:MODULE 4(EXPANDED DISPLAY)
770 GCOL 0,3:REM WHITE
780 CLS:X=1279/W:REM EX.GRAPH
790 PLOT 4,X,(A(J)*G)+40
800 FOR I=0 TO W
810 PLOT 5,X*I,(A(J+I)*G)+40:NEXT I
820 D=(V*U)/N:REM TIMEBASE EXP.GRAPH
830 PRINTTAB(0,0)"CHANNEL(L)=";R
840 PRINTTAB(0,1)"CH(L)VALUE=";A(J)
850 PRINTTAB(0,2)"CHANNEL(R)=";S
860 PRINTTAB(0,3)"CH(R)VALUE=";A(K)
870 PRINTTAB(21,0)"TB.EXP(ms)=";D
880 PRINTTAB(21,1)"(START-END)CHS=";V
890 REM:MODULE 5(MIN MAX VALUES)
900 INPUTTAB(21,2)"MINIM.VALUE=",L
910 IF L=9999 THEN CLS:GOTO 230
920 FOR I=0 TO W
930 PRINTTAB(21,2)"MINIM.VALUE =";L
940 IF A(J+I)=L THEN 970
950 NEXT I
960 L=L+1:GOTO 920
970 C=I+R:IF C>2047 THEN C=I+R-2048
980 PRINTTAB(21,3)"CHN.WITH MIN.=";C
990 PLOT 4,X*I,0:REM MARKER(MIN)
1000 PLOT 5,X*I,(A(J+I)*G)+40
1010 INPUTTAB(21,4)"MAXIM.VALUE=",M
1020 IF M=9999 THEN CLS:GOTO 230
1030 FOR I=0 TO W
1040 PRINTTAB(21,4)"MAXIM.VALUE =";M
1050 IF A(J+I)=M THEN 1080
1060 NEXT I
1070 M=M-1:GOTO 1030
1080 Z=I+R:IF Z>2047 THEN Z=I+R-2048
1090 PRINTTAB(21,5)"CHN.WITHMAX.=";Z
1100 PLOT 4,X*I,0:REM MARKER(MAX)
1110 PLOT 5,X*I,(A(J+I)*G)+40:K=0
1120 REM:MODULE 6 (SELECT CHANNEL)
1130 INPUTTAB(0,4)"GO TO CHAN(X)="D
1140 IF D=9999 THEN CLS:GOTO 230
1150 IF D>2047 THEN 1400
1160 IF K<>0 THEN 1280
1170 IF S>R THEN 1210:REM CH(L),CH(R)
1180 IF S<R THEN 1190
1190 IF D>=R OR D<=S THEN 1250
1200 GOTO 1400
1210 IF D<R OR D>S THEN 1400
1220 PRINTTAB(0,4)"
1230 PRINTTAB(0,5)"
1240 PRINTTAB(0,4)"GO TO CHAN(X)=";D
1250 I=D-R:IF I<0 THEN I=D-R+2048
1260 J=D-Q:IF J<0 THEN J=D-Q+2048
1270 GOTO 1340
1280 GCOL 0,0:REM BLACK
1290 PLOT 4,X*I,0:REM MARKER CH(X)
1300 PLOT 5,X*I,(A(J)*G)+40
1310 GOTO 1170
1320 I=D-R:IF I<0 THEN I=D-R+2048
1330 J=D-Q:IF J<0 THEN J=D-Q+2048:K=0
1340 GCOL 0,3:REM WHITE
1350 PRINTTAB(0,5)"
1360 PRINTTAB(0,5)"CH(X)VALUE=";A(J)
1370 PLOT 4,X*I,0:REM PLOT MARKER(X)
1380 PLOT 5,X*I,(A(J)*G)+40
1390 K=K+1:GOTO 1130
1400 PRINTTAB(0,5)"CH(X) OUT OF RANGE"
1410 GOTO 1130
1420 END
```

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Kalman filtering – noise-corrupted signal processing

The Kalman filter can out-perform a first-order l.p. filter and will provide an element of state prediction.

G. F. STEVEN

The Kalman filter is now over 25 years old, but has only achieved wider application in recent years because of more accessible, faster and cheaper means for its computation. The term "filter" applies because of its ability to reduce the effects of noise on a signal, but the Kalman filter is more correctly called a State Estimator, the term "state" being used to describe an attribute of a system. Thus, if we consider an aircraft being tracked by radar, the aircraft states of interest might be its course, height and speed; these states would need to be correctly assessed, say, for the purposes of air traffic control. In this case a Kalman filter might be used to estimate the "states" of the aircraft, based on radar measurements.

This example is deliberately chosen, not only because it is a textbook example of Kalman filter application, but also because it underscores the fact that such techniques, at least until recently, have been associated predominantely with the space, defence and communications industries.

NOISE ASPECTS

Kalman filtering is used to process signals which are corrupted by noise, which can be interpreted here not only in its conventional sense of "unwanted signal" but also to express the idea of uncertainty. Thus, fluctuations in the Financial Times Index or changes in national unemployment figures could both be considered as examples of uncertainty or noise superimposed on an underlying trend or signal.

Such noise may arise within the system itself and is variously known as process, plant or system noise. It is associated with uncertainty in the dynamics of the system (such as in weather forecasting). Alternatively, noise may arise within the observation mechanism or sensor, when it is known as observation or measurement noise. It can arise for a variety of reasons: for example, electrical and/or mechanical inaccuracies in the sensor such as training misalignment and backlash in the radar tracking example above; or because of arithmetic resolution in the computing elements, rounding off errors and limitations inherent in the computing algorithms. However, to simplify the mathematics, fundamental assumptions are made concerning both process and observation noise which have a bearing on the development and application of the Kalman filter.

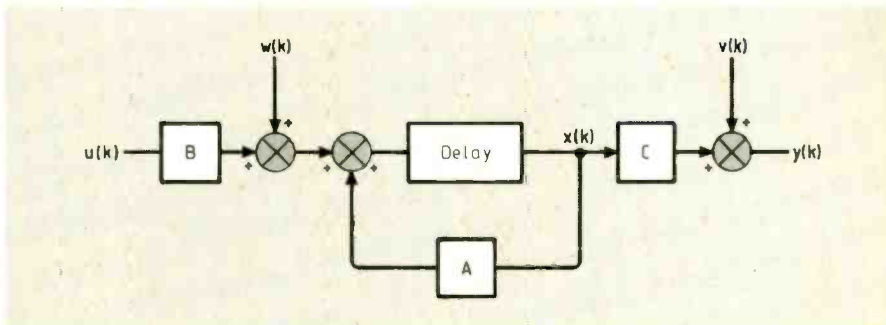


Fig.1. System diagram of a Kalman state estimator.

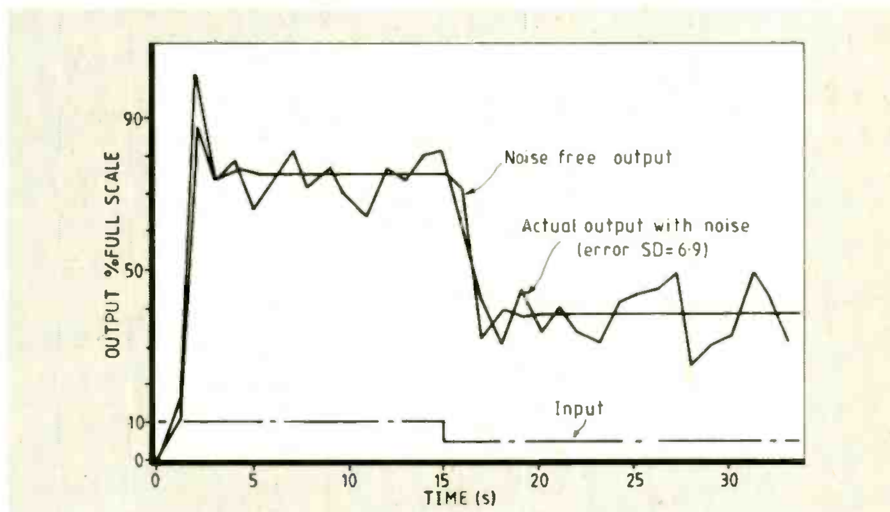


Fig.2. Model representing ideal and noisy behaviour of airflow, providing an input to the Kalman filter.

GENERAL FEATURES

The Kalman filtering operation is generally concerned with discrete-time or sampled-data systems. The filter output at any particular instant is a weighted combination of two elements: a prediction of the correct output at that instant, based on earlier data; and a noisy observation made at that instant.

The weighting of each element depends on whether the filter places greater faith in its own prediction or on the observation, bearing in mind that both are subject to uncertainty. Thus, the composite output is an intuitively acceptable combination of prediction and observation, in which the error in the combination is less than either of the errors in the components taken separately.

KALMAN FILTER FORMULATION

Consider the simple case where a single-input, single-output system is subject to process and observation noise as referred to previously. We are concerned with the state of that system and can write in standard state space form:

$$x(k+1)=Ax(k)+Bu(k)+w(k) \quad (1)$$

(process equation)

$$y(k)=Cx(k)+v(k) \quad (2)$$

(observation equation)

where $y(k)$ is an observation at time k, $x(k)$ is the system state at time k. A and C are linear scaling factors. $w(k)$ and $v(k)$ are process and observation noise components respectively. These equations can be expressed diagrammatically as in Fig.1.

We assume that the noise sequences w(1), w(2) . . . w(k) and v(1), v(2) . . . v(k) have zero mean, that each successive value of noise is independent of previous values and that w(k) and v(k) sequences are independent of each other. Further, we assume that the state x(k) is similarly independent of either of the noise values w(k) and v(k). These assumptions need to be borne in mind and checked for validity when any particular application of Kalman filter is being considered. Extensions to the theory do exist to cater for departure from these assumptions, but are not considered here.

We now make three further fundamental assertions in the formulation of the Kalman filter.

(1) On average, the difference between estimated state and actual state at time k is zero. This is expressed notationally as:

$$E[\tilde{x}(k)]=E[\hat{x}(k)-x(k)]=0$$

Where E is the expectation, or "averaging", operator and $\hat{x}(k)$ the estimated value of x(k). This is termed an unbiassed estimate.

(2) The expected value of the square of the previously mentioned error is a minimum. This is the "minimum mean square error" (m.m.s.e.) criterion and is expressed notationally as:

$$\min E[\hat{x}(k)-x(k)]^2 \text{ or } \min E[\tilde{x}(k)]^2$$

The estimate of state at time k is a linear combination of observation at time k and prediction of the state at time k based on previous data thus:

$$\hat{x}(k/k)=J(k)\hat{x}(k/k-1)+K(k)y(k) \qquad (3)$$

where notationally $\hat{x}(k/k)$ = estimate of state based on data up to present time k and $\hat{x}(k/k-1)$ is an estimate of state at time k based on data up to time (k−1): i.e. a one-step-ahead prediction. y(k), of course, is an observation at time k. J(k) and K(k) are both weighting factors which may be time-varying and are therefore shown as functions of k.

We now have all the required information to formulate a Kalman filter. Making substitution into (3) from the observation equation for y(k):

$$\hat{x}(k/k)=J(k)\hat{x}(k/k-1)+K(k)[Cx(k)+v(k)]$$

Taking expectations (strictly, unconditional expectations)

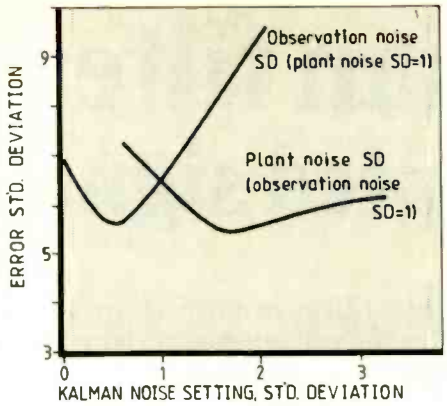


Fig.3. Variation of error, showing that proper choice of plant and observation noise setting can reduce estimate error.

$$E[\hat{x}(k)]=J(k)E[x(k)]+K(k).$$
$$CE[x(k)]+K(k)E[v(k)] \qquad (4)$$

Note that the last term on the r.h.s. is zero, from the assumption that the noise is zero mean. Now, referring to the requirement for unbiassedness, $E[\hat{x}(k)-x(k)]=0$ implies that $E[\hat{x}(k)]=E[x(k)]$.

Therefore expression (4) reduces to

$$J(k)=1-CK(k) \qquad (5)$$

Substituting (5) into (3),

$$\hat{x}(k/k)=\hat{x}(k/k-1)+K(k)[y(k)-C\hat{x}(k/k-1)] \qquad (6)$$

Equation (6) embodies the idea of filter output consisting of a combination of predicted and observed data. We now wish to evaluate K(k), commonly, known as the Kalman gain. Examining the m.m.s.e. requirement, repeat (6) $\hat{x}(k/k)=\hat{x}(k/k-1)+K(k)[y(k)-C\hat{x}(k/k-1)]$

subtracting x(k)

$$\hat{x}(k/k)-x(k)=\text{"error"}$$
$$=\hat{x}(k/k-1)+K(k)[Cx(k)+v(k)-C\hat{x}(k/k-1)]-x(k)$$
$$=[1-K(k)C]\,\hat{x}(k/k-1)-x(k)+K(k)v(k)$$

Squaring and taking expectations,

$$E[x(k/k)-x(k)]^2=\text{"mean square error"}$$
$$=E[(1-K(k)C)(\hat{x}(k/k-1)-x(k))+(k)v(k)]^2$$

Fig.4. Plot of estimates against true airflow after choosing combination of noise values, to be compared with Fig.2.

Now, if the r.h.s is expanded as a squared expression and expectations taken, the following results are obtained. It must be remembered that we have assumed that noise sequences and states are not correlated and therefore the expectation of these cross products is zero.

Also $E[v(k)v(k)]=\sigma_v^2$, observation noise variance by definition.

We define $E[x(k/k)-x(k)]^2$ as P(k/k),

and $E[x(k/k-1)-x(k)]^2$ as $P(k/k-1)^2$.

Thus $P(k/k)=[1-K(k)C]^2.$
$P(k/k-1)+K(k)^2\sigma_v^2$

We wish to minimize this expression with respect to K(k) to arrive at the m.m.s.e. criterion. This may be done by differentiation methods; however, a more straightforward method is to carry out a completion of square procedure as follows.

$$P(k/k)=[C^2P[k/k-1)+\sigma_v^2]K(k)^2-2CP(k/k-1)K(k)+P(k/k-1)$$
$$=[C^2P[k/k-1)+\sigma_v^2]\left[K(k)^2-\frac{2CP(k/k-1)K(k)}{C^2P(k/k-1)+\sigma_v^2}\right]+P(k/k-1)$$
$$=[C^2P[k/k-1)+\sigma_v^2]\left[K(k)-\frac{CP(k/k-1)}{C^2P(k/k-1)+\sigma_v^2}\right]^2+P(k/k-1)-\frac{C^2P(k/k-1)^2}{C^2P(k/k-1)+\sigma_v^2}$$

and this is minimized, by inspection, when

$$K(k)=\frac{CP(k/k-1)}{C^2P(k/k-1)+\sigma_v^2} \qquad (7)$$

by back substitution,

$$P(k/k)=P(k/k-1)-\frac{C^2P(k/k-1)^2}{C^2P(k/k-1)+\sigma_v^2} \qquad (8)$$

$$=\frac{\sigma_v^2P(k/k-1)}{C^2P(k/k-1)+\sigma_v^2} \qquad (9)$$

Re-expressing (8):

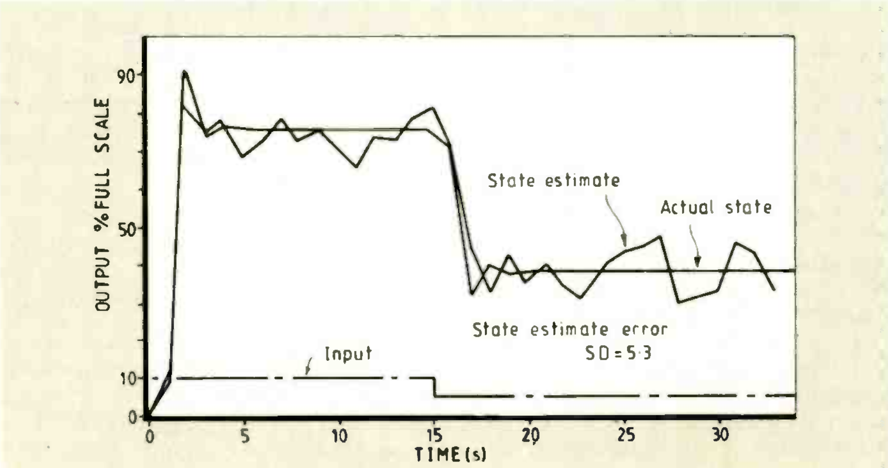
$$P(k/k)=P(k\text{-}k-1)[1-CK(k)] \qquad (10)$$

Now, $x(k+1)=Ax(k)+Bu(k)+w(k)$ again.
Thus, $\hat{x}(k+1)=A\hat{x}(k)+Bu'(k)$,
and $\hat{x}(k+1)-x(k+1)=A[\hat{x}(k)-x(k)]-w(k)$

Squaring and averaging (hence mean square error) and assuming noise is uncorrelated with states gives:

$$P(k+1/k)=A^2P(k/k)+\sigma_w^2 \qquad (11)$$

where σ_w^2 is the plant noise variance.



KALMAN FILTER OPERATION

We now have the complete formulation of all computational steps to allow the Kalman filter to estimate system state from successive observations of system output. These steps involve iterations of the following sequence.

1. Calculate Kalman gain (equation 7).
2. Input new observation, update current estimate (equation 6).
3. Update the current m.m.s.e. estimate (equation 10).
4. Input new control if known. Generate new state prediction (equation 1).
5. Generate a new m.m.s.e. prediction (equation 11).

6. Repeat from step 1, at new sample instant. The necessary expressions used in such filtering are summarized below for reference. They are shown in the order in which they might be used in a practical situation:

Kalman gain $$K(k)=\frac{CP(k/k-1)}{C^2P(k/k-1)+\sigma_v^2} \qquad (7)$$

Current state estimate

$$\hat{x}(k/k)=\hat{x}(k/k-1)+K(k)[y(k)-C\hat{x}(k/k-1)] \qquad (6)$$

Current m.m.s.e. estimate

$$P(k/k)=P(k/k-1)[1-CK(k)] \qquad (10)$$

New state prediction

$$x(k+1)=Ax(k)+Bu(k)+w(k) \qquad (1)$$

New m.m.s.e. prediction

$$P(k+1/k)=A^2P(k/k)+\sigma_w^2 \qquad (11)$$

To start the computational sequence, initial values need to be chosen for $P(k/k-1)$ and $\hat{x}(k/k-1)$, that is, $P(1/0)$ and $\hat{x}(1/0)$ respectively. Values for noise variances are assumed to be known.

AN EXAMPLE

The application of a simple, scalar Kalman filter can be illustrated in a real example where airflow within an industrial dryer was to be estimated using a single anemometer. Airflow distribution in such an application is complex and measured airflow is subject both to actual disturbances in the dryer and to inaccuracies within the anemometer.

To cope with the degree of uncertainty in airflow measurement it was decided to pass the anemometer output through a Kalman filter in order to make optimal estimates of actual airflow. As already stated, noise variances for the plant and sensor needed to be quantified beforehand, and some value for m.m.s.e. and state estimates were required to start off the filter algorithm. These values

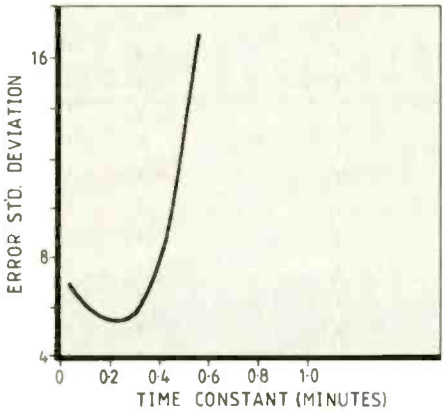


Fig.5. Plot of estimate error against time-constant of first-order filter, showing that its best performance is poorer than that of Fig.4.

were found by experiment: a simple mathematical model of the plant's behaviour was determined following a series of step response tests carried out on the dryer and from which process and observation equation parameters were evaluated. This model was run on a hand-held calculator with a value of noise superimposed on the noise-free model output, sufficient for its performance to represent that of the actual plant. Thus a record of true airflow and noisy airflow measurements were available for feeding into a Kalman filter. A plot of such values appears in Fig.2.

The filter algorithm was based on the filter equations quoted earlier and run on the same hand-held calculator. The airflow measurement record was applied to the filter for a variety of plant and observation noise settings and error between filter output and true airflow were determined; a simple statistical analysis was then carried out to find the values of plant and observation noise that yielded the best estimate of airflow, ie: minimum standard deviation (S.D.) in estimate error.

The variation of estimate error – accuracy – with plant and observation noise settings is shown in Fig.3. This figure shows that estimate error can be minimized by judicious selection of plant and observation noise figures. The Kalman filter was again run with the best combination of noise values and a plot of filter airlow estimates against true airflow is shown in Fig.4.

PASSIVE FILTERING

The airflow measurement record was also passed through a simple first-order filter for comparison purposes. A plot of estimate error against filter time constant is shown in Fig.5 which shows that the most accurate performance is not as good as that in Fig.4: a short time constant fails to filter out system noise and a long time constant degrades the filter's tracking performance. Against this, a simple Kalman filter provides reasonable steady state and tracking performance combined with a facility for state prediction, albeit at greater computation cost. In this application however, where a computer was to be used for airflow datalogging at slow sample rates, the inclusion of Kalman filtering to improve airflow measurements in the face of extremely noisy data would be considered to be a significant and worthwhile improvement.

Graham Steven, M.Sc. B.Sc., MIEE, is a Principal Engineer with EASAMS Ltd. Camberley, Surrey.

LEGO LOGO

Engineering training can now begin as early as primary school age, with the help of the Lego Control package. Using materials in the package, seven to 13-year-olds can construct simple machines from technical Lego pieces and then learn how to control them. Parts provided include motors, lamps and an optical sensor, all of which can be connected to a BBC microcomputer by an interface module.

High-level software is Logotron Logo (the most popular Logo in British schools) with control extensions. A special feature of these is the Setpower command, which can prevent tearful mishaps of the kind that occur when a newly-completed motorized buggy careers off the table at full throttle on its first outing. (Tip for parents, from Lego's splendidly-produced accompanying literature: for more shock-proof models, you can stick Lego bricks together temporarily with p.v.a. wood glue. Warm water and gentle scraping should remove the glue afterwards). Among the possibilities of the kit are a traffic light, a washing machine, a lift and a merry-go-round.

Several schools have been trying the system over the last two years and all are enthusiastic about it, says Lego – even ones which had little or no computer experience. And the company stresses that the package has proved helpful right across the curriculum, not just in the mathematical area. Themes for broader projects are described in one of the six booklets in the comprehensive information package. Lego Control Logo also has the blessing of Seymour Papert, the father of Logo.

Price for the interface, construction kit and resource pack is about £300; all are available from educational suppliers. Lego UK Ltd, Educational Division, Wrexham, Clwyd LL13 7TQ.

SIDEBANDS BY MIXER

Moving literature

We're at it again. Every so often, someone here decides that we've all been in our offices too long and that we ought really to be moved a bit. The trouble is that people keep being given new jobs with an office to themselves, which means that everyone else has to shuffle up like a lot of cab-horses to make space.

It doesn't usually matter too much, but in our case there is the library to consider. We (I, actually) have just finished packing everything up in bright orange boxes for the move to a cleverly selected position where we can't get at it so easily. All the junk had to be tossed out, because the new location is too small to take all the stuff we had, and that naturally meant that it all had to be scanned and, occasionally, given the "thumbs down". You do come across some interesting reading this way, though.

For instance, the very first issue of *The Wireless World* from 1913, bound volumes of *Experimental Wireless* and more issues of IEEE *Transactions* than most libraries could boast all saw the light of day for the first time in eight years. The problem lies in knowing which to keep: masses of information on Quantum Theory do not seem to be highly relevant, but, as I have said before, the day after it is given the chop one article from about 1947 is inevitably needed in a great hurry.

One set of boxes I came across had in them the binders for six issues of the journal in its stapled period of a few years ago. If anyone would like them, they can have a pair for £2. I hope someone will have them, because we're running out of space.

Don't fence me in

The only captions I could come up with for this picture involved concepts which, I am sure, are foreign to the nature of *EWW* readers. It shows a BT engineer mending a telephone cable right in the middle of the Dee estuary and illustrates the length that BT will go to keep its subscribers happy; there is, apparently, only one telephone on the end of this cable – on an island in the river. This area is normally several feet deep in Irish Sea.

I feel sure that someone will be able to contribute a caption which treats the subject in the proper spirit, whatever that is, and will arrange a year's subscription to *EWW* for the best one sent in.

Acronymics Anonymous

After many years of research, I am forced to the inescapable conclusion that there lurks, in some remote and heavily guarded cell in a Western capital, a grey-faced, shabby, single-minded former crossword addict, who was kidnapped several years ago by a consortium of p.r. companies and made to earn his single daily meal of left-overs from press receptions by composing acronyms for new products.

What does slightly worry me is that there might be a temptation to tailor the product to fit the acronym. For example, it is not widely known that first-in, first-out registers were originally designed as first-in, Heaven-knows-when-out registers, but had to be modified because fiHkw didn't seem to flow too well.

I now have a data sheet from Motorola on their MC3419-1L telephone line-feed circuit, which provides BORSHT functions. This, it is said, provides (Battery), Overvoltage protection, Supervision, two-wire to four-wire conversion (Hybrid), Ring trip detection and Testing. Everything else it does doesn't fit into the acronym. But think of the temptation, when faced by this elliptic BORSHT, to change the chip so that it does something elese starting with C and to ditch the Testing bit so that it could be called a BORSCH. It might be arranged to Cut out obscene 'phone calls or to Control something. It might even be necessary to alter the whole thing to Supervision and Overvoltage protection while Under Power and hang the rest – it's probably unnecessary anyway.

Driver's mate

I seem to have seen a good deal about car navigation systems recently. There are the inertial kind, the radio kind and several others the hang of which I have not yet got. But, however they work, I can hardly wait to have one insinuated into my car – I have never fully understood why car designers start with the radio and build the car round it, thereby making it necessary to train intelligent octopuses to service it, or to change the installation.

Thing is, my wife is a first-class navigator who labours under the delusion that I am clairvoyant. Her idea of a direction to the driver is something along the lines of "Turn left before you get to the little side road leading to the Shell garage". Or she will say "Turn here" and when we finish up in someone's garden "No, the next one". So I am hoping that the new electronic ones won't assume that I am able to see into the future to quite that extent.

What I would like to have, please, is something that will tell me "You need to bear right in 300 yards, but watch the dreadful pothole five feet from the kerb as you turn and ease off on the loud pedal because there's a speed trap in half a mile." Or, in my case, "Speed up a bit because you're getting to a 30 mile/h area".

If it could also be arranged that the device would be able to flash rude messages to people flashing at me from behind, that would be most gratifying.

Fly-by-committee

I heard an A320 test pilot describing the control system to a television interviewer last week. The A320 is a "fly-by-wire" aircraft, which means that the pilot does not move the control surfaces and engine controls directly, but via computers. This means that the aeroplane is never asked to perform outside its designed flight envelope and that the engines burn fuel more economically. Flight management, it's called.

But I did wonder when the test pilot said that four computers out of seven on the aircraft were concerned with the flight controls. I would have thought that an odd number would have been needed to avoid deadlock between computers. If one of them disagrees with the others – no problem; it's outvoted. But if two disagree with the other two, there's a "Yes it is, no it isn't," condition which could very easily lead to tears. I expect the Airbus people have it all well worked out, but I do remember the old Trident, which had three computers for that very reason, having three engines and therefore three power supplies.

Magnets

Principles, uses and current status of permanent magnets – often taken far too much for granted

JOULES WATT

If you remember the time during your early days when you placed various objects in a magnetic field, the most notable observation pointed to the fact that some of the bits and pieces became strongly affected. These belong to the *ferromagnetic* group. You noticed others not affected – the non-magnetics, or if examined closely, more properly called the para and diamagnetic materials, which form by far the largest group. They have no further interest if we go on now to talk about magnets. The ferro and ferrimagnetic groups show fascinating properties, which we well and truly exploit in a wide range of technological devices.

You might have experimented with a piece of iron (ferromagnetic) and thereby established that placing it in a given magnetic field appears to enhance the field strength. In earlier discussions, I have said that, from one point of view, a magnetic force field vector (**H** amperes per metre) sets up a proportional flux vector which streams through unit area (**B** webers per square metre, or *teslas*). In empty space,

$$\mathbf{B}=\mu_0\mathbf{H}$$

where μ_0 is a kind of magnetic modulus of "elasticity" of space, which we call the *permeability* (henries per metre). In our present SI units μ_0 has the value $4\pi\times10^{-7}$ Hm^{-1}.

If you place a ferromagnetic substance in a given force field **H**, the flux density $\mu_0\mathbf{H}$ still exists as in empty space*, but in addition you find that a sometimes vast increase in flux appears due to some power in the elementary particles of the ferromagnetic to produce magnetization. We know that magnetic fields arise from circulating electric currents, so in the ferromagnetic material, some kind of current must turn on, or existing currents line up in some way under the externally applied **H**, thus augmenting the magnetic effects.

These "currents" themselves produce two effects – a total magnetic flux field linking them, together with a magnetic force field driving the flux.

From the first viewpoint, some authors denote the extra flux density generated by the material as the *polarization*, **J** tesla. This **J** sometimes acquires another name – the *magnetic moment per unit volume*. You can see the meaning of this by writing tesla in its more descriptive form of *weber per square meter*. Multiplying top and bottom of this by metres gives *weber. metres per cubic metre*, which agrees dimensionally with moment per unit volume. Thought about either way, the total flux in the region becomes

$$\mathbf{B}=\mu_0\mathbf{H}+\mathbf{J}$$

Alternatively, you can account for the increased magnetic effects by writing **M** Am^{-1} for the *magnetization* taken up by the material, so that

$$\mathbf{B}=\mu_0(\mathbf{H}+\mathbf{M})$$

Like **J**, **M** has a "moment" meaning, sometimes called the *area moment*. These quantities relate according to $\mathbf{J}=\mu_0\mathbf{M}$. Notice that **J** (or **M**) measures the amount by which the magnetic properties of a volume of space is altered by the presence of the material.

If you continued to experiment with the iron bar, placing it inside a coil passing a current to set up the magnetization, together with something to measure the flux density **B** – in other words a fluxmeter – then as Fig.1 shows, you could draw the initial magnetization curve for the sample. As I mentioned in the footnote, you would use a very long bar or a toroidal shape to get away from the effects of poles on nearby ends.

A number of points arise from the results. The non-linear relationship between **H** and **B** shows up straight away. **B** rises slowly at first, rapidly builds up, then tails off towards a saturated value. A very close look shows that **B** rises in small jumps as you increase the field **H**. We call this the *Barkhausen effect*.

Another point concerns the effective permeability, μ. In space **B** and **H** lie in the same direction and we can take the quotient of their magnitudes to get $\mu_0=B/H$, a constant as we have seen. The question arises concerning how we handle the appropriate quotient B/H in the iron? Assume for the moment that **B** and **H** lie in the same direction again. Divide $B=\mu_0H+J$ or $B=\mu_0(H+M)$ right through by H so obtaining either

$$\frac{B}{H}=\mu_0+\frac{J}{H} \text{ or } \frac{B}{H}=\mu_0\left(1+\frac{M}{H}\right)$$

Various authors call either J/H or M/H the *magnetic susceptibility* according to the convention they adopt. I have discussed both, so to clear up confusion we must distinguish between these two possibilities. We should call $J/H=K_a$ the *absolute* susceptibility, while $M/H=K_r$ carries the term *relative* susceptibility. The relation between them is $K_a=\mu_0K_r$.

From either equation for B/H you can write $\mu_r=1+M/H$ or $1+J/\mu_0H$, so that B/H $=\mu_0\mu_r=\mu$; therefore μ_r turns out to be the common or garden relative permeability of

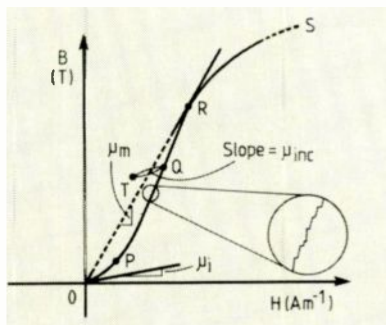


Fig.1. The relation between B and H in ferromagnetic materials is very non-linear. The various slopes from the origin give the permeabilities under different conditions. One of them, the incremental permeability, arises from the shallow slope Q-T as H oscillates along this path.

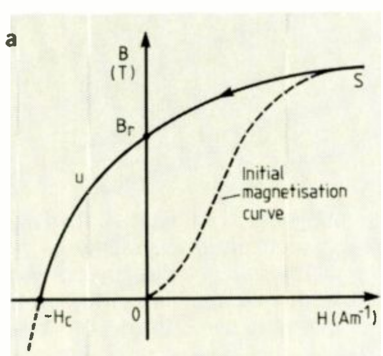
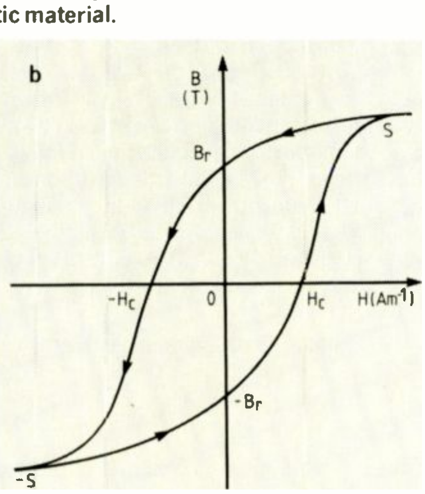


Fig.2. Looking at (a), moving back from saturation near S, a negative value of H eventually reduces the flux density to zero. The path from B_r to $-H_c$ carries the title *demagnetization curve*. The full curve in (b), obtained by going right through a complete magnetization cycle, shows the familiar *hysteresis curve* of a ferromagnetic material.



*The magnetic sample has to be very long, or in the form of a toroid so that "free poles" at the ends have little effect at the point of interest.

the ferromagnetic material, which, by the way, has no physical dimensions.

Although I have called μ_r the common or garden permeability of the iron, a quantity we all tend to take for granted, you should beware of doing so, because it is anything but simple. From Fig.1 you can see that μ_r and therefore μ vary greatly. So complication number one arises: we do not have one permeability for a magnetic material, but many.

The slope of the magnetization curve, B_i/H_i right down near the origin, gives the *initial permeability*, μ_i. Then, as we increase the force H (more current in the coil), B grows until B/H reaches the greatest slope at R. The *maximum permeability* occurs at this point. Further increases in magnetization cause μ to fall – the ferromagnetic material approaches *saturation*, at S.

It might be tempting (I know someone who tried) to find dB/dH at a point Q near the middle of the steep rise between P and R and claim that you had found the greatest *incremental permeability*. This would be erroneous, because immediately you would notice perculiar behaviour in trying to wobble the value of H up and down at Q. The value of B does not follow the initial magnetization curve at all, but moves along a small path such as QT, so that an incremental permeability does exist, but it is the slope of the considerably flatter line (or little loop in reality) QT.

Such peculiar behaviour always attracts much more interest, so investigating a little further shows that wherever we reverse H on the curve (after point P) the path of the magnetization moves off in a different direction. In particular, moving back from saturation follows a path such as S → U in Fig. 2(a), so that even when H reaches zero, there remains a flux density of B_r teslas in the iron. We call this the *remanance*. To get the flux density down to zero, you must apply a *reverse* field, minus H_c, termed the *coercive force*. Some authors call the maximum remanance – obtained by coming back from a saturating field strength the *retentivity*, and the corresponding maximum coercive force, the *coercivity*, so you have to keep your wits about you when considering who is using what term in this work. If you continue back with a reverse magnetizing field beyond the coercivity, the sample magnetizes to saturation in the other direction, so that cycling back and forth with a large peak H generates the lagging B locus moving round and round the familiar *hysteresis loop*, $-S$, $-B_r$, $+H_c$, $+S$, $+B_r$, $-H_c$ and back to $-S$, as shown in Fig. 2(b).

DOMAINS OF EXPLANATION

When anyone arrives at an interesting stage in a set of observations such as these, the question of a satisfactory explanation arises.

In the case of ferromagnetism, the crystal structure and entities called *domains* crop up early in the theory. Some time ago, *Wireless World* carried a series of articles about magnetic materials[3], so I will avoid going into great detail about them here and refer you to these articles and others[4] for further details.

But a brief word shows how successful the

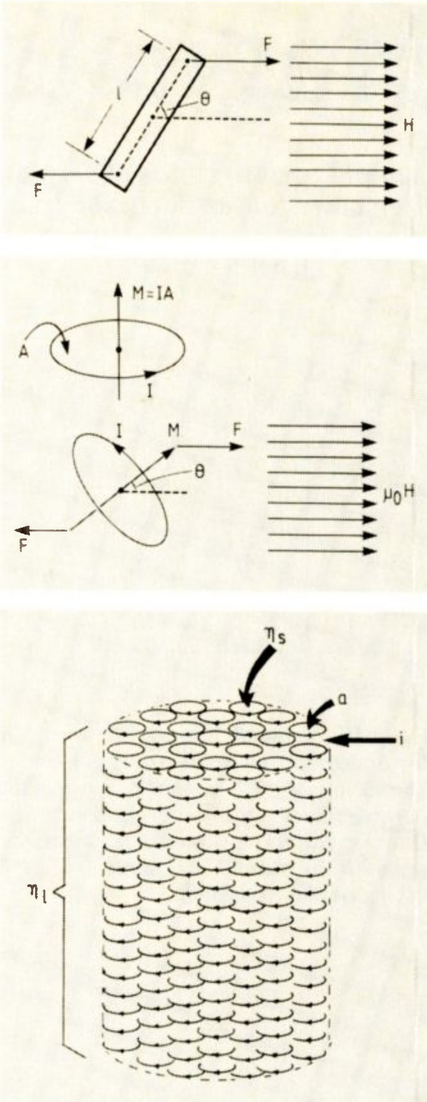


Fig.3. Magnets in an external field experience a torque or turning moment trying to align them a long the direction of the field lines. Hence the function of the magnetic compass. You can see the two ways of looking at this in (a) and (b). The relation between the elementary loop moments and the total moment should become clear from (c).

domain theory of ferromagnetism has been in explaining the initial magnetization curve, saturation, the Barkhausen effect and hysteresis. In the case of iron atoms, it all starts with four electrons spinning in phase so that each looks like a small current loop generating a magnetic field.

We can draw upon the two "moment" quantities, **J** and **M** to delve a little into the meaning of these small elementary currents and the moments of force acting on magnetized bodies. First look at **J**. Since this means the total moment per cubic metre in the magnetized sample, we can divide by the number of atoms per unit volume to get the average atomic moment; in other words,

magnetic dipole moment per atom

$$j=\frac{J}{N}=\frac{JV}{n}$$

where $N=n/V$ and n is the total number of atoms in the volume V.

Now volume $V = Sl$ for a bar of cross section S and length l.

$$\therefore \qquad J=\frac{nj}{Sl}$$

so that the total flux Φ issuing from the end of such a bar magnetized to saturation is

$$\Phi=JS=\frac{nj}{l}$$

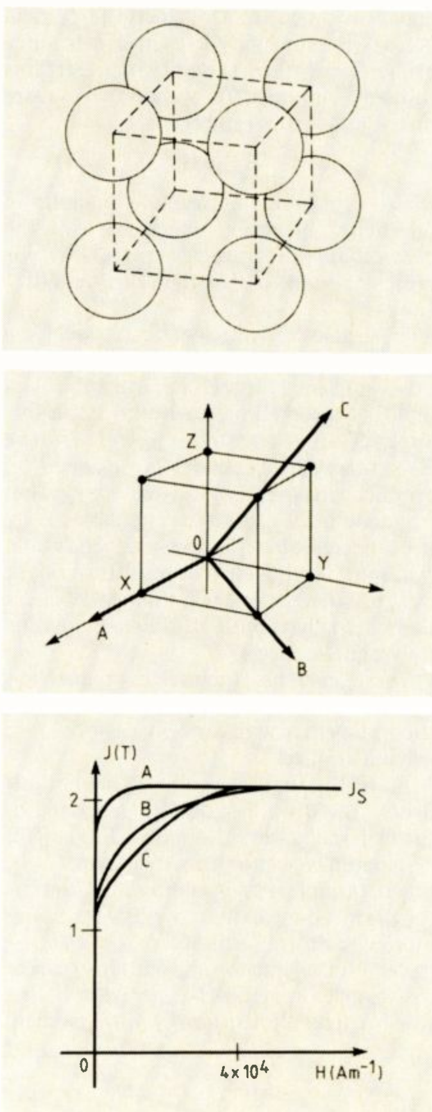
At last we arrive at the result. You find that the total magnetic moment of the sample, Φ multiplied by l, works out as

$$\Phi l=JSl=JV=nj$$

so that the total moment of any magnetized sample depends only on its volume and vector **J**, but not on the shape. The actual torque you will get acting on your bar by placing it in a uniform external force-field **H** is $\mathbf{T} = V\mathbf{J}\times\mathbf{H}$ newton-metres, as in Fig. 3(a) (vectors needed, of course). By the way, this result shows that you should work a compass needle as near to B_r as possible (maximum J), for a given amount of material in the needle.

The alternative of magnetic moment – the area moment I mentioned above – uses the "electric current" approach. Suppose a loop

Fig.4. Iron has the cubic crystal structure with preferred directions of easy magnetization, as the graph shows.



of area A has a current I amps flowing round the perimeter, as in Fig. 3(b). The product of I and A gives the area moment M ampère metres^2. If you place this into an external field written $\mu_0\mathbf{H}$ this time, in other words flux density, then the torque trying to turn the loop is $\mathbf{T} = \mathbf{M} \times \mu_0\mathbf{H}$ newton. metres.

Looking at each atom as a small circulating current shows that the area moment per atom $m = ia$, so from Figure 3(c) you can write.

$$n_s ia \times n_l = (n_l i)(n_s a) = IA = M = mn$$

where $n = n_s n_l$ the total number of atoms in the sample.

Finally on this point, the torque calculated from either viewpoint must be equal because we are describing the same bar, so that

$$\mathbf{T} = \mathbf{VJ} \times \mathbf{H} = \mathbf{M} \times \mu_0\mathbf{H}$$

$$\therefore \quad n\mathbf{j} \times \mathbf{H} = m n \times \mu_0 \mathbf{H}$$

$$\therefore \quad \mathbf{j} = \mu_0 \mathbf{m} \quad \text{at the atomic level.}$$

BOHR MAGNETONS

The atomic physicists handed down a convenient unit for measuring the magnetic moment per atom, named after one of their notables, Niels Bohr. Earlier we saw that the saturation magnetic moment $\mathbf{J} = N\mathbf{j}$. Further, we can write the magnitude of j as $n_{eff} j_B$, in which n_{eff} stands for the average number of Bohr magnetons of value j_B in each atom of the ferromagnetic.

To find out something about j_B, you require a small amount of physics. The equivalent current i of an electron going round at 2π radians per second in its classical orbit amounts to

$$i = -\frac{e\omega}{2\pi} \text{ amps}$$

The electronic charge $-e = 1.602 \times 10^{-19}$ coulombs. The area of the orbit $a = \pi r^2$, where r is the classical Bohr radius.

$$\therefore \quad j_B = \mu_0 ia = -\frac{\mu_0 e\omega\pi r^2}{2\pi} = -\frac{\mu_0 e\omega r^2}{2}$$

Subsequently, quantum mechanics entered the picture and required the classical result to be modified by introducing quantized angular momentum in units of $h/2\pi$, where h is Planck's constant. Ordinary angular momentum $\mathbf{p} = \mathbf{r} \times \mathbf{p} = mr^2\omega$, where $\mathbf{p} = mv = mr\omega$ is the ordinary linear momentum. Writing the Bohr Magneton as

$$j_B = -\frac{\mu_0 e}{2m} . mr^2\omega$$

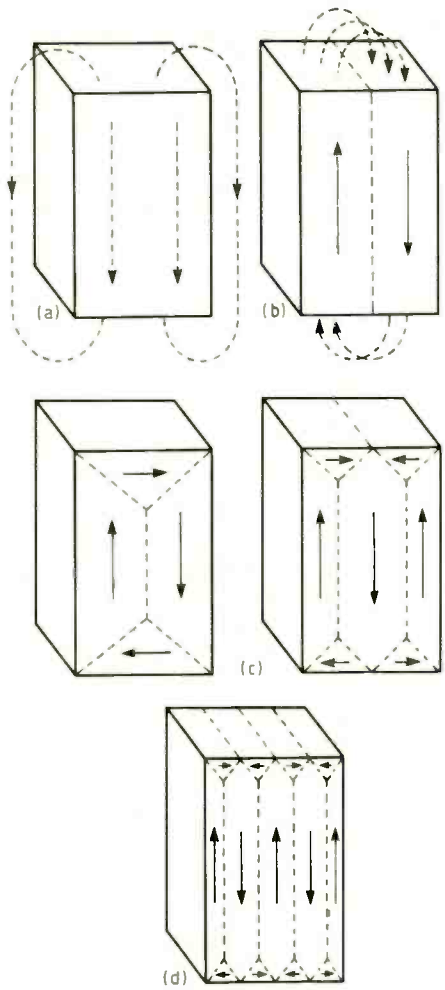
puts us in a position to replace the classical momentum with the quantum mechanical expression.

$$\therefore \quad jB = -\mu_0 \frac{e}{2m} . \frac{h}{2\pi}$$

so that by putting in all the fundamental physical constants (try it yourself...) the value of the Bohr magneton (itself a fundamental constant) becomes

$$j_B = 1.1653 \times 10^{-29} \text{ Wb m}$$

Fig.5. This sequence of steps gives a simple picture of *domain formation*. From the single magnetized rectangular block in (a) the final domain structure in (d) has minimized the energy. "Walls" between the domains must exist, of course, and the more of these there are, the greater the local energy again.



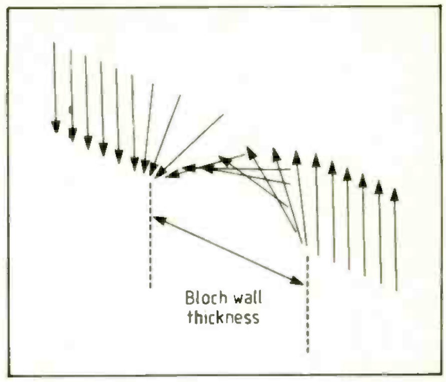


Fig.6. The Bloch Walls mark a region where the direction of magnetization has to change by 180°.

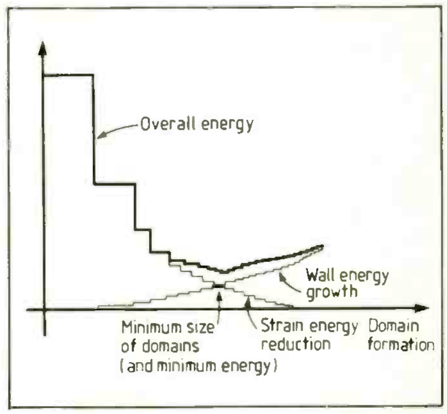
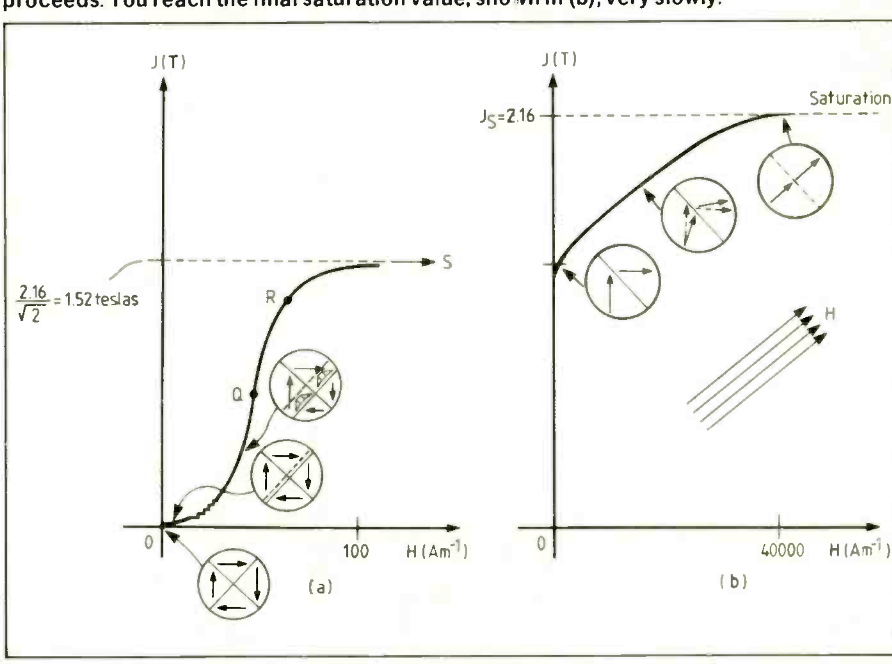


Fig.7. This shows my attempt to illustrate that an optimum number/size of domains will appear in any given sample.

As in all good physics discussions, I now inform you that no magnetic moments arise from orbital motion in ferromagnetic substances. The moments come from electron *spin*. Each electron has a spin of either $+\frac{1}{2}$ or $-\frac{1}{2}$, giving rise to one Bohr magneton. In most atoms, the magnetic moments of the electron spins cancel in pairs, but in iron four inner electrons add their moments and

Fig.8. The magnetization curve of Fig 1 reappears in (a), with suggestions about what is happening to the magnetic directions and domain boundaries as the magnetization proceeds. You reach the final saturation value, shown in (b), very slowly.



you would, therefore, expect each iron atom to contribute a j of $4j_B$. In practice, because of crystal lattice coupling, the magnetic moment turns out to be $2.221j_B$, which is in good agreement with experiment. Other ferromagnetics include cobalt and nickel which have appropriate unpaired electrons.

Iron forms a cubic crystal structure, as in Fig.4. The magnetic contributions from the atoms line up so that the cubic crystallites in the iron spontaneously magnetize to saturation along the cube edges. The least energy occurs along these edges. Free poles appear on the faces at the ends though, as in Fig. 4(a). From these, *demagnetizing* field lines thread back through the crystallite, and this means considerable energy stored.

The block might split into two oppositely magnetized regions (notice, the magnetization still directed along cube edges), see Fig. 5(b). A *wall* appears between these regions, now renamed *Weiss domains*. The much reduced external field means less surface pole formation and less energy. If no free poles exist at all, demagnetizing field energy falls off to zero. And as L. Néel predicted, the domain wall production obligingly continues until *closure domains* occur at the ends, as in Fig. 5(c), so that no external field appears at all.

The trouble is that strain energy appears as the rectangular crystallite distorts under the magnetic forces by *magnetostrictive effects*. The domains continue to subdivide with smaller and smaller closure domains reducing the strains at the ends, resulting in something like Fig. 5(d). H.J. Williams actually observed such domains and their walls, and they had a characteristic width of about 0.14 mm. The energy decreases as the lamellar domain boundaries form.

But these *Bloch Walls* themselves contain a wall energy per unit area, stored by the work done to turn round the elementary magnetic vectors through the required 180°, Fig.6. I have made an attempt in Fig.7 to show that all these conflicting energy conditions result in a minimum size for the domains corresponding to the minimum energy in any one crystallite.

BULK MAGNETIZATION

If you apply the external field as before, something like the following seems to occur. First, the domain walls shift reversibly through small distances. At this stage of proceedings we are at the initial permeability point near the origin on Fig.8. Then the first few "jumps" of the Barkhausen effect begin to occur as the domain walls shift irreversibly.

This jump-like movement of the domain boundaries occurs because of such inclusions as impurities, strain and dislocations of the crystal structure, the presence of alloying elements, and of prior heat and mechanical working of the material – in other words, because of the presence of a vast number of possibilities, which presages that ferromagnetic materials will differ markedly in their properties. Figure 9 summarizes what might happen at an inclusion as the Bloch wall tries to move away from it. The wall jumps to the inclusion to minimize the local energy, then holds back until the force has grown sufficiently for it to suddenly snap away. This explains the Barkhausen jump in flux density. Peculiar "Néel spikes", which minimize the dislocation energy at the inclusion site, remain there. Néel predicted these[5], and people have actually seen them. They are small local triangular domains.

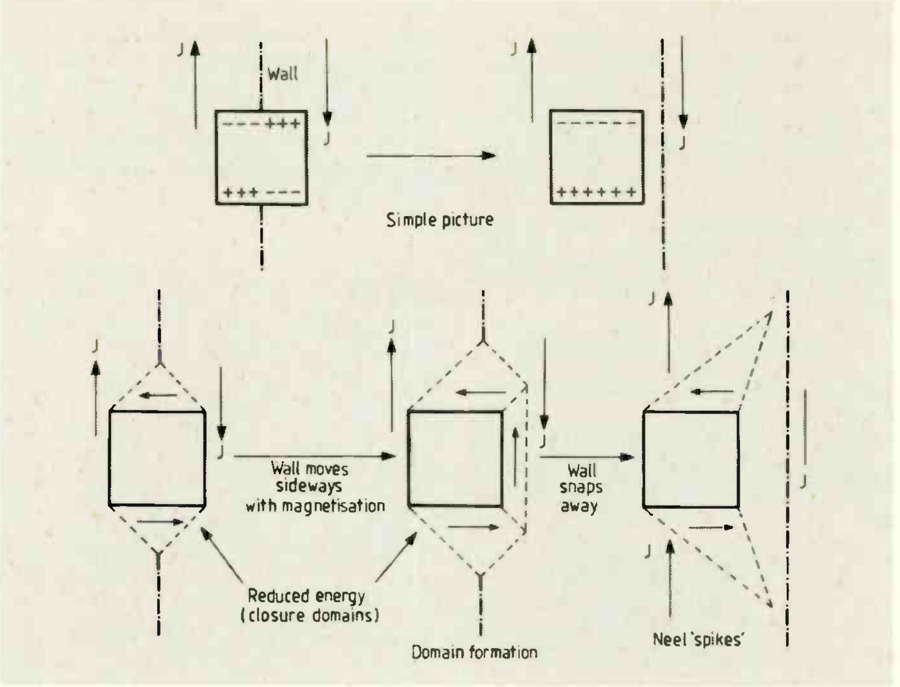
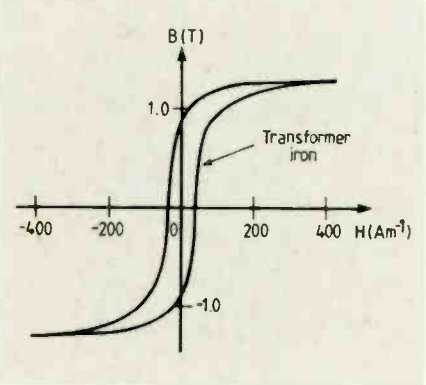


Fig.9. As the Walls move, they might encounter inclusions of various types. I have shown one here as a rectangle. The sequence shows what might occur as the Wall "snaps" away from the inclusion, leaving the "spikes" that people have actually seen.



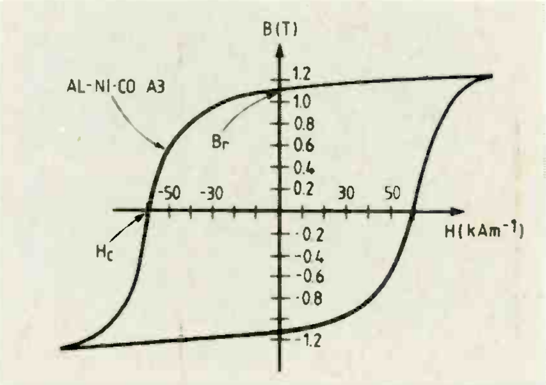
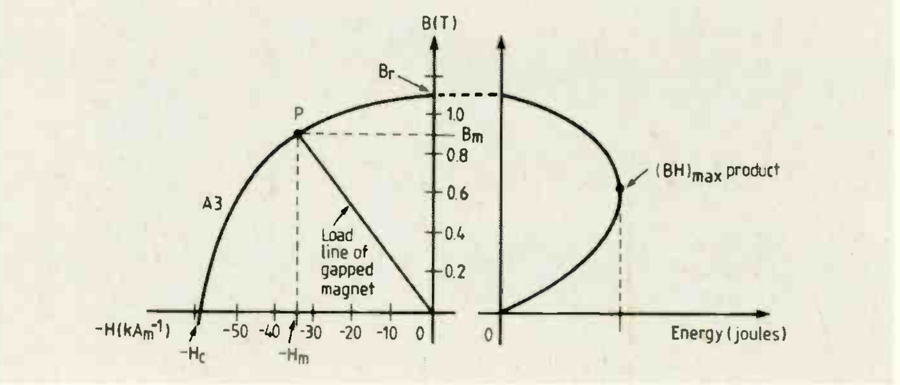


Fig.10. This illustrates the narrow hysteresis curve characteristic of a "soft" magnetic material. Notice the small magnetizing force required for a rapid rise in flux density. Fig.11 (right). A "hard" material has a wide hysteresis loop with a large coercivity, H_c.

Narrow loops: broad loops. If your ferromagnetic specimen has a very pure, nearly single crystal structure, then a relatively

Fig.12. If you open a magnetic circuit, the operating point moves away from B_r to some point P on the demagnetization curve. The actual position of P depends on how wide you make the gap, the cross section of the magnetic sample and its length.



small magnetizing force **H** will rapidly line up all the domain magnetization directions into the cube edge directions aligned most favourably to the applied field direction. While this is occurring, you are on the fast rise past of the curve at Q on Figure 1 or 8. At the knee in the curve, the magnetization vectors begin to be wrenched round into less favourably directions, thus the rise becomes slower. When all the vectors become aligned, saturation occurs and you will have a powerfully magnetized material, but which will lose its magnetization very easily when you remove the external field. Such a "soft" magnetic material has a tall, thin hysteresis loop such as that in Fig.10.

If you try the same thing with hard steel, full of inclusions, strained, and with all the other effects that make domain boundary movement difficult, then you will have to apply a large field to get the flux density up to saturation. But having done so, you will then find an equal difficulty in demagnetizing the sample, so that a large coercive force arises for this "hard" magnetic material. This results in a relatively stable magnetization, which has a stubby open type of hyteresis loop, as shown in Fig.11.

PERMANENT REQUIREMENTS

By exploiting all these possibilities you can "doctor" your material by various treatments to yield the tall thin hysteresis curves with very small enclosed areas of the type in Fig.10, or you can arrange for the production of the shorter, but much more stocky ones in Fig.11.

The first type describes the soft materials of high permeability, easy to magnetize and demagnetize. You would choose these for transformer cores, relays, r.f. inductors and other electro-magnetic devices employing alternating or on/off fields. The lower-permeability, broad-hysteresis-loop materials possess the characteristics needed for permanent magnets. I shall concentrate on these for the remainder of the discussion.

Look at Fig.11 again. This shows a typical hysteresis loop from saturation to saturation of what we would regard as a "good" material for a permanent magnet. You only obtain the maximum remanence B_r at the centre of a very long bar, or better, by arranging the flux to go round a toroidal sample. The large coercive force $-H_c$ shows that you would find it difficult to demagnetize this material. Of course, all the flux remains inside the toroidal core so that you observe nothing outside, which makes it rather uninteresting as a permanent magnet.

Interesting things happen when you cut a slot in the toroid, or as we would say, open the magnetic circuit. Doing this drives the operating point down the demagnetizing curve, so that the flux density weakens to a value B_m and a reverse, or *demagnetizing force*, $-H_m$, appears in the material, corresponding to point P on Fig.12. We now get a useful external field in the air gap.

Driving the flux across. When you cut a slot through the toroidal magnet, the flux has to leave the iron, cross the high-resistance air region, and then re-enter the iron again. The flux lines always thread round a loop and do

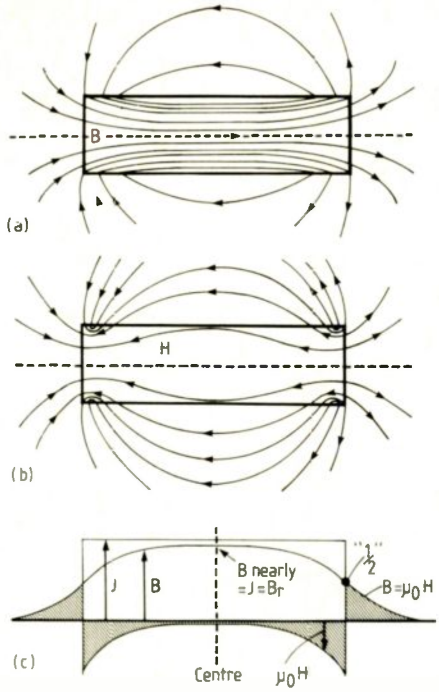


Fig.13. The continuous flux lines shown in (a), concentrate towards the remanent value in the centre of a bar, while the H field strength drops off towards zero at the same position. The field lines proceed in different directions to the flux lines. In general they go in opposite directions inside the material. The graph shows qualitatively how the field strength and the flux density varies from point to point in the material and nearby space.

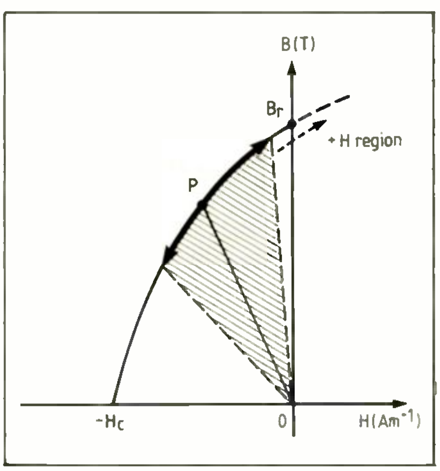


Fig.14. Very rarely do magnets possess a single operating point such as that on Fig.12. Different parts of the material operate on different sections of the demagnetization curve as shown here.

not appear or disappear on anything. In other words as "magnetic charges" do not exist, **B** lines start and end on themselves. If you remember, this means $\mathrm{div}\mathbf{B} = 0$[2]. But the magnetic force **H** does notionally end on the surface poles set up when you cut the magnet. Lines of **H** appear across the air gap and account for the flux density in it via $\mathbf{B} = \mu_0\mathbf{H}$. *Internal* **H** lines also start and end on the surface poles, but go backwards through the iron – this is the demagnetizing field already mentioned. Thus the **B** field weakens but does go across the gap, and you can think of the **H** field in the iron setting up a *magneto-motive force* (m.m.f.) equal to $H_m l_m$ driving a total flux Φ through the magnet, together with an equal but opposite m.m.f. across the air gap maintaining the same flux there.

You can see that this follows from the argument that the total m.m.f. adds to zero round a closed path when no electric current threads it.

$$\therefore \qquad \oint H dl = 0$$

From the flux continuity

$$B_g A_g = B_m A_m$$

for the magnet and gap. But, $\mu_r = 1$ in air.

$$\therefore \qquad \int H dl = \int \frac{B_g}{\mu_0} dl$$

for the gap. And as I said above,

$$\int_{\text{magnet}} H dl + \text{m.m.f.}_{(\text{gap})} = 0.$$

$$\therefore \qquad \int_{\text{magnet}} H dl = -\int_{\text{gap}} \frac{B_g}{\mu_0} dl$$

so that H in the magnet is opposite to B in the magnet and to H in the gap. Figure 13(a) shows the lines of B in a fairly short uniformly magnetized bar magnet. They are most dense near the centre, and in fact approach the saturation value, B_r. Figure 13(b) illustrates what happens to the H field in the bar. The *reverse* H nearly falls to zero at the centre and the lines start and end on the surface poles at the ends. The directions of **B** and **H** clearly do *not* lie in the same direction inside the bar.

After the rude shock of the likely complexity just mentioned regarding bar magnets with their extremely large air paths, we can hurriedly revert to the ring magnet with small gap. This simpler situation leaves the fields much more uniform in the material*. The operating point occurs somewhere down on the demagnetizing curve in the fourth quadrant of the B,H plot and the question arises as to whether an optimum position P_{opt} exists. Now the flux in a gap Φ = BA = μ_0HA. If for argument's sake, the m.m.f. arises from a current I amps going round a coil of n turns then, m.m.f. = Hl = nI ampere turns. This force drives Φ across the gap, as we have seen, and by analogy with Ohm's law in the electromagnetive force case, we have

$$R = \frac{\text{m.m.f.}}{\Phi} = \frac{Hl}{\mu_0 HA} = \frac{l}{\mu_0 A} \text{ Henries}^{-1} \text{ (for air)},$$

where R is the magnetic resistance, which we now rename *reluctance*.

The reluctance has dimensions H^{-1} and we know that the energy stored in henries of inductance equals $LI^2/2$

$$\therefore \qquad E = \frac{1}{2}LI^2 = \frac{H^2l^2}{2R} = \frac{1}{2}\mu_0\frac{AH^2l^2}{l} \text{ joules}$$

But Al = the volume of the region.

*By placing soft iron pole shoes on the magnet ends, a much more uniform internal field can be arranged, as the iron amounts to being an extremely low reluctance path to the flux.

$$\therefore \quad \frac{\text{energy stored}}{\text{volume}} = \frac{BH}{2} \text{ joules m}^{-3}$$

This reasoning shows that the concentration of energy in a volume of magnetic material goes as the product of the flux density and the magnetic force-field strength. It looks as if we will obtain the smallest and lightest magnets for a given flux in an air gap, if we use materials with large values of B_m and H_m and position the operating point for the greatest BH product. In fact, you will find BH_{max} quoted as the *figure of merit* for a magnetic material and this figure governs the geometrical design of actual permanent magnets. A curve of the product BH, showing the BH_{max} point, appears on the right hand side of Fig.12.

Long and thin, or short and fat? Suppose you possess a material with a rather high maximum remanence but with a limited coercive force. The $BH_{(max)}$ point occurs high up on the demagnetizing curve and although the large B_m means you can set up a considerable flux Φ in a certain air gap, your magnet will have to be a long one to give sufficient m.m.f. to drive it across.

On the other hand, if a low-retentivity ferrite, say, with a vast coercivity, turns up for use in a certain magnet design, then you might expect a $BH_{(max)}$ point far along the −H axis, but not very high up. I will point out later that your naïve expectation on this point gets confounded somewhat by a mechanism yet to be considered. If you make magnets from high coercivity material, you need large area pole faces to generate the total flux from the usually low B_m. On the other hand, the magnet lengths remain very short for the required m.m.f. because of the large H_m. You might have to concentrate the flux into a gap of smaller cross sectional area by employing shaped soft iron pole pieces.

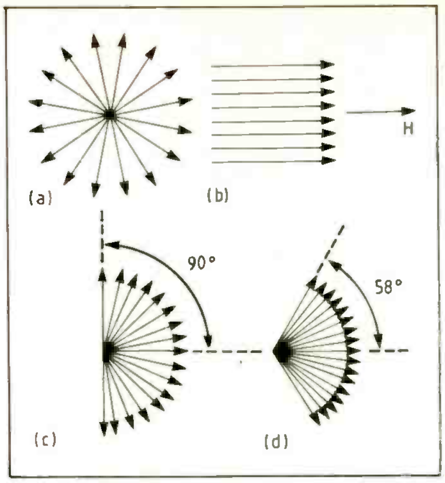


Fig.15. Whether or not the crystals of the material possess a preferred direction affects the shape of the demagnetization curve noticeably. The vector diagrams show a simplified picture of the likely effect on the remanence.

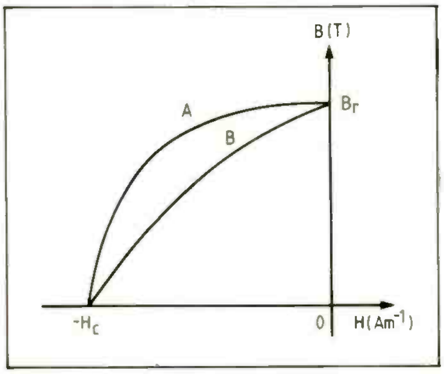


Fig.16. Although the two hypothetical materials shown here possess the same coercivity and remanence, the BH product differs. Material A has a larger "fullness factor" than B.

DESIGNING A MAGNET

Suppose you want to set up a flux Φ in an air gap of length l_g and area A_g. Assume a uniform flux density B_m in the magnet, so that $B_mA_m = B_gA_g$ webers. If your magnet ring has a magnetic path length l_m, then the m.m.f. $= -H_ml_m = B_gl_g/\mu_o$ from earlier reasoning.

$$\therefore \quad \frac{B_m}{H_m} = -\frac{\mu_o A_g l_m}{A_m l_g}$$

$$= -\frac{\Phi}{\text{m.m.f.}} \cdot \frac{l_m}{A_m} \text{ henries m}^{-1}$$

From the first of these equations, dividing through by μ_o, we get the slope of the load line. Notice the slope clearly depends only on the geometry of the situation, in other words, the areas and lengths involved.

Of further interest, relating energies

$$\Phi.\text{m.m.f.} = -B_mH_mA_ml_m = -B_mH_mV_m$$

$$= \frac{B_g^2V_g}{\mu_o} \text{ Joules}$$

where V_m is the magnet volume, which if we divide right through by 2, yields the energy in the magnet.

Finally, from the m.m.f. and total flux expressions, assuming you have arrived at the optimum B and H point, the area of the magnet is,

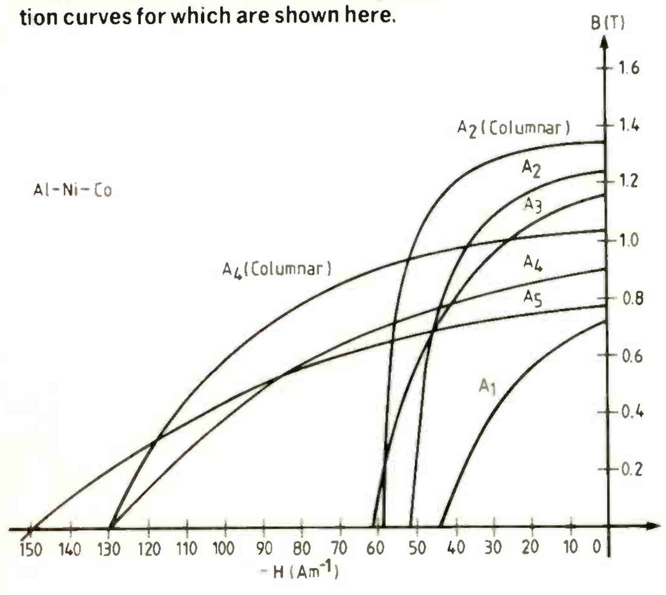
$$A_m = \frac{B_gA_g}{B_{opt}} = \frac{\Phi}{B_{opt}}$$

and its length,

$$l_m = -\frac{B_gl_g}{\mu_oH_{opt}} = -\frac{\text{m.m.f.}}{H_{opt}}$$

The product of these two yields the volume

Fig.17. Once dominating the market, and still forming a sizeable slice of it, we have the Al-Ni-Co materials, some demagnetization curves for which are shown here.



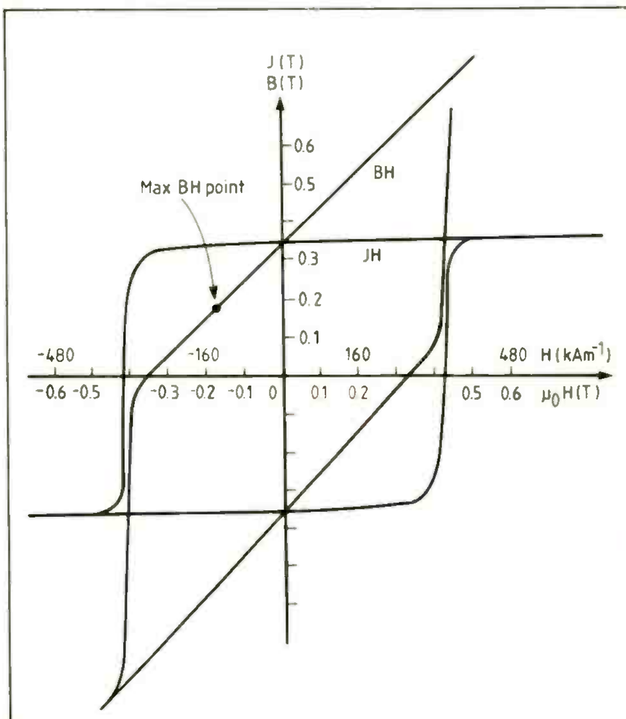


Fig.18 (right). The enormous coercivity, but considerably lower remanence of the ferrite materials produce an interesting effect. The axes can now be plotted to the same scale, as I have done here. The B-H curve now has a maximum slope of minus unity, whereas the J-H curve has a large horizontal section. B can reverse, even while J is still near the saturation value.

of the magnet material you require. Knowing the density of the material, you also have the weight of the magnet.

LEAKAGE

All this looks fine, I hear you say. And it is fine for a fairly long magnet with a very small gap and with little fringing flux, or what amounts to saying the same thing, a small leakage flux.

You will, however, notice a problem if you make the air gap wider. Not all the flux passes between the poles; some fringes out, bulging round the gap. Yet more passes across the magnet geometry from poles on the surface that form elsewhere than in the gap. This means your design from the above equations becomes too conservative, and a more ample magnet size invariably arises in practical situations.

The trouble in dealing with leakage flux turns up from all the guesswork involved. That explains why good magnet design becomes a case of looking up data from previous successes and by drawing on experience. Some general rules of thumb do exist, and empirical methods, such as working with analogues in an electrolytic tank can give an indication of what is required. Such wide-gap magnet designs move nearer to the open, or bar magnet situation, and we saw how complex that can be.

You will notice one effect immediately: different parts of the material in the magnet begin to work at different points on the demagnetizing curve, as in Fig.14. The area of operation might even push into the forward (first quadrant) region and force some of the precious material to drive a flux density greater than B_r through a portion of itself, which, if replaced by soft iron, would work better. Of course, you would have a very bad magnet design if this happened.

The flux density in the magnet weakens towards the ends of poles, in the extended-air-space designs. You would be correct to assume that such magnets ought to taper towards the poles, so that the larger girth in the centre can support the greater total flux required to supply the gap flux and the increasing leakage. Doing this yields approximately the same B in all parts of the material. As a matter of fact, the ideal shape for uniform flux density in the material turns out to be an ellipsoid of revolution, and such shapes receive the lion's share of discussion in texts on theoretical magnetism.

Practical designs exploiting the approximation to an ellipsoid include the magnetron magnet in radar systems. One way of looking at the fattening of the centre of these magnets is to imagine the "sheath" supplying the leakage flux, while the core supplies the (uniform) gap field.

Once you have arrived at the required gap flux together with an estimate of the leakage, the sum of these will give you the total magnet flux. From knowing this, you can insert a correction factor, k_1, given by

$$k_1 = \frac{\text{magnet flux}}{\text{gap flux}}$$

into the design equations. Your problem is arriving at a good estimate of k_1. The

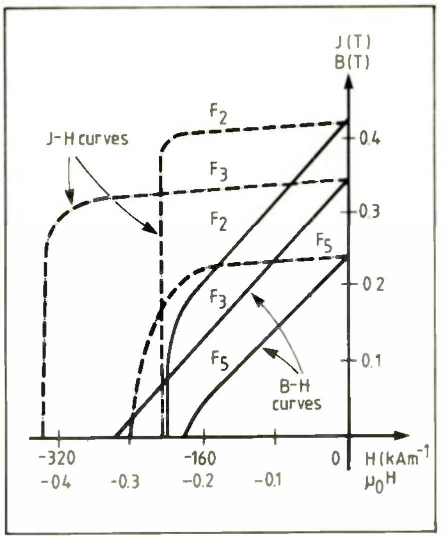


Fig.19. The B-H and J-H curves for various grades of ferrite material all show the characteristics mentioned in Fig.19.

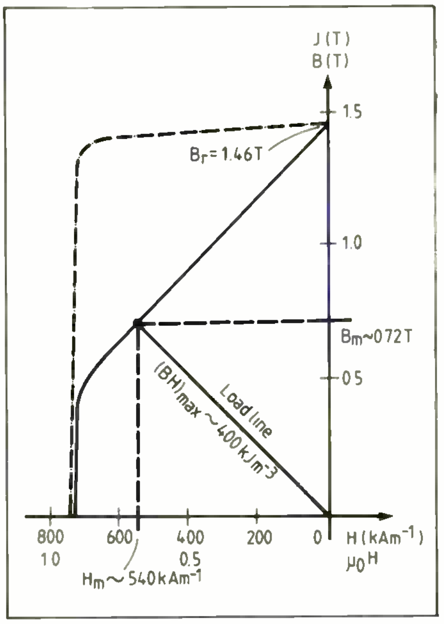


Fig. 20. This curve applies to the largest energy product achieved in a sample of permanent magnet material. The picture also illustrates that the optimum operating point yields a load line slope of 45° in these materials.

situation is exacerbated somewhat by another effect: some of the m.m.f. might be "used up" in driving the flux across other gaps, such as junctions between the magnet and pole pieces, and so on. The only way out is another "k" factor, k_2.

$$k_2 = \frac{\text{Magnet m.m.f.}}{\text{gap m.m.f.}}$$

According to A. Edwards[7], k_1 rarely falls below 2 and might reach 20 or more for large magnets with long air gaps. The factor k_2, usually much smaller, ranges from about 1.05 to 1.45. E. Megaw[8] offered empirical estimates for these factors: $k_1 = 1 + 7l_g/D_m$ for air gaps of length l_g between circular pole-faces of diameter D_m; and $k_2 = 1 + l_g/5D_m$ for similar geometry.

Therefore if from these, or otherwise, you have a shrewd knowledge of k_1, k_2, then by using the modified design equations,

$$\frac{B_m}{\mu_0 H_m} = \tan\theta = -\frac{k_1 A_g l_m}{k_2 A_m l_g}$$

$$V_m = -\frac{k_1 k_2 B_g^2 V_g}{\mu_0 (BH)_{max}} \,\mathrm{m}^3$$

$$A_m = \frac{k_1 B_g A_g}{B_{opt}} \,\mathrm{m}^2$$

$$l_m = -\frac{k_2 B_g l_g}{\mu_0 H_{opt}} \,\mathrm{m}$$

a fairly economical design should result. A.E. Falkus discussed loudspeaker magnet designs with estimated leakage factors in an interesting article some time ago[9].

SOME REAL BH CURVES

A final word or two on what we have at our disposal rounds off this interesting subject. First, you will find the actual shapes of BH loops depend on a number of factors I have not yet mentioned. The value of B_r in many curves seems to be near one half to the saturation value. This most nearly applies to random polycrystalline materials that magnetize equally in all directions. You can understand the reasons for this by considering the unmagnetized material in which $\mathbf{J} = 0$ and $\mathbf{H} = 0$. All the internal domains cancel as in Fig.15(a).

If you now take the material to saturation, it becomes totally magnetized along the **H** direction, as in Fig. 15(b). When you remove the **H** field, the old preferred directions reassert themselves, but as direction → is identical to ← the result appears as in Fig. 15(c). Therefore a remanent magnetization of $\mathbf{J}_r$ remains, equal to $1/2\mathbf{J}_s$.

On the other hand, if you have lined up your crystals by special treatment during manufacture so that you have a preferred direction then, in this anisotropic material, magnetization will be very good in one direction, but will be poor in others. If only crystal anisotrophy remains to be dealt with, then the diagonal angle amount to 58° in a cube predicts that a remanent value for **J** of $0.78\mathbf{J}_s$ should result, as shown in Fig.15(d).

The above discussion shows that the *shape* of the BH curve may differ – even though materials might have the same coercivity and remanence. The material with the largest "fullness factor" will have the greatest $(BH)_{max}$ product, Fig.16.

The qualities of permanent magnet materials just before, during, and after the second world war, rested upon the properties of the Al-Ni-Co alloys, some demagnetization curves of which appear in Fig.17. The many grades of Alnico and the anisotropic versions (Alcomax, Columax), which would take a whole article to describe fully, still figure in the economics of permanent magnet production.

Earlier, I remarked that modern ferrite permanent-magnet materials might possess a huge coercivity but not much retentivity. Ferrites yield smaller BH products, but they figure prominently in the market for magnets because of low material density and cheapness. Table 1 compares the market pattern c.1986[10]. The ferrite materials often show strongly anisotropic properties, which predicts that the JH loops (notice I have used

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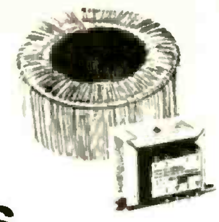

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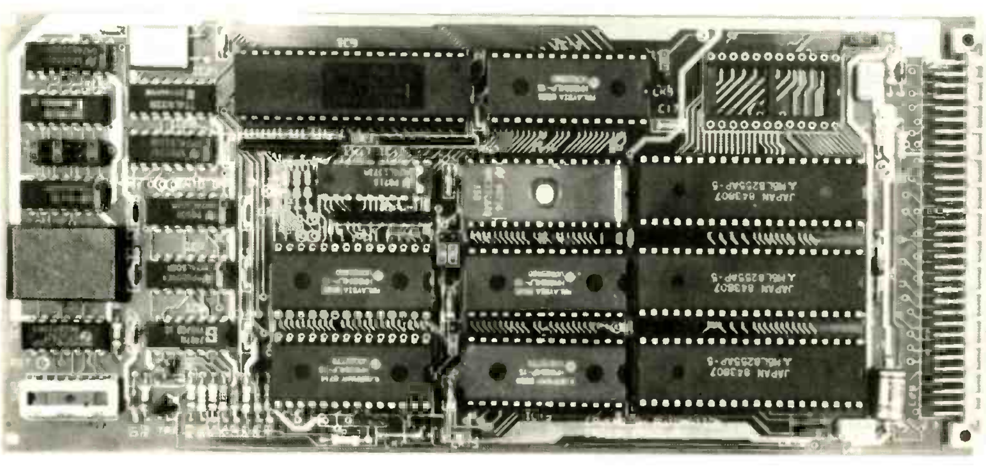

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Table 1 Market share of modern materials

Magnet material	Percent market value
Al-Ni-Co	15
Ba and Sr Ferrites	70
Rare-earth	15

J here) will have very flat tops and bottoms. Now $\mathbf{B} = \mu_0\mathbf{H} + \mathbf{J}$ so that the BH loop differs from the JH loop according to this. You will find this especially noticeable with low $\mathbf{B}_r$ values and the surprising fact emerges that **B** might very well reverse as we move back along the negative **H** axis, even though **J** stays constant. Figure 18 illustrates this, together with the obvious result that $(BH)_{max}$ is obtained from the mid-point of the straight demagnetization line. Figure 19 gives a few JH and BH curves for ferrite materials.

Finally, the most recent developments of all involve rare-earth materials[11]. The largest BH product of any magnet turned up recently in a NdFeB rare-earth sample (Sagawa *et al*[12]). Its demagnetization curves shown in Fig.20 indicate that the $(BH)_{max}$ product reached the enormous value of 405 kJm^{-3}.

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Events

11-13 October, Wembley Exhibition Centre, London: **Computer Graphics 88.**

26-28 October, Dublin: **Intron 88,** Irish Electronics Exhibition. SDL Exhibitions Ltd, Dublin, 01-900600.

3-6 November, Hydro Hotel, Windermere: **Reproduced Sound,** fourth annual weekend conference organized by the Institute of Acoustics (031-225 2143) in collaboration with AES, APRS and other professional bodies. Up to 35 contributed papers.

15-17 November, Kensington Exhibition Centre, London: **Image Processing** 88.

Satcoms on the move

Spare satellite capacity, and the availability of a new frequency allocation in L-band (around 1.6GHz) have enabled Inmarsat, the international maritime satellite organization, to press ahead with a new communications service for land mobiles.

Live demonstrations of the pre-operational service through Inmarsat's Atlantic Ocean satellite were given this summer in seven countries of Eastern Europe, by members of an Inmarsat team who drove some 3600 miles in their specially equipped Ford van. On the tour, which took them as far as Red Square in Moscow (pictured), they dispatched 200 test messages; and position reports were sent every 15 minutes by the vehicle whilst it was on the move. The area covered by the Atlantic satellite extends as far as the Middle East, and to the eastern side of the Americas; but other Inmarsat satellites could expand the service worldwide by the end of next year. Future demonstrations are planned in North America, Asia and Australia.

The land mobile service, which is awaiting approval by Inmarsat's council, is based on the compact Inmarsat Standard C terminal. Standard C is a low-cost store-and-forward two-way messaging service based on a small non-directional, non-stabilized antenna fitted to the vehicle – no dish is required. Data rate is 600bit/s, with three levels of coding to eliminate errors; the channel is transparent and can accept non-text information too. Sending a 1000-bit message (about 100 characters) costs about $1 on Standard C. Efficiency of the system is high: a single 5kHz carrier on the satellite can accommodate some 10 000 mobiles; and a second-generation satellite could support several hundred carriers.

Inmarsat believes the system could satisfy a widespread need for global communications. Lorry drivers on international routes would be able to keep in contact with their offices by means of a terminal in the cab, and even clear their customs documentation in advance. Their costs could fall, too: a Swiss company has developed a long-distance theft alarm for lorries, and insurance companies are said to be interested enough to be offering discounted premiums on the strength of it. Other users could be railways, which apprently have enormous difficulty in keeping track of their rolling stock: fitting an automatic position-reporting device to stock could enable managers to reduce the number of vehicles they need by as much as 30 per cent. Portable terminals could also be of use to groups such as journalists and disaster relief teams: the breakdown in communications in Sudan which accompanied the August floods emphasizes the need for communications which do not depend on fixed lines.

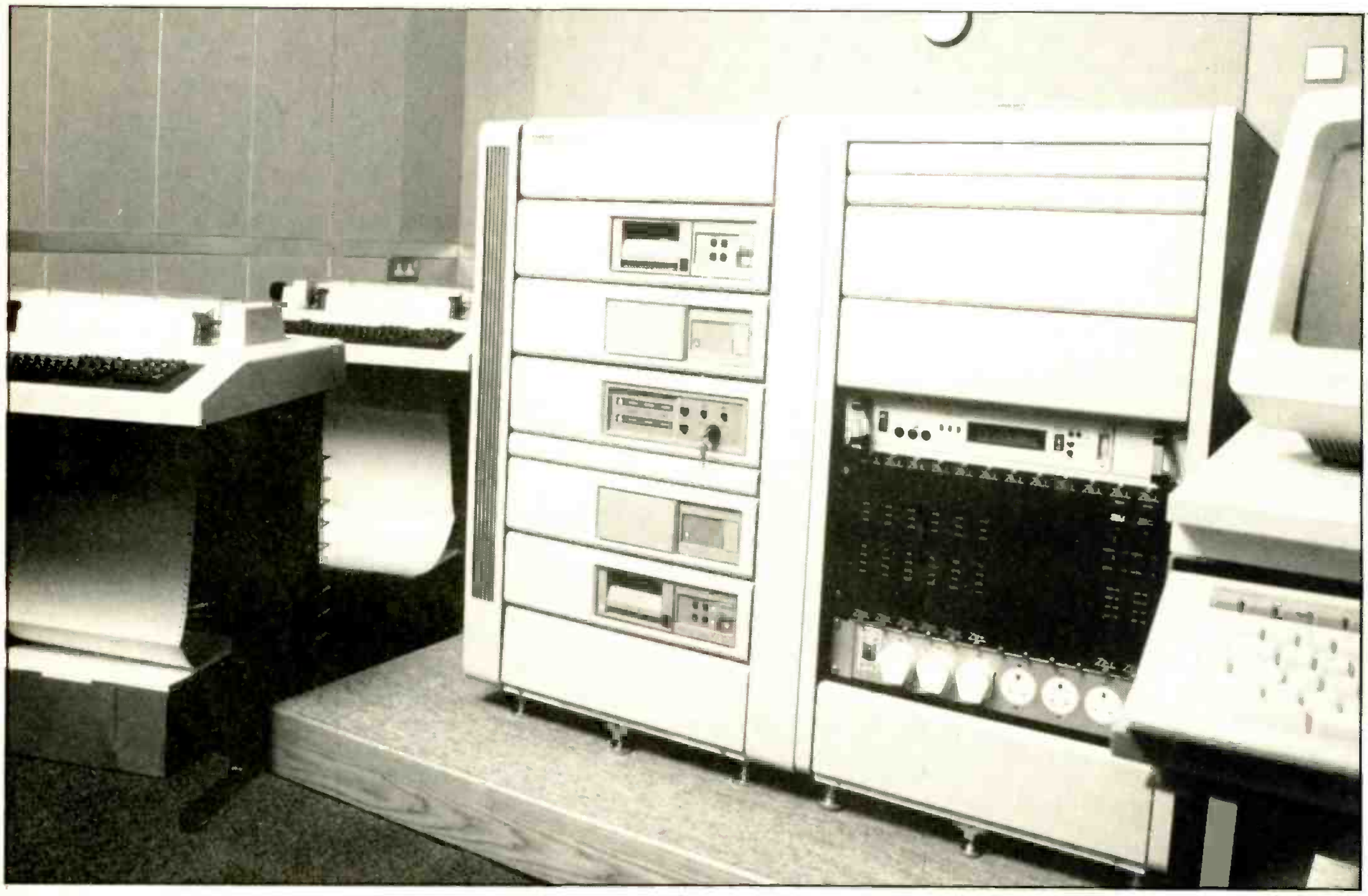
Two-way voice communications are still some way off, though Inmarsat plans to evaluate three possible systems at the end of this year. Decisions to be made include the choice of voice coding scheme. But a bigger, steerable antenna would be required (a prototype will be ready in November), and more power (25W instead of 10W). Such a system could, by the early 1990s, bring radiotelephone communications to areas which otherwise would be out of reach. But it would not be cost-effective in built-up areas, because satellite systems cannot re-use frequencies as ground-based trunked networks can.

In front of the Cathedral of St Basil the Blissful, and the Kremlin's Spassky Tower (centre), is Inmarsat's converted Ford mobile home. Fitted inside the vehicle are a Racal Standard C terminal, a GPS/Loran receiver and a Magnavox terrain navigator. Inmarsat, an international co-operative supported by 54 member countries, provides global communications for some 7000 ships: now it is moving into land mobile radio.

What is happening to RDS?

With the launch of Radio Data System on all BBC f.m. radio transmitters in England, set-makers can now offer receivers with automatic tuning and other novel features. In this article, the BBC's RDS Project Manager summarizes the current situation.

BEV MARKS



Here in the UK both the BBC and the IBA have been working on RDS transmitter equipment installations for the last three or four years, and something like 75 percent of the population are within reach of an f.m. transmitter which is already transmitting some RDS features[1,2]. Well over 150 BBC transmitters are radiating RDS and work is progressing to complete the necessary installation throughout the UK. Fortunately a fairly high proportion of the remaining transmitters are relays of others and so they will start as soon as their mother station is on air with RDS.

Across Europe, all major European Broadcasting Union members have now said they will provide RDS over the next few years. Several countries, like the UK, are well ahead with installing RDS encoders, notably Sweden, France and West Germany. All broadcasters are conforming to the EBU specifications described in document Tech. 3244, creating a large receiver market to make it worthwhile developing the technology to take advantage of RDS.

R·D·S RADIO DATA SYSTEM

BBC Radio's central RDS computer at Broadcasting House, London. From left to right: the logging console printers; the DEC MIRA Micro PDP11 computers; and the radio clock with, below it, the limited-distance modems which connect the computer into the Nicam programme distribution system.

It is interesting to note the differing features that broadcasters have chosen to implement at the initial stages. In Sweden, for example, they have a similar network and local radio structure to the UK's, and have chosen similar features apart from the addition of Radio Paging (RP), which in the UK is already served. France has started RDS with RP as a major consideration, because it can bring revenue to enable the long term expansion of other RDS features.

BBC Radio felt that RDS was of major importance in helping the listener to find the programmes – high in both editorial and technical quality – which it already offered. So the prime objective was to find features which would meet this criterion, yet cost relatively little to provide: it was not desirable or possible to arrange for RDS to be charged to the listener by an increased licence fee.

FEATURES OF RDS

At this stage it is worth briefly describing the features and introducing the concept of static and dynamic RDS. All BBC f.m. trans-

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6809	2.50	2.20	1489	0.25	0.16
6821	1.25	0.95	LM2901	0.80	0.60
6845	2.50	2.20	LM2917-8	1.50	0.75
6850	1.60	1.40	2732-A	2.50	2.30
6502	2.80	1.90	2764A-25	2.20	2.00
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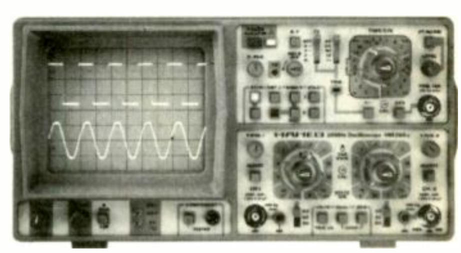

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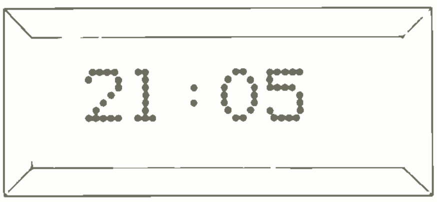
mitters with RDS provide the following static features:

- Programme Service name (PS)
- Programme Identification code (PI)
- Alternative Frequencies list (AF)
- Other Networks information (ON)
- Clock Time (CT)



Straight away it will be obvious that CT cannot be totally static! In fact is is transmitted in a special group on the minute edge; the RDS encoder has this function built into its software and no external command is required to put this group into the data stream. In the BBC system, CT is synchronized by off-air reception of MSF from Rugby to give the accuracy considered essential for these days of digital timepieces. The other features are all derived from data held in prom in the encoder, which will continue cycling around to provide the necessary groups in a pre-determined sequence. Hence the description, static RDS.

Dynamic RDS, on the other hand, requires information to be sent to the encoder to change the normal cycle of transmitted groups. The following features are included in this catgory:

- Travel Programme (TP)
- Travel Announcement (TA)
- Programme Type (PTY)
- Programme Item Number (PIN)
- Radio Text (RT)

And there are a good number of further RDS features which the broadcasters can implement in the future. RDS is already well standardized[3,4] but it has been designed to be upwardly mobile, allowing the broadcaster to add features when the demand develops.

RDS AND THE MANUFACTURER

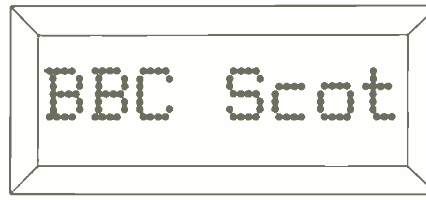
So far we have not talked about the vital ingredient in the development of RDS, the receiver manufacturer. Across the world many companies are developing RDS receivers. Initially, car radio manufacturers are deeply involved – probably every one is developing a receiver simply because of the enormous advantage that the automatic tuning aspect gives to these products. At the least they have to decode PI and AF to

One of the first hi-fi tuners with RDS: this model from Grundig's Fine Arts 9000 series will be available in the spring. Two further hi-fi tuners with RDS are being introduced by Revox.

achieve automatic tuning and most also provide station names from the PS.

A number of different implementations are possible for displaying the PS: some receivers use dot matrix displays, some use starburst displays, some are back-lit for increased visibility. For the user, dot matrix displays have the added advantage that upper and lower-case characters can be displayed. This aids recognition of the station name if the broadcaster is using both. BBC Radio has studied display recognition and uses upper-case for the national network stations, but finds that a mixture is best for local radio where the slight limitation of only eight characters is easily overcome: for example, BBC Radio Cambridgeshire is identified as "Cambrdge".

The display features of RDS are very important, but the receiver manufacturer must use RDS for control functions if automatic tuning is to be implemented. Processing of the incoming data stream demands considerable complexity, to decode with enough accuracy to be useful and then to act



on the data in a logical way. A great amount of development is necessary to achieve sensible responses from the receiver in the variable reception conditions that will exist as it is moved about. The car radio manufacturer has a further challenge, to pack all the extra electronics into a very small DIN/ISO case which cannot be increased in size to accommodate RDS technology. Thus large scale integration has been a must from the start: committing to silicon is a big step which has been necessary in the development of RDS for the listener.

Clarion's first car radio with RDS is a radio-tape combination unit, with the option of a separate display for the station name. Thus can be mounted on the top of the car's instrument panel.

TRANSMITTING RDS SIGNALS

At the BBC's national network transmitter sites, such as Sutton Coldfield in the midlands, pairs of f.m. transmitters are installed in a parallel configuration so that if one fails there is only a reduction in power. Each transmitter drive has to be modulated by a data stream from an RDS encoder which is connected to a data channel fed with update information from the central RDS computer situated in Broadcasting House, London. It is from here that dynamic RDS information is derived in accordance with a network schedule and any changes initiated from many locations in the BBC studios around the UK.

Network transmitters can provide these dynamic RDS features because the data links are provided within the BBC Nicam digital distribution system. But it is important to note here that local radio transmitters cannot yet provide dynamic RDS: only static RDS is possible because they simply have a programme circuit from the local studio to the transmitter and no data connection with London.

It is possible to assume that any of the static RDS features could also become dynamic on a network transmitter; and this is just what we are doing. But why? Well, again, we can give the listener even more information very easily. In the crowded f.m. band, the BBC has been forced to make maximum use of the allocation over the years by putting different programmes on f.m. from those on medium and long wave at various times of the day. Perhaps one of the best known examples is the schools broadcasts which during school term time are carried on Radio 4 f.m. whilst Radio 4 long wave carries other programmes. So with RDS it is possible for us to give the listener who has perhaps just tuned to Radio 4 f.m. in the middle of a schools broadcast a good clue to what is going on by changing the PS name from "BBC R4" to "BBC R4Ed" – for Education. This example is but one, there are many more; and over the coming years there will be quite a bit of change as the f.m. band expands and as other changes occur to the broadcasting scene. But RDS through dynamic PS names will keep the listener in touch.

RDS is a complex subject for the manufacturer and the broadcaster and so it must be treated very seriously by them if the listener is to rely upon the automatic responses which have suddenly become possible in his receiver. In a way we each have half an operating system under our control and each half must work perfectly with the other. Maintaining perfect sympathy between the two halves has been a vital objective of the EBU and the BBC has given strong support to that ideal.

But for the listener RDS must be very simple. Our complex discussions have eventually to be distilled into a very easily used product. Indeed, with the first-generation RDS receivers we are finding that it really is quite boring if all you want to do is listen to Radio 2 all the way from Newcastle to Newquay – for "BBC R2/1" is all you will see on the front of the receiver, yet unobtrusively it will have retuned as many as six or seven times on the way.

If, however, you want to retune to another BBC service after 150 miles or so, then the likelihood of your knowing the appropriate frequency for BBC Radio 3, say, is quite slim.

RDS car radio from Grundig. Other manufacturers who have produced RDS car radios in prototype or production form Alpine, Ford, Panasoic, Philips, Pioneer and Sharp. Below: specimen Radiotext message.

```
CBSO Conducted by David Atherton
Vaughan Williams-London Symphony
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But RDS can come to your aid with the ON feature. This has been telling your receiver as a background routine all about the other BBC services, so the receiver will already know what frequency BBC Radio 3 is available on in that area.

"OTHER NETWORK" INFORMATION

Alternatively you may like local radio, and already have your BBC local station pre-programmed on a memory button on the receiver. If so, then by another method being pioneered by the BBC and known as generically linked PI codes, second-generation receivers will build up knowledge about other BBC local services and load then into the memory behind your local radio button. Once you are out of range of your first choice you can then press the button again and the receiver will retune to an adjacent BBC local radio service.

An application of the ON feature which has caused much interest is the ability to cross-reference other networks to allow a very refined travel service to be constructed – so that, whatever service you are tuned to, you can hear the local travel information from the nearest BBC local radio service. Any basic RDS travel service must be based upon a method of signalling to the receiver to tell it firstly that this is a service carrying travel information at some time (in RDS this is signalled by the TP flag); and then, when a travel announcement is actually being spoken, to tell the receiver (in RDS, by putting on the TA flag) that it should perform one of several possible actions: increase volume, wake up from a quiescent state, or even stop cassette replay and revert to off-air reception.

If you want to listen to BBC Radio 2, however, and also want to benefit from travel information from the nearest BBC local radio service, then RDS can help. By using the ON feature on the national networks which are under dynamic control it is possible to reference all the other BBC services and inform the receiver about TA flags being switched on for BBC local radio services. This way, while one is listening to a national network service, the receiver may find a travel message from the nearest BBC local radio station, giving relevant, timely and accurate information about the local travel conditions.

Buried in this process is a lot of data communication between the local radio studio, the central RDS computer in London, the national network transmitters and the local radio transmitters. Again the BBC is pioneering methods of effecting this at low cost to the broadcaster. This is achieved by the use of update data labelled with a service number so that RDS data can be received off the air at the local radio transmitters to command them to switch their flags.

RDS IN PRACTICE

Where does all this get us? Many manufacturers are making receivers, especially car receivers, but having many other features such as cassette decks these are complex and inevitably quite expensive. As with all technological developments we expect prices to fall progressively. Already some tuners are about and it seems likely that RDS will be incorporated into more in the future. Clearly Radio Text would be particularly useful on a tuner if for example it could be used to give the phone-in number for a particular programme, or the address to write to for further information. When c-mos technology becomes available then portable receivers can be expected to take advantage of RDS too.

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

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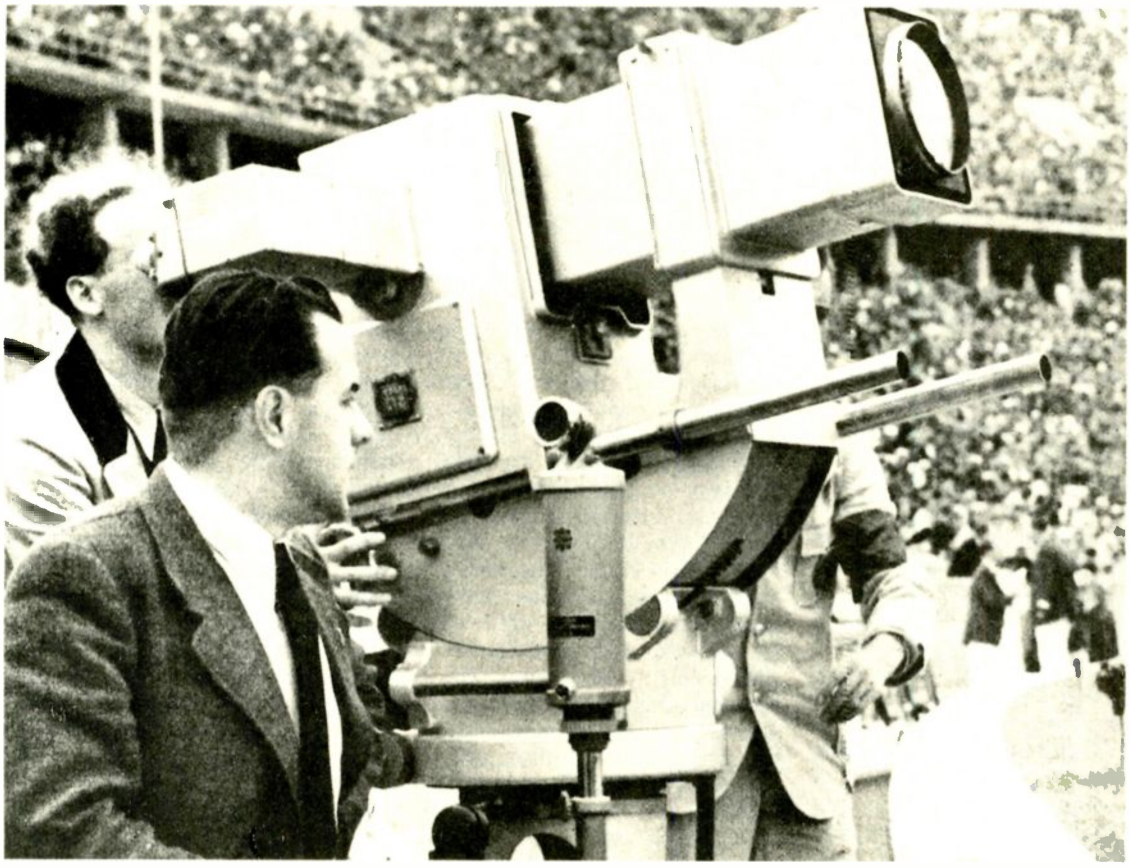
Pioneers

23. Walter Bruch (born 1908): a night at the opera

W.A. ATHERTON



Telefunken's 180-line television camera at the 1936 Olympic Games in Berlin. The operator is Walter Bruch (also pictured below), who helped develop it. Photographs by courtesy of AEG (UK) Ltd.

The first telegrams arrived at 6.45 a.m. Newspaper reporters and the television cameras followed. Even on his eightieth birthday, Walter Bruch observed, he could not eat his breakfast in peace. At least the cameras were no problem. Bruch has been captivated by television since he first saw a flickering image on a screen when he was seventeen years old.

He is known as Mr PAL, after the colour television system he conceived in 1958 as an improvement of the American NTSC standard. His wife, Ruth, has even been nicknamed "PALina". Prof. Dr-Ing.E.h. Walter Bruch, to give him his full title, was 80 years old on 2 March this year. He has seen television through from the age of spinning Nipkow discs to the time compression of MAC. Whilst he knows technical improvements can still be made, he believes it more important to improve the programmes. Television, he advises, should be used with discretion.

"Mr. PAL" was born in Neustadt in the Haardt region of Germany in 1908. He says he inherited an iron will from his forbears. As a small boy he was fascinated by technology and preferred using his hands to learning at school. Playing truant gave him time to

spend in the Deutsche Museum in Munich. His school, it is said, "departed from him". Did any of his teachers, I wonder, live to see the portrait of their strong-willed pupil which now hangs in a place of honour in that same museum?

After a three-year apprenticeship as a "machinist" and some time in a shoe factory, he entered an engineering school to study electrical engineering. But the turning point in his life came in 1925 when, at a communications exhibition in Munich, he saw a primitive television for the first time. This was probably a mechanical Nipkow disc machine exhibited by Max Dieckmann. The 1920s was a time of great experimentation and excitement in several countries as the dream of television seemed to be approaching reality in the work of J.L. Baird, C.F. Jenkins, H.E. Ives and others. The flickering pictures fired the 17-year old Bruch with an unquenchable ambition to work with television. It was a dream he cherished through his remaining education and apprenticeship.

Three years later at the Berlin Radio Exhibition of 1928, he saw another example of television. This one was exhibited by the exiled Hungarian inventor Dénes von Mihály. In 1933, Bruch began his career in television engineering at Mihály's Berlin laboratories.

ICONOSCOPE CAMERA

Within two years, however, he had moved on. Electronics was challenging the Nipkow discs and spinning drums which had fostered the dream of television and gained many notable firsts. When the radio firm Telefunken offered him a position in its department of television and physics, he took it.

So began in 1935 his long career with

Telefunken. With others Bruch was soon helping to develop the first German electronic television camera. This iconoscope camera was one of three used at the famous 1936 Berlin Olympics. On 1 August, live transmissions were begun to some 25 television rooms and two television theatres in Berlin. In all, around 150 000 visitors are said to have seen the 180-line pictures[1].

Later Bruch was involved in developing the first German television studios. "Already in 1939 television should have been introduced in several towns", says Bruch. Plans for constructing 10 000 receivers for the 441-line standard were dropped, an early casualty of the second world war. The Berlin transmitter was bombed in November 1943[1].

WAR WORK

As the war progressed, Bruch found himself working on military tasks but still made time to continue developing television. His knowledge and skills in this sphere were soon in demand. The Air Ministry became interested in his moonlighting and he was summoned to Peenemünde where the V1 and V2 rockets were being tested.

In 1941 he led a team at Peenemünde developing and installing a closed-circuit television system to give low-risk monitoring of the rocket launches. A two-camera system was installed at the launch pad to relay live pictures along a cable to a control room 2.5km away. One of the compact cameras had a telephoto lens and the other a wide-angle lens, and one of them had to be replaced after being destroyed when the first V2 rocket blew up[2].

After the war Bruch set up a private laboratory in Berlin to undertake independent research. In 1954, however, he rejoined Telefunken. He was appointed director of research and allowed to work on colour television and develop television reception.

In the 1950s work on colour television intensified in several countries. Black-and-white television had just been able to whet people's appetites before the war although, as Bruch describes it, it was an exclusive toy of the rich. "When we started with television I didn't imagine it would become a medium, more than a programme", he reminisced on his 80th birthday. "Such thoughts were not considered. Each evening, two hours. Saturdays and Sundays free."

ADDING COLOUR

By the early 1950s television broadcasting was becoming established and researchers were vying to produce reasonably inexpensive but worthwhile colour television which could be compatible with the existing black and white broadcasts.

In the United States CBS began broadcasts in June 1951 in New York City with a colour television system which was totally incompatible with the existing black and white service. RCA had been to the Supreme Court to try to get it stopped, but had failed. But after two years it came to an end anyway when the Federal Communications Commission reversed its earlier decision in favour of CBS and instead approved an RCA system which was compatible with the black-and-white system, and which had been recommended by the National Television Standards Committee (NTSC). This NTSC system, as it is known, became the basis of the world's colour television.

Europe was not yet ready for colour and time could still be devoted to improving the NTSC standard. The first to do this was Henri de France in Paris in 1957 with what was developed into the SECAM system, as now used in France, the USSR and some fifty other countries.

Bruch pondered the problems, mainly that of the need with NTSC transmission to adjust the colour control frequently – the evening keep-fit exercises, as he terms it. It was a cruel wit who renamed NTSC Never Twice the Same Colour. The breakthrough came one night in 1958 when Bruch and his wife were relaxing at the opera.

One of Bruch's favourite themes is the link between relaxation (including dreams and day-dreams) and the germination of ideas. He has described how despite struggling for years with the problems of colour television this had not led him to any suggestion of changing the NTSC system. He had even experimented with alternating the phase of the chrominance sub-carrier, the technique which became the crux of his successful invention. The crucial improvment was to use a delay line, invented during the war by a colleague, Fritz Kruze, to split the received signal into its two original components in the receiver. This thought occurred to him spontaneously "one evening as I was dreamily watching an opera"[3]. He has described himself using two fingers of each hand "graphically adding, subtracting or multiplying pointers and vectors" with "an annoyed wife beside me". The next morning it was his assistants' turn to be annoyed as they learned that demonstrations carefully prepared over two months had to be changed to accommodate the new idea – over the Christmas holiday.

Years of development work followed as Bruch and his companions at Telefunken turned the idea into reality. It took seven years, says Bruch, "to reach the point where the technique could be said to speak for itself". Edison's famous observation that genius is 1% inspiration and 99% perspiration underestimates the amount of hard work involved, says Bruch.

Much time was devoted to showing and explaining PAL to others. Invention is one thing, he says, acceptance another. On 3 January, 1963, the PAL system was demonstrated to the European Broadcasting Union in the "cellar" of the Telefunken laboratories in Hanover. Subsequently it was demonstrated in over 20 countries, with Bruch and his colleagues often working through the night to get the demonstrations ready on time. "Those magical evenings will not be forgotten by those who were there."

Four years later PAL was officially introduced in Germany and also in Britain (on BBC), after long and acrimonious political fighting. In particular, the President of France, General de Gaulle, wanted the whole of Europe to standardize on one system – the French SECAM of course. It was not to be, though the widespread adoption of PAL (now in over 90 countries) earned it the nickname Peace At Last. Bruch, meanwhile, demonstrated the first SECAM/PAL standards converter.

Although Walter Bruch retired in 1974, his last years of employment were just as active as those that had gone before. In the mid-1960s he worked on the problems of component television, with the specific aim of producing colour video recorders. Even though the PAL system has been eminently successful, Bruch is well aware of its limitations and has sought to improve it. In 1970 he played an important role in the development of future television systems when he introduced to television the concept of time compression, as now used in the MAC family.

Walter and Ruth Bruch, who celebrated their golden wedding anniversary this year, still live in Hanover, the home of Telefunken. He has acquired a reputation as a perfectionist and is of course renowned in many countries as the inventor of PAL. But as we have seen here, he has contributed more to television than that one great invention, and he holds about 200 patents in all. In his seventies he turned historian, delving through archives in Germany, Britain and America to unearth the technical history of the television he has loved for so long. The treasures he uncovered have produced many booklets.

Walter Bruch has received many honours including an honorary doctorate from the Technical University in Hanover and an honorary professorship from the University of Saarland in 1968, as well as honorary membership of institutions and awards from many countries.

A BRIGHT IDEA

Bruch has stressed the need to inspire and train young people as researchers. The Emperor Constantine the Great, he notes, showed how to train young engineers. In the year 334, apparently, Constantine issued a decree to the governor of Africa to train engineers; and, as an encouragement, freed them and their parents from personal taxes. Ten years later, a further decree freed teachers of engineering and their parents from personal taxation as well. Unfortunately, Bruch remarks, the decree was issued 1640 years too early for his own tax assessment.

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The photograph at the top of page 1041 (last month) showed one of the relics of James Clerk Maxwell's apparatus held by the Cavendish Laboratory at Cambridge: its purpose was to demonstrate the inertia of electric currents.

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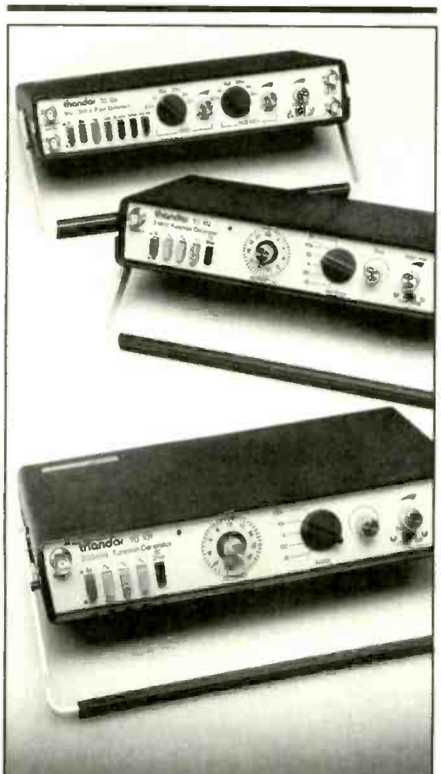

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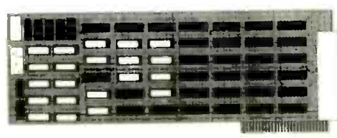

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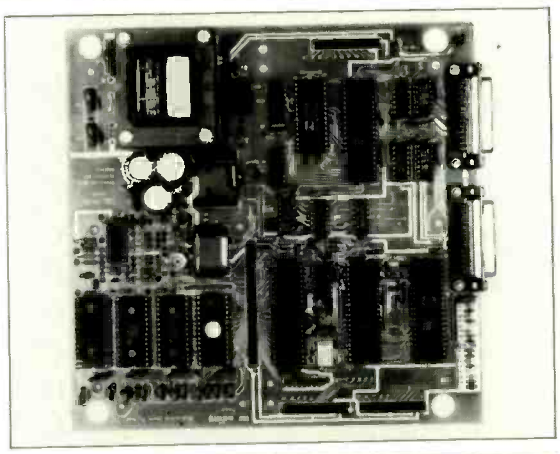

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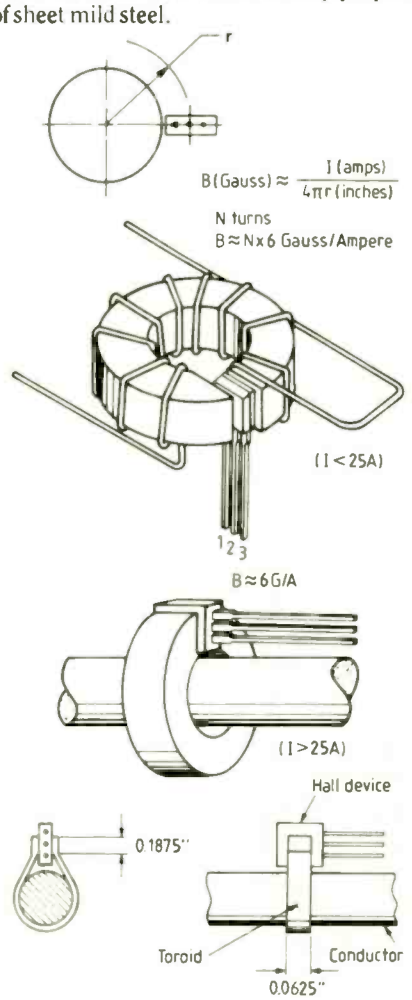
APPLICATIONS SUMMARY

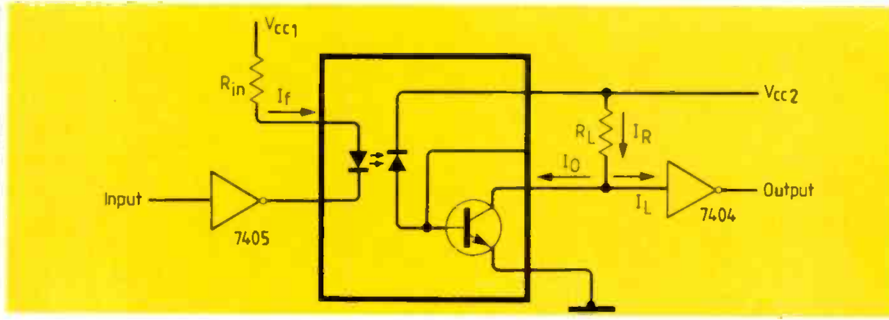
Designing and using slotted cores for current sensing

Two complementary notes give comprehensive details of how to apply hall-effect sensors and slotted ferrite cores in current measuring and sensing applications. One of these notes, from Salford Electrical Instruments, concentrates on the design of slotted ferrite cores and the other, found in the latest Sprague Hall-effect sensor data book, discusses sensing.

Current sensing using Hall-effect devices is reasonably fast and has the advantage that the conductor being sensed need not be modified. One problem is that for a set up as shown in the first diagram, the field around the conductor is often too small to operate a Hall-effect device; with a radius of about 12mm for example and a current of 1000A, flux density at the sensor is about 0.0159T(159G).

For smaller currents, a toroidal or closed magnetic circuit like those shown is needed. One of the circuits has a ferrite toroidal core suitable for higher frequencies. The second circuit has some limitations but it is simpler and it is not necessary to break the conductor to fit it. Here the toroid is simply a piece of sheet mild steel.

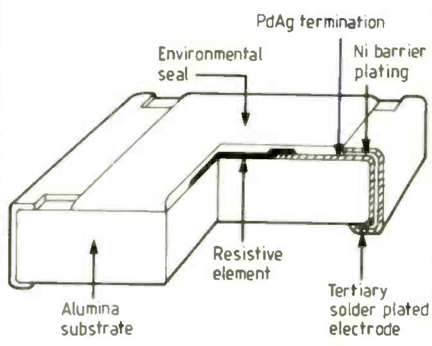




Current-transfer decay in optical couplers

In optoelectronic circuits, degradation of current-transfer ratio due to ageing should be taken into account at the circuit design stage. A worst-case design must accommodate the gradual reduction in light emitted from the diode over the life of the circuit.

Factors affecting current transfer and design details for this simple digital isolator are presented in a short note called "Designing for c.t.r. ageing in optoelectronic circuits" from Isocom.



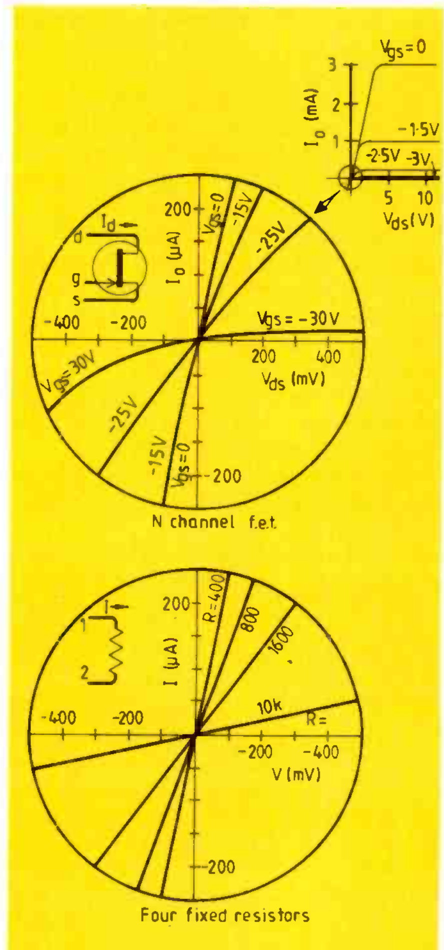
Leaching on s.m.cs

Molten solders, particularly those rich in tin, cause dissolution of silver from terminations of surface-mounting components. This can destroy the termination's metallization layer or affect its bond to the ceramic substrate.

A brochure called "Surface-mount application guide" from Integrated Ceramic Components briefly discusses the leaching of palladium-silver, and the effects on leaching of a nickel barrier layer. Other topics covered are advantages of surface mounting, design criteria and soldering.

Voltage-controlled resistors

Very brief details on using junction fets as v.c.rs are given in a note called "Voltage-controlled resistors" from Siliconix. The note includes three circuits, – including one for a voltage-controlled video attenuator.



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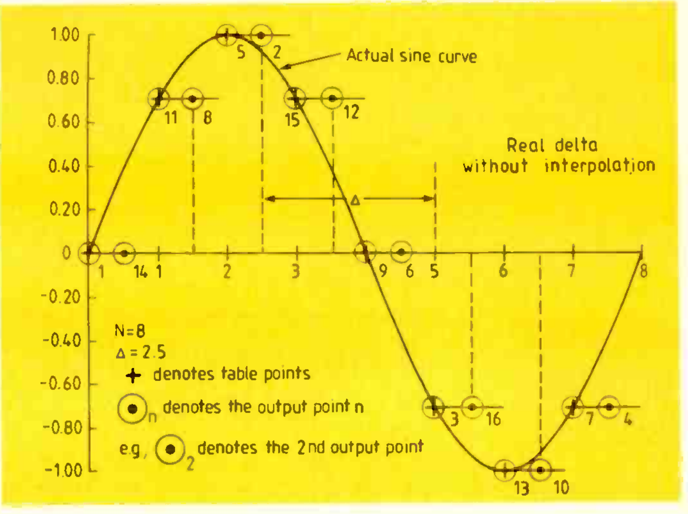
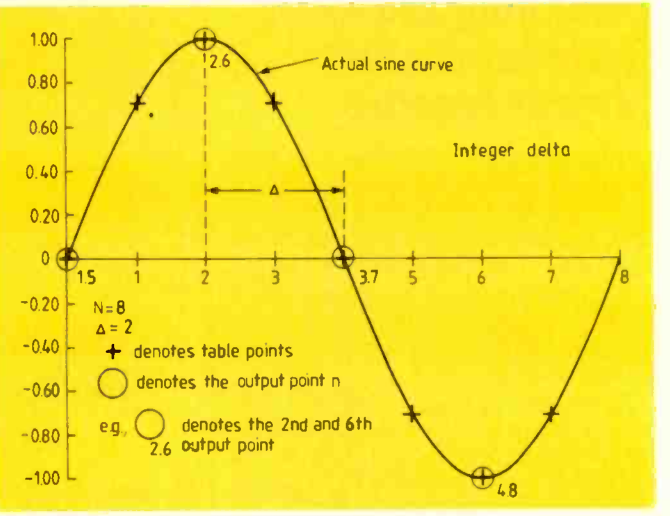




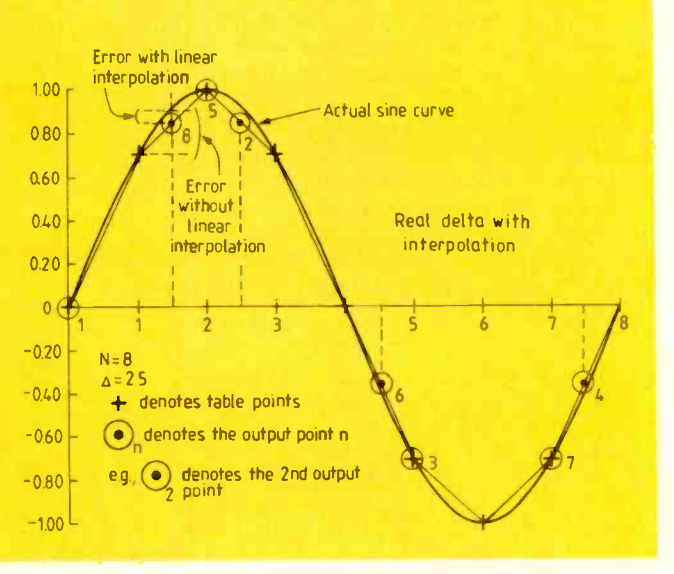
Digital sine wave synthesis

More and more, the stable and low-distortion sine waves needed for communications and control applications are produced using high-speed digital signal processors.

Three types of look-up table suitable for d.s.p. sine-wave generation are discussed in "Digital sine-wave synthesis using the DSP56001" from Motorola. Of the three routines described, the first two are compromises. In integer-delta synthesis, values for the sine wave are taken and used directly from the look-up table. As a result, fast, low-distortion sine waves can be produced, but only at frequencies that are multiples of the fundamental table frequency. To produce frequencies at non-integer mutliples of the table fundamental, a d.s.p. routine that estimates values for points falling between table entries can be used, but at the expense of upper frequency limit and t.h.d.

The third section of the note describes how interpolation produces low-distortion sine waves at frequencies that are non-integer multiples of the fundamental.

Each of the three descriptions is accompanied by an assembly-language routine in 56001 code and the note includes look-up table values.



NEXT MONTH

High-definition television. The Eureka HD-MAC transmission, chain, given its first full demonstration at Brighton in September, was one of the many technical developments shown at the International Broadcasting Convention.

Spectrum analyser with d.s.p. Spectrum analysis based on swept heterodyne techniques is the best solution for signals in the megahertz range. Pat Meehan and John Reidy of Analog Devices describe a high-performance design.

Synthesizer for 900MHz. New mobile communications services in the u.h.f. region have created a growing demand for improved performance. This new c-mos circuit, for use in radios or test instrumentation, overcomes problems encountered with conventional p.l.ls for this frequency range.

The v.s.w.r. enigma. It is rare, says P.B. Buchan, to find in books or journals a lucid and factual explanation of the phenomenon of standing waves. He ventures out to tame the beast.

Pioneers – Georg Simon Ohm. A web of naked fancies, with no support in even the most superficial of facts: that was how one contemporary objector described Ohm's Law. W.A. Atherton recounts the story of Ohm's researches, and his riposte to that critic.

Thirty-six nanoseconds faster than relativity. A.G. Obolensky and Dr P.T. Pappas describe experiments which they believe indicate a definite anisotropy of the normal velocity of light. The observed effects are real, they say, and are not generated in the apparatus.

State machines and reliability

This procedure, describing the development of a car theft protection system, is an illustration of sound logic design.

by JEREMY STEVENS

Following a recent attempt by thieves to remove the radio-cassette from my car while it was parked just a few feet from my bedroom window I decided to fit a burglar alarm.

Most of the proprietary systems available today detect an intruder by infra-red or ultrasonic beams, or by monitoring voltage drop. The first two types are quite expensive and often operated by a radio key which, with the right equipment, is easy to defeat. Although cheap and easy to fit, the third type is particularly prone to false triggering especially in a dirty r.f. environment.

As I was not happy with either the cost or the reliability of commercially available systems I decided to design my own based on the following design criteria,

- reliable operation and immunity to false triggering
- automatic reset after a predetermined time
- built in entry timer with audible warning
- automatic priming of alarm
- visual indication of alarm primed
- protected from vehicle power supply transients
- low stand-by current consumption
- cheap and easy to build using off-the-shelf components.

I decided to use the existing interior-light door switches to trigger the alarm. Some four-door cars only have switches on the front doors so extra switches may have to be fitted. Most alarms of the non-radio-controlled type use an extra key-switch to prime and deactivate the alarm.

To avoid drilling the bodywork or adding a hidden switch I decided to use an existing signal from the 'Auxiliary' position on the steering lock/ignition switch for this purpose. Thus the alarm was to be deactivated when the 'Auxiliary' position on the ignition switch was selected and was to self prime the first time a door was opened and closed after the key was removed from the ignition switch.

With the input signals to the system defined it was now time to develop the state diagram for the alarm.

Detection of states $S_{2,3}$ is required to activate the visual indication that the alarm is primed and detection of S_3 is required to trigger alarm timers and sound entry warning. The four states above are selected in the following sequence,

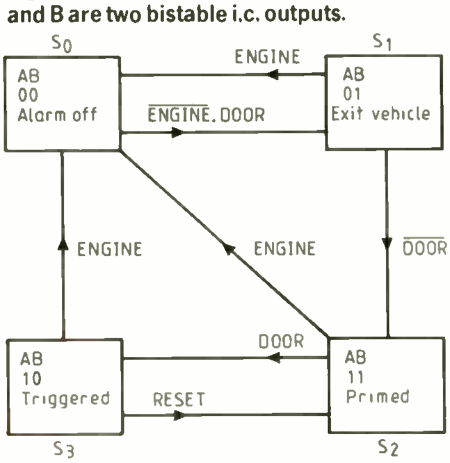
- S_0 – the quiescent state, the alarm is off when in this state.
- S_1 – this state is selected on leaving the vehicle when the door is opened for the first time after removing the key from the ignition switch.
- S_2 – this state is the primed state, selected when all the doors are shut on leaving the vehicle or after the alarm has timed out.
- S_3 – this is the triggered state selected the second time a door is opened after leaving the vehicle.

Note that state S_0 is selected from all states if the ENGINE signal is true. The four states are defined by two bistable i.cs arbitrarily assigned the references A and B.

By direct reference to the state diagram the set and reset equations are,

$$\mathrm{SA=S1.\overline{DOOR}=\bar{A}.B.\overline{DOOR}}$$
$$\mathrm{RA=S3.ENGINE+S2.ENGINE=(A.\bar{B}+A.B).}$$
$$\mathrm{ENGINE=A.ENGINE}$$
$$\mathrm{SB=S0.\overline{ENGINE}.DOOR+S3.RESET=}$$
$$\mathrm{\bar{A}.\bar{B}.\overline{ENGINE}.}$$
$$\mathrm{DOOR+A.B.RESET}$$
$$\mathrm{RB=S1.ENGINE+S2.ENGINE+S2.DOOR}$$
$$\mathrm{=ENGINE.(\bar{A}.B+A.B)+A.B.DOOR}$$
$$\mathrm{=B.ENGINE+A.B.DOOR}$$

Fig. 1. State diagram of the alarm system. A and B are two bistable i.c. outputs.



These equations could be implemented either as an event driven circuit or as a clocked sequential circuit.

Arrival at state 3 initiates the alarm timing sequence which consists of an entry period of about 30s which, when elapsed, triggers the main alarm for 1-2mins. When the main alarm period has elapsed the RESET signal becomes true and re-arms the alarm.

The above timer sequence could be implemented using a dual monostable but to time such long periods, very large values of capacitance and resistance would have to be used. This is undesirable on the grounds of reliability and size as a good quality timing capacitor would be physically large.

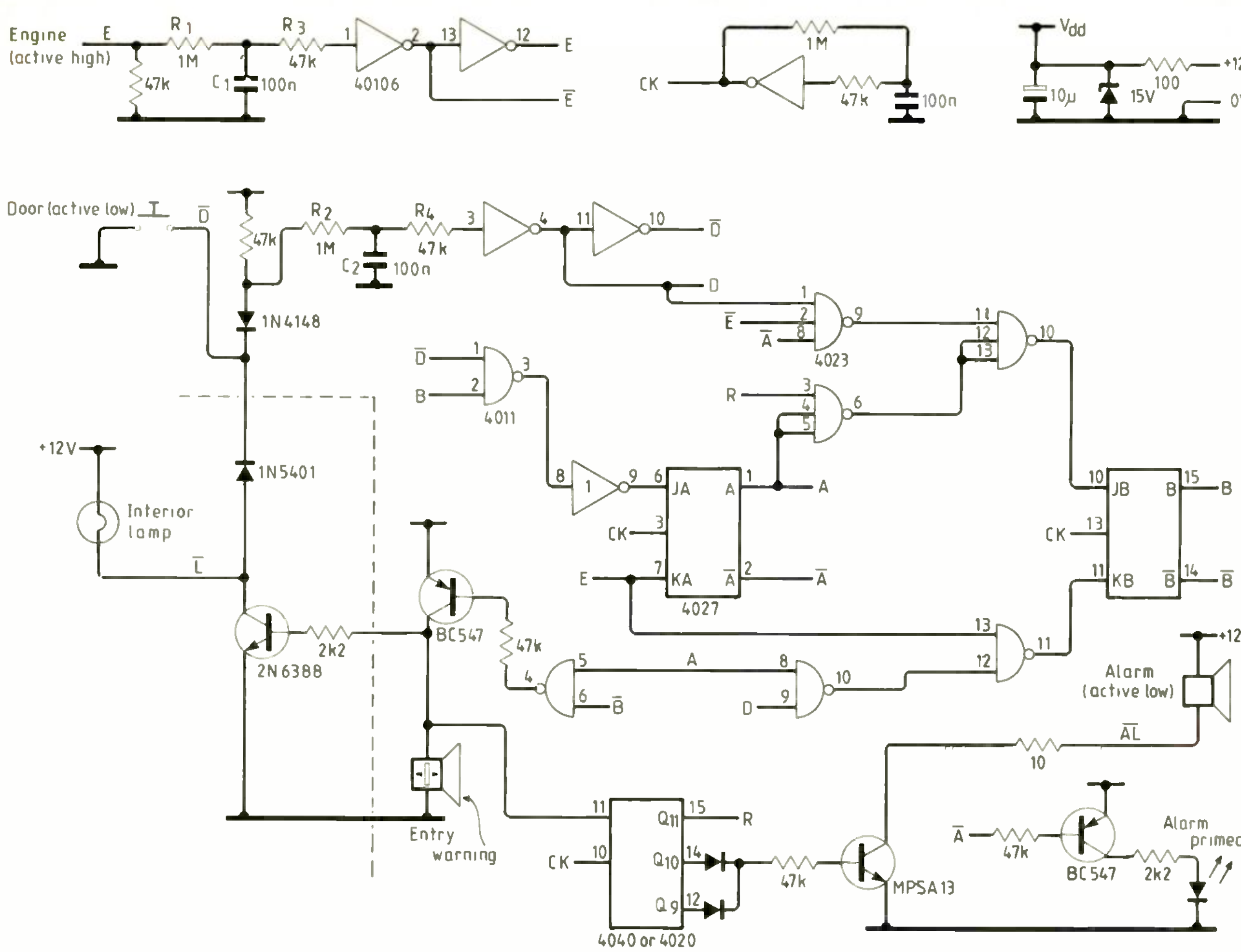
I decided to use a binary counter running from a low-frequency oscillator to generate both time periods. The main part of the circuit could then be implemented in JK bistable devices using the oscillator as a clock. A low-frequency clock can improve the noise immunity of the circuit by greatly reducing its response time.

A 12bit binary counter was chosen, running at a clock frequency of about 10Hz. The gating signal for the main alarm was tapped off at $Q_{9,10}$. Output Q_9 becomes true on the 256th clock pulse, giving an entry time of about 25s and output Q_{10} becomes false and Q_{11} becomes true on the 1024th clock pulse, giving an alarm time of about 80s. Output Q_{11} provides the RESET signal which is required to re-arm the alarm.

During the entry period it is convenient to keep the interior light on to facilitate finding the ignition switch in the dark. The correct signal to switch a suitable transistor is already available in the form of the trigger signal to the alarm timers generated when in state S_3. All that is required is a Darlington driver to switch the interior light and a decoupling diode to prevent latching. These components are optional and are shown enclosed within the dotted lines on the circuit diagram.

Equations for a JK bistable device in terms S and R in the equations above are,

$\mathrm{SA=\bar{A}.JA}$
and
$\mathrm{RA=A.KA}$



Equations for a JK bistable device implementation become.

$JA=B.\overline{DOOR}$
$KA=ENGINE$
$JB=\bar{A}.\overline{ENGINE}.DOOR+A.RESET$
$KB=ENGINE+A.DOOR$

Requirements of 12V operation combined with very low current consumption means that c-mos devices could be the only choice. Generally, c-mos devices are only specified to operate up to a maximum supply voltage of 18V so the circuitry must have some kind of power-supply protection network to afford protection from the high-voltage transients that often occur in vehicle electrical systems. I decided to use a simple Zener-diode clipping network for this purpose. A shunt Zener-diode will give reverse polarity protection as well as clipping any transients. Most Zener diodes fail short-circuit (if not grossly overloaded) so the circuit will be protected even under a prolonged fault condition. A 15V Zener-diode was chosen as this would remain non-conducting even when the vehicle battery was at its normal on-charge voltage of 14V.

Gate input protection is provided by high value input resistors $R_{1,2}$ in combination with the on chip protection diodes of the integrated circuit.

Input capacitors $C_{1,2}$ are included to give additional protection from false triggering due to noise spikes and gate-input series resistors $R_{3,4}$ are to prevent input currents from destroying the protection diodes of the i.c. Such a condition can occur if the main

Fig. 2. Good design can save components. This reliable alarm has a number of features including automatic reset, entry timer and automatic priming.

power supply line collapses whilst input capacitors $C_{1,2}$ are charged.

I built and tested the circuit and it worked first time, proving the benefits of formal design. Component cost for the prototype was under £7.00 (not including the alarm sounder) thus meeting all the design objectives.

Clearly the circuit as described is not 100% thief proof, but it should deter an opportunist thief like the one that tried to steal my radio-cassette.

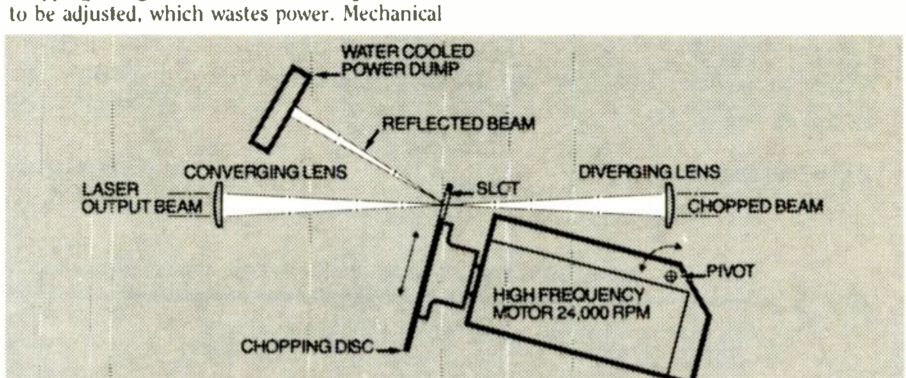
Further reading

D. Zissos, Problems and Solutions in logic design, chapter 3, Oxford University Press, ISBN 0 19 859348 1.
B Holdsworth, Digital logic design, chapter 8, Butterworth, ISBN 0 408 00566 1.

Mechanical laser-beam chopper

In laser cutting, high power beams often need to be chopped at a few thousands of kilohertz in order to produce the desired effect.

With the normal electronic method of beam chopping, the gas mixture within a CO_2 laser has to be adjusted, which wastes power. Mechanical beam choppers – available in abundance for lower power lasers, but not for larger units – allow the beam to be used at full power. Electrox of Hitchin is now manufacturing a chopper for lasers from 80W to 2kW.



Enhanced-instruction-set processor

While most processor manufacturers are concentrating on reduced instruction sets, Linn has gone completely in the opposite direction with its first product in the digital field.

RUPERT BAINES

Reduced-instruction-set computing, risc, is clearly in fashion, as witnessed by the multitude of risc products, related acronyms and advertisements. But in computing, nothing stands still for long and new chips that could become the next big thing are already under development. These devices are based upon totally different ideas from risc, and have been designed to function in a very different way.

Everyone knows that risc philosophy is based on having fewer, faster instructions. Streamlining the architecture and removing all the complexities make the processor run very fast indeed. That this approach works is undeniable. Devices in this new generation have triple the raw speed of their conventional complex-instruction-set computing (cisc) rivals. For instance Motorola's new 88100 has a declared speed of 16Mips, which makes the 3+ of the 80386 look a little shabby.

While no-one would dispute the speed of these chips, there is a growing debate about their real power. The argument concerns their ability to handle situations that occur in real data processing rather than in advertising copy or in a laboratory bench-test. Perhaps risc, in concentrating so blatantly on raw speed, is not quite the right approach. Could it be that these designs are very impressively, very cleverly, solving the wrong problems? We want better performance from a chip so that it can run our programs faster, sort data more quickly and handle blocks of information more efficiently. How well will these aims be met by risc; might they be better met by a different approach?

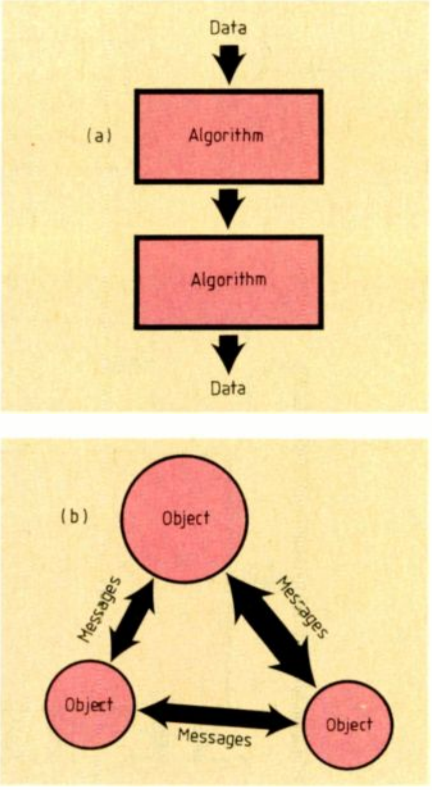


Fig. 1. (a) shows a conventional programming paradigm and (b) object-oriented programming.

Processors are planned, designed and manufactured for particular application areas. For example, the four-bit controller in a washing machine is obviously very different from the thirty-two bit processor inside a workstation. The complexity, the instruction set and the hardware are all designed to suit a particular task.

It is now becoming apparent that the architecture and design philosophy should also be chosen to suit the application. To illustrate, Intel has retained the conventional cisc philosophy for the new 80486 (compatible with the 8088/86/286/386 family, with all the architectural complexities required) but adopted a sparse risc design for the 80960 high-speed micro-controller. (By the way, design work has already started on the 80586, which will also be a cisc device).

This is only the beginning. There are now chips that have been designed from scratch to run particular high-level languages, and to run them very quickly and efficiently. They have large, rich instruction sets, with many specialized registers and an architecture tailored to suit their particular application – a world away from the stark-

OBJECT ORIENTED PROGRAMMING – OOPS

Conventional programming schemes view the world as a collection of pieces of data, which are operated upon by procedures and algorithms to produce more data. The object-oriented programming system (Oops) paradigm is different. This sees the world as a number of sophisticated, self-contained objects that communicate with each other using messages.

The required data structures come first, the control process last. For example a given object within an architectural cad program might be 'Building'. This would contain data such as dimensions, shapes, descriptions, costs etc, together with rules to describe how they relate to each other and to incoming messages like 'Show plan', or 'Print front view'. Data within the 'Building' object could thus initiate a whole sequence of actions.

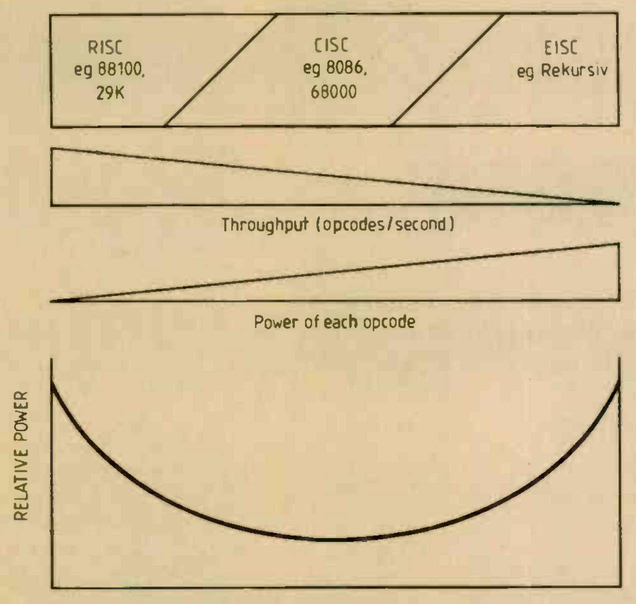
Detailed implementation of an object and what messages will mean to it are carefully hidden from the rest of the system, with messages being the only interaction between them. Thus objects can be created or modified without causing unexpected side effects.

One of the major benefits of object-oriented programming is that it is flexible, working in a way that is much easier for human beings to cope with. It can be highly expressive, with each message conveying a lot of information to a sophisticated object.

Addtionally because all the objects are communicating, sealed units there are benefits to security (the only way into an object is through a message whose consequences are known) and integration; since interaction can only occur through messages it is irrelevant what language an object has been internally coded in.

This style of programming has been around since the 60's, but until recently its success has been limited since object-oriented programs execute very slowly on conventional computers. The need for large amounts of memory and serious processing power has confined object-oriented programs to research labs. However, with the ever growing power of processors, the expansion in memories and ideas like the Rekursiv these obstacles are diminishing.

Although C++ and ADA are becoming more popular, the most widely known language of this type is Smalltalk/V. This, along with Ethernet, mice, windows and most things worthwhile in modern computing, was developed at Xerox's Palo Alto Research Centre. If Oops fares as well as its siblings have then there's little doubt over the languages of the future.



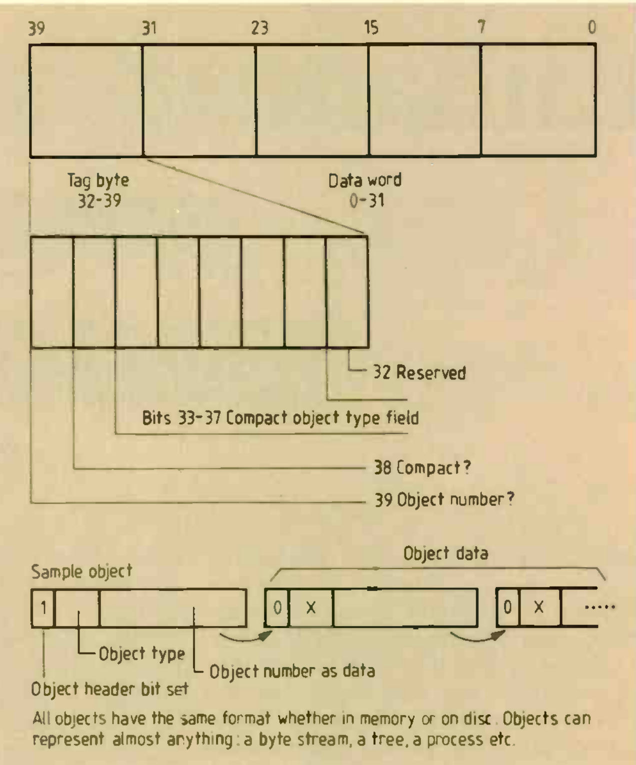


Fig. 2. Relative merits of reduced, complex and extended instruction set processors, top, and Fig. 3. Words and objects within Rekursiv, right.

ness of risc with its simple design, few op-codes, and general-purpose nature.

Some of these new processors have been well publicized. Hitachi produces the H series, with specialized procedure-call hardware for running C very efficiently. Several companies have produced devices that can run Forth directly (using powerful stack based designs) while both TI and Symbolics have developed processors that have been planned and optimized to run Lisp applications. These are complex chips with large instruction sets tailored to the commands, addressing modes and structures that are needed for list processing, tree handling and lots of (virtual) memory.

The most recent product in this field is the Rekursiv from the Scottish company Linn. For me, it is the most interesting, and certainly the most innovative of any of these devices. From the beginning the Rekursiv processor has been developed with the aim, not merely of running a given language well, but of solving problems efficiently. And it is designed to handle large and complex data items in the fastest and most powerful manner.

Both TI and Symbolics have designed processors for running Lisp efficiently. Although Lisp is well established, it does not embody the latest research. The Rekursiv on the other hand takes into account current developments in programming style and languages.

Linn Products is famous for making high-quality turntables that play real vinyl records very well. This is not the place to squabble about the relative merits of analogue versus digital sound (suffice it to say that c.ds do make excellent roms), but despite the pre-

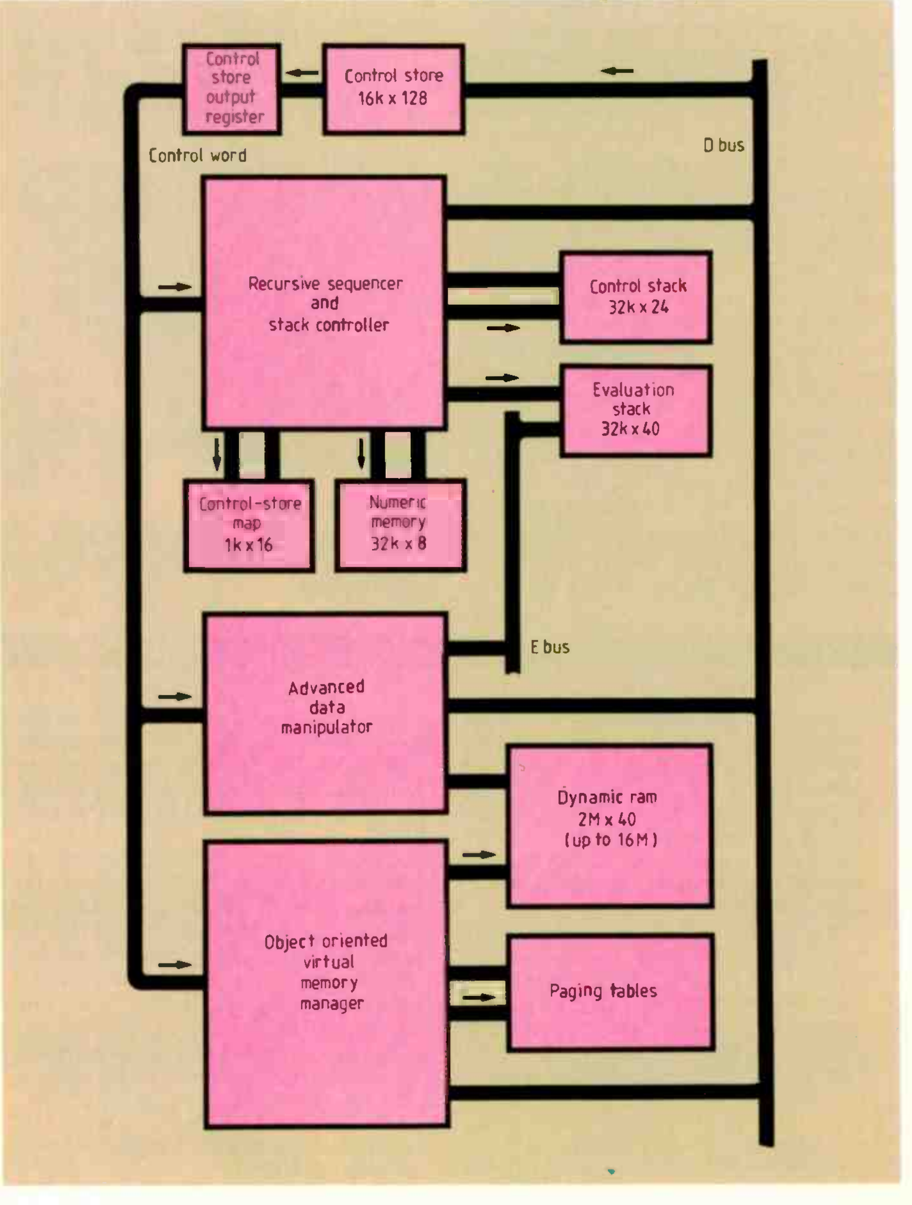
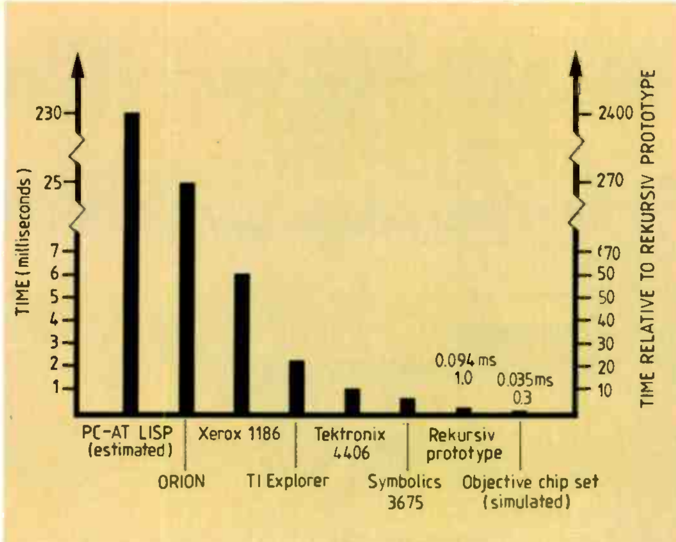


Fig. 4. Structure of one of the first products to incorporate the Rekursiv chip set – a single-board computer.



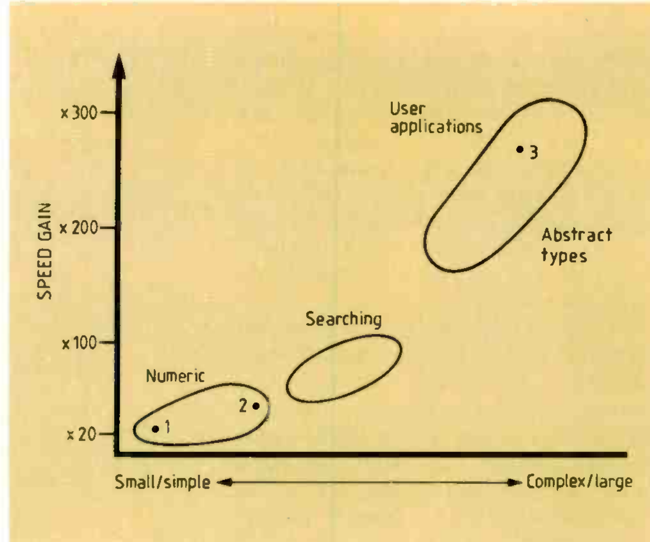


Fig. 6. Performance of several processors executing the code of Fig. 5 (left).

Fig. 7. Projected relative speeds of Rekursiv with microcoded algorithms and an Orion. Example 1 is a linear factorial program (thirty times), example 2 is a recursively coded factorial (fifty times) and example 3 is the tree copy routine from Fig.5 (270 times). An Orion is roughly equivalent to a mid-range Vax computer.

judices of digiphiles the company is anything but old fashioned. The manufacture of the Sondek (as the Linn turntable is called) is highly computerized, with a high level of automation, robot vehicles and advanced electronics. It was this high-technology production process that inspired the Rekursiv.

Unhappy with conventional software, Linn decided that Oops offered the efficient way of meeting its needs. After developing its own language, Lingo, along these lines Linn found that it was far too slow when running on a VAX. Accordingly the company invested in a semi-custom computer in the form of a specifically micro-coded Orion machine – but even this gave disappointing results. Not to be beaten, Linn decided to take the adventurous step of developing its own architecture, recruiting Professor David Harland from Glasgow University and giving him the task of designing a processor that was capable of supporting Lingo while running at an acceptable speed. A daughter company, Linn Smart Computing, was formed and started creating the Rekursiv.

THE REKURSIV IDEAL

One of the major problems with an object oriented language like Smalltalk/V, Lingo or C++ is that it requires data structures (and the associated operations) or arbitrary size and complexity. This requires large amounts of programming to define the necessary primitives, and a huge amount of memory access, which combine to make the system very large and very slow. The aim of the Rekursiv was to overcome these difficulties.

Fig. 5. Lisp procedure to copy CONS-tree structure and the equivalent Rekursiv program that defines a new op-code called MICRO COPYTREE.

```
(DEF COPYTREE(ITEM
    (COND ((ATOM ITEM) ITEM)
        (T (CONS ((COPYTREE (CDR ITEM))
                        (COPYTREE (CAR ITEM))))))

MICROSCOPYTREE: entf 1 pagebus d=ustac
    crtf IDXBADTYPES  newtrbr_CONS
    incmsp m.sp' newmptr
    jf MICROSCOPYTREE ldustk d=tgrorr //THE CDR
    m.fp 1 uaddbr newmptr
    readustk
    pagebus d=ustack
    idx2 newsr newbr loadaddr
    idxget nocheck  incmsp m.sp' newmptr
    jf MICROSCOPYTREE ldustk d=memout  //THE CAR
    js RTNSCONS
    rtf
```

The chip's designers had the advantage of starting from scratch; unlike other companies already in the field they had no worries about compatibility but were free to design their processor as they saw fit. They decided that conventional processor design had not kept up with research, and that a great many design choices were based on principles and folklore that were no longer relevant. The architects of risc had come to a similar conclusion in choosing their minimalist solution, banishing the majority of functions to become the responsibility of the compiler or the user.

Linn's team has taken totally the opposite tack, extending the processor's instruction set and hardware to such an extent that tasks are directly handled that traditionally were overseen by the compiler, the operating system or even the programmer! In particular the higher order, more complicated functions like persistent storage and recursion can be expressed from machine code (or below; microcode support for recursion is a unique feature of the device.

The machine core has been planned to closely correspond to the requirements of an object oriented language; for example op-codes exist to search an environment, to exchange messages between processes, or even evaluate a whole tree in one swoop. And the processor has been expressly designed to allow users to enlarge the instruction set by adding their favourite op-codes.

Conventional processors spend a great deal of time and effort fetching and decoding instructions before they can start to execute them. Processors are featuring more and more complex pipelines and cache structures in an attempt to minimize this waste (the von Neumann bottleneck). Reduced-instruction-set computing offers one way out, by streamlining the op codes to such an extent that the fetch/decode overhead is minimal, with every instruction being executed quickly and directly. The Rekursiv is instead an enhanced-instruction-set computer (or e.i.s.c.) whereby the machine supports very high level op-codes which perform a great deal of work for a given instruction. This solution avoids the bottleneck by requiring very few instruction fetch/decodes and getting good value from each one.

One engineer made the interesting analogy, "... if you start from a car and remove all the frills; roof, two wheels, etc., you end up with a motor-bike. That is risc – very fast and very responsive. It is ideal for a courier delivery service but perhaps not so good for big loads. On the other hand if you go the other way and add a powerful engine and a vast boot then you've got an articulated lorry – and that is the Rekursiv. It needn't have the same speed to deliver more". And in the middle? Well in between these two approaches are the conventional cisc devices, Fig. 2.

INSIDE THE REKURSIV

Rekursiv is a processor architecture and Linn has had a chip set made, called the Objectiv, that implements this architecture.

Probably the most fundamental decision that a chip designer makes is choosing the data width. With its 40bit word length, the Rekursiv is distinctly different from mainstream processors. The bottom thirty two bits are used as data bits, allowing the Rekursiv to be compatible with devices such as the 80386 or 68030 (e.g. using standard IEEE P745 format real floating-point numbers) but the extra eight are very different. This special purpose byte is used by the processor as a tag, to tie extra information to each word. Five bits are used as type field, which allows the processor hardware to know whether a word represents an integer, a real number, a character or up to twenty-eight other data types.

New object types can be defined, with their own operations, and the processor can react accordingly; for example an ADD operation applied to an integer would trigger the internal hardware; applied to a real number it could call the appropriate subroutine, and applied to a character string it could trigger an error sequence – all automatically. Integers, characters, pointers and the like are all scalars, or compact objects simple enough to be stored in one word: the more interesting, more complex objects are stored as packets, with a header number and then a series of data words, Fig. 3. This too is flagged from the tag field, simplifying the work of the processor.

This idea of tagged data, of designing the fundamentals of the hardware around object handling, is not unique, with most Lisp oriented chips (for example the Symbolics Ivory) using a similar scheme. However the Rekursiv takes the idea further. Not only is the data tagged from hardware but so are the addresses. One of the fundamental ideas in Oops is that of 'persistent storage'. All objects have their own unique label (for example thing#1, thing#2 etc), and can only be accessed by that label. It is irrelevant whether the object is in memory or on disc.

The labelling remains constant and is used exclusively. This contrasts to conventional systems where the programmer uses addresses to access a structure and has to cope with the address changing as the object moves. Persistent storage means that discs are treated exactly as memory; there is no addressing, there is no filing, there are only objects. This builds on the idea of virtual memory (where pages of memory are 'transparently' swapped by the operating system between disc and ram as required) but is considerably more sophisticated.

In a conventional system the working units are addresses or pages, with objects requiring an additional extra layer of software to find them, slowing down the system. If they are to be dealt with independently, every object requires its own page, which is wasteful. Alternatively if objects have to share pages then their independence and security (major attractions of Oops) are compromised.

Supporting a persistent storage system from scratch solves these problems. Of course at some point there have to be physical addresses and real disc control, but these are totally invisible to the programmer, being handled by a dedicated chip called the object-oriented memory-management co-processor), Fig. 4. As well as providing direct access to objects this chip also performs boundary and range checking, preventing corruption or inspection of adjacent items. It also handles page-fault and useless-data collection automatically from hardware, rather than from an operating system.

A persistent storage system has significant benefits. For instance, because object addressing is transparent, the integration between different programs, different languages or even different users is automatic. Similarly the code becomes more portable; for automatic access it is essentially irrelevant whether an object is located within a single-user personal computer, somewhere within a networked system or inside a remote host.

There are major security advantages too, since a user is removed from direct contact

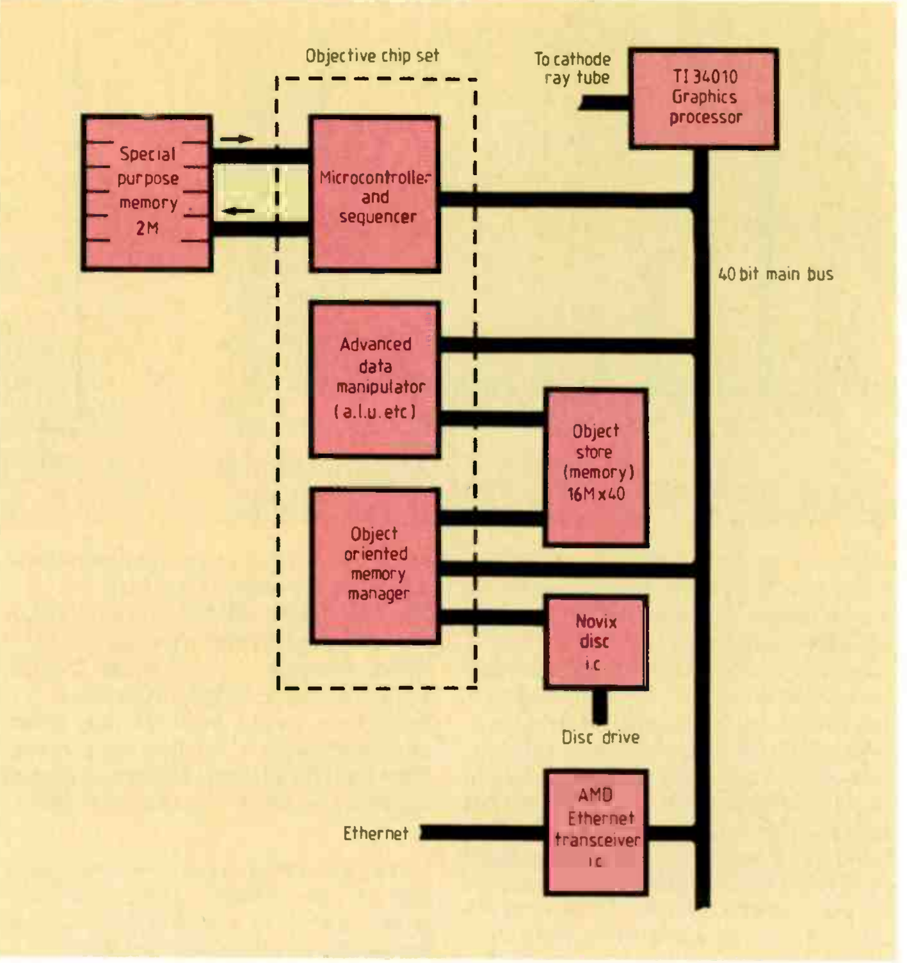


Fig. 8. Since the article was written, this product, mentioned in the article, has become available. Its name is Hades, which is an acronym for hardware accelerator for data-base expert systems. It is available with C or Prolog and runs 18 times faster than a Symbolics 3675 when tree copying.

with memory or disc, whether accidental or malicious. Obviously these benefits apply whatever Oops is used; the Rekursiv's direct implementation is obviously very much faster than the approach of simulating them from software within a conventional von Neumann byte-oriented machine.

This genuine single-level approach (i.e. disc and memory are equivalent) to persistent storage is unique. The decision to have this explicit support for abstract reference to virtual memory, eliminating the role of the operating system, was one of the fundamental design choices of the Rekursiv, and the resultant reversal (from disc operating system to hardware) of the conventional hierarchy of computer design is probably the single most revolutionary concept within it.

Coordination and organization of the processor is carried out by the second chip in the Objektiv set, the micro-controller. It contains the processor's microcode, the micro-sequencer and the recursive stack controller. Microcode is the internal language of a processor, which translates the op-codes into gate-level strobes and enables of hardware, and it is this microcode that gives a chip its character.

Designers of risc chips abhor microcode, as they work towards simplicity of design and hence direct execution of op-codes. Contrarily, the Rekursiv is an extended-instruction-set computer with a large and powerful instruction set and an abundance of supporting microcode. Instructions already supported cover typical Oops requirements to create an object of given type or send messages between objects, as well as giving direct support for recursive subroutines.

That is by no means all. This chip can be customized and it allows users to define their own microcode in ram or rom, extending the instruction set as desired. Since these codes are written in the ultimately low-level language they are extremely fast, and allow you to create arbitrarily complex operations that will be carried out as a single machine-code instruction.

DATA PACKAGING

According to Linn a great deal of time is wasted in conventional systems, "packaging data at the end of one instruction only to have it opened out at the start of the next op-code". Consequently, if the desired algorithm is coded directly, with none of this packing/unpacking overhead, the speed gain is at least a factor of ten. As the program becomes larger, and more sections are coded the speed gains accelerate (especially if they are the recursive, or inner-loop elements).

Figure 5 shows an example; there is a Lisp procedure to copy CONS-tree structures and the equivalent recursive program for the Linn that defines a new op-code MICROSCOPYTREE. Some timings are given for

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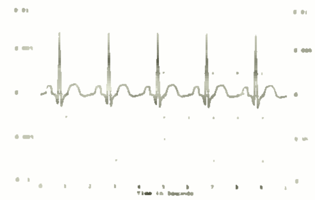
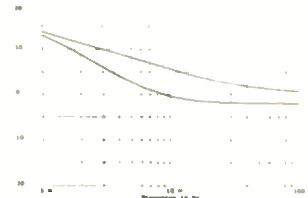


Waveform through switching circuit



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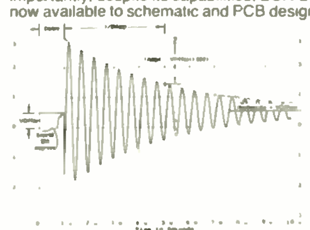
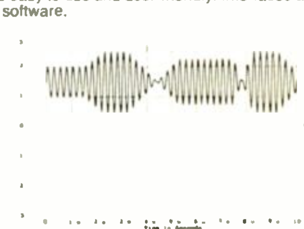


Internal generator programmed to produce sine wave with exponential amplitude decay



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other processors running the same Lisp program in Fig. 6. (Support for recursion and the power of the memory control co-processor allow the microcode to be generalized to a greater extent than is usually the case).

Arithmetic and logical processing is carried out by the third and final chip in the Objectiv set, the a.l.u. This 32bit device, based on an AMD29023 maths chip, is built up to order from 2903 bit-slice maths processors. It includes a 32×32 multiply instruction and an integrated barrel shift register.

All three processor modules – the object-oriented memory chip, the microcontroller and the a.l.u. – have been fabricated in LSI Logic's "Sea of Gates" technology in 1.5 micron c-mos. These three devices, together with the main object store of 16Mword of 40bit dynamic ram (plus disc storage), and 2Mbyte of special-purpose internal memory, will make up a single-board object-oriented processor. The chips are still under manufacture and subject to further testing, and are not due to be released until later this year. Structure of this board is shown in Fig. 4 on page 1112.

PERFORMANCE

Until the chips are available, the best indications of the Rekursiv's performance come from prototypes and simulations (hardware and software). Some idea of the performance can be gained from the graphs in Figs 6, 7. These indicate that the Rekursiv is particularly good at complex tasks.

In addition to using the Rekursiv in its factory, Linn has several plans for the device. The first of these is likely to be an add-on board for Sun workstations (scheduled for release later this year). There are also plans to sell the design to other original equipment manufacturers, so it should not be long before the first PC-compatible additions are advertised.

Such add-on boards will act as accelerators; compared with a conventional 32bit system, speed gains of between 100 and 1000 fold have been mentioned. Since most applications are currently written in C, I would imagine that the first few Rekursiv chips have been code optimized for Kernighan and Ritchie's famous creation. The "smart" languages, such as Lisp, Prolog and most 4GLs are simple implementations of an Oops, and as such any programs written in these languages should benefit greatly from such an accelerator.

Some other applications – for instance relational data bases – are ideally suited to an object oriented approach, and these too would gain enormously in speed. With other programs the gains would be far less significant; word processors for example are mostly limited by the user's typing speed.

Linn also plans to produce a complete, stand-alone board based on the Objectiv chip-set that will be suitable for work stations, Fig. 8. This includes the complete processor described above, a Novix chip for flexible disc access, TI's new graphics processor and the AMD Ethernet chip-set.

Rekursiv's designers have taken a totally different approach from everyone else in the computer industry. While risc is solving this year's problems, Rekursiv is setting forth the ideas and opportunities for how we can think about the future; the types of problems that we can tackle and the way we go about them. I think that the Rekursiv, coupled with the growing interest in Oops, is going to radically alter the way we program, the way we use computers and the attitudes we have towards them.

My view is that this chip set sounds the beginning of the end for general purpose processors. Today it is considered usual that, for a scientific application you use a computer with a numeric co-processor (8087, 68881 etc). Nobody finds it at all odd to use a different language for a different type of problem. As v.l.s.i. technology advances, as research develops, as needs become more specialized, it is certain that we are going to see more of this kind of chip designed specifically for a language and/or an application.

Application-specific ics are familiar devices; perhaps in five years time the application-specific processor will have become equally common, and you'll select the c.p.u. that best meets your particular needs that day.

To end on a sombre note, the Transputer is another example of a revolutionary British processor. However even now, the future of Inmos is not as secure as it might be, with Thorn still looking for a buyer. The dismal history of British investment and management of high-technology companies does not let me be as optimistic as I'd like to be about the future of the Objectiv chip-set and the Rekursiv architecture. I very much hope I'm wrong and the Rekursiv becomes a roaring success, with the backing it so clearly deserves. But I won't hold my breath.

Rupert Baines is a free-lance hardware engineer in Hull, tel. 0482 219150.

Further reading

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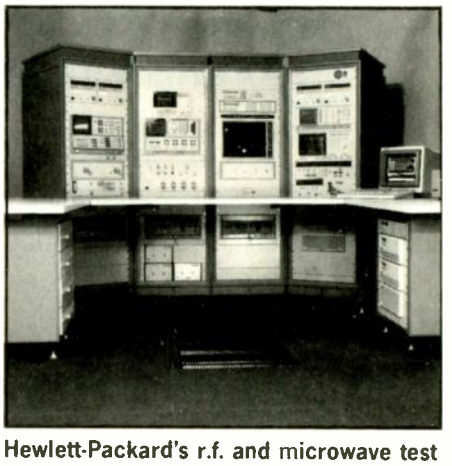
Microwave testing complex

Hewlett-Packard and Ferranti Defence Systems have collaborated to produce one of the most complete r.f. and microwave test systems yet seen in Europe, which has recently been augmented by the inclusion of more measurement facility and a greater degree of automatic control.

The equipment uses a selection of H-P bus-controlled standard instrumentation and provides a test station for automatic test; for design and development work; or for computer-assisted design and manufacture. It also keeps a log of results on disc for future reference. Ferranti wrote the specification and Hewlett-Packard has been able to satisfy the requirements by, in the main, catalogue instrumentation, further sections being custom-designed. It was a fixed-price contract and indicates the direction in which H-P wishes to proceed, namely towards the provision of complete measuring systems as solutions to specific requirements.



Hewlett-Packard's r.f. and microwave test complex, installed in the Ferranti factory at South Queensferry, Edinburgh.

At the core of the complex is the 8510, an r.f. and microwave vector network analyser, which has built-in error correction and which is capable of displaying up to 801 data points. The instrument employs narrow-band, frequency-selective techniques to measure, in conjunction with a synthesized sine source, transfer and impedance functions of linear networks at low noise levels. In addition to the 8510, the simpler 8756 scalar network analyser is included, using broad-band techniques where noise measurements are not of interest and where input and output frequencies differ, as in mixers, for example. Among the other instruments is a 3048 phase-noise measuring set which demodulates the frequency and phase disturbances of a signal, displaying the results spectrally.

The complex is, naturally, installed in a screened room, since the Ferranti factory is in the business of making radar equipment, transmitting in the band of interest.

TELECOMMS TOPICS

Telling the driver where to go

A revolution is under way in the manner in which the drivers of London's radio taxis will receive instructions for their duties. Voice-based systems are about to be replaced with data-despatch, which will not only make more efficient use of the limited number of available radio channels, but will provide a much more efficient service overall.

With the voice-based systems currently in use, the taxi despatcher broadcasts abridged details of each job. Drivers on that radio circuit who are plying for hire listen on their radios for a job in their vicinity. The first driver to respond is allocated the job and given all the necessary particulars over a voice channel. Because of the quality of the radio channel and bottlenecks in the system it is not unusual for ten minutes to have elapsed between the 'phone request for a cab and the driver getting all the details. To this delay must be added the time that it actually takes for the cab to get to the pick-up point.

Dial-a-Cab is scheduled to be the first of the London companies whose system will go live. It has already embarked on an installation programme to fit all 1420 of its cabs with data terminals and expects to be fully operational before the end of the year. Its system is being supplied by the Canadian company Mobile Data International (recently taken over by Motorola Communications) which has considerable experience in this field. And if there are no problems to be ironed out, Radio Taxis (London) will follow some six to nine months later with its own MDI system.

When a taxi driver begins work, he will key his location to the specially designed data terminal. The system maintains a queue of all cabs registered in each of the zones into which London is divided. A driver can check at the touch of a button how many cabs are queueing in his and adjacent zones. He can then decide whether it would be advantageous to move to another zone where the queue for jobs appears shorter.

Once a request for a cab is received at the operations centre, the operator keys details into a v.d.u. It only takes seconds for the system to work out which cab is at the head of the queue in the particular zone and send it the details. The pick-up address etc. appears on the 32 character, four-line display of the terminal in that driver's cab. He then hits a button to accept the job and is removed from the queue of cabs plying for hire. Should he not accept the job, it is passed to the next driver in the queue.

The data communications system must be designed to survive in a mobile environment where radio signals are subject to deep fades, burst and random errors, and multipath fading. A combination of forward error correction (FEC) coding and automatic retransmission (ARQ) techniques must be used to obtain reliable, error-free data transmission.

However, to maximize the throughput, the type of error-correcting code must be chosen very carefully to suit channel characteristics. Burst error correcting codes are better suited to fading channels (in which errors occur in bursts corresponding to the fades) than random error correcting codes.

A code that requires few redundant error-correcting bits offers higher throughput, but may be too weak to correct most errors, and will result in repeated transmission retries. On the other hand, extremely powerful error correction codes require the retransmission of many redundant error correcting bits that in turn reduce overall throughput. There is, therefore, an optimum redundancy that balances protocol efficiency against error-correction power.

In the MDI system, a message consists of a header followed by the text message. Each header in the transmitted bit stream contains error detection and correction coding information. In addition, three copies of this header are inserted at the front of each transmitted text string. This provides a data redundancy factor of 200 percent, so that the correcting power is 100 percent, and a simple two-out-of-three majority vote at the terminal can be used to perform correction. Capture of a correct header ensures byte synchronization, so that the text message that follows can be decoded even if badly garbled.

The text string is broken into 45-character blocks, of which there can be a maximum of eight, and an FEC algorithm is applied. This expands each 45-character block to 63 characters. The aim is to reconstitute and display the original message. However, in order to maintain the driver's confidence, it is imperative that erroneous messages are not displayed

The FEC technique used is effective on multi-burst errors and random single-bit errors; it can recover and correct a test string if up to 17 percent is lost or garbled; it reduces retransmission requirements to less than five percent of all messages, assuming an average link bit error rate of 1×10^{-2}.

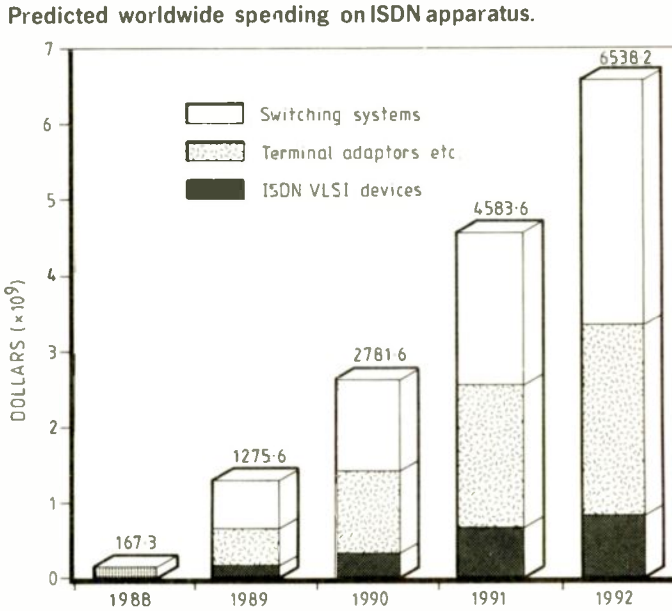
If a message cannot be displayed correctly after the first transmission, up to four retries take place automatically. The number of transmissions needed to regenerate a correct message are reduced by the fact that, as the message is split up and sent as discrete blocks, forward error correction is performed independently on each of these segments. Consequently, if one or more segments is uncorrectable, valid segments are retained and the terminal waits for a retransmission. Thus there is a high probability that it will be possible to re-assemble the correct message, since it is only looking for "good" segments to replace ones that were previously faulty – it does not need to receive a complete good message. The terminal will acknowledge receipt of the message once it has received it perfectly.

With an effective transmission rate of 4800bit/s it takes only about a second to send an entire message. This is obviously much shorter than the time taken for an equivalent amount of information to be handled by voice. Furthermore, such a system offers the potential to automate other functions such as billing.

Transatlantic ISDN chips

National Semiconductor and SGS-Thomson Microelectronics have announced the general availability of their first jointly-developed ISDN components. Although ISDN (see Towards ISDN, Telecomms Topics, August p. 774 and September p. 908) does not at present occupy a major segment of the telecommunications industry, it is expected to have grown 40-fold by 1992, when worldwide turnover is predicted to reach $6538.2 million. As some 10% of this will be in ISDN v.l.s.i. devices, the

Predicted worldwide spending on ISDN apparatus.



strategic importance of this partnership can be readily appreciated.

According to Aldo Romano of the monolithic microsystems division of SGS-Thomson, "Both companies have committed significant resources dedicated to the development of these and future ISDN products. We are focussing our attention to both American and European marketplaces." This is an important factor as, according to Detlev Kunz of National Semiconductor, there is a need to align the standards adopted around the world, to achieve economies. For example, even though the 2B1Q line code has been agreed in both the USA and Japan, no such agreement has yet been reached in Europe.

The first chips are an interface transceiver to meet the latest "S" interface and a programmable "combo" for digital terminals. The S interface device, TP3420/ST5420A, is a monolithic transceiver for ISDN applications. In addition to all the functions specified in the CCITT I.430 recommendations, it implements all the features needed for TE (terminal equipment), TA (terminal adapter), NT1 and NT2 (network terminations) and PABX line card applications. It supports links up to 1.5km in point-to-point and up to 200 metres in point-to-multipoint configurations (where up to eight terminals can be connected).

The device uses a high-resolution phase-locked loop in its receiving circuitry which is claimed to provide transmission performance far superior to the minimum requirements of I.430. Such performance ensures a low bit-error rate throughout the network, regardless of the type of twisted-pair wiring used at the S interface.

In addition, all activation and "D" channel access algorithms are handled automatically without the need to invoke any action from a microprocessor. Other features of the device simplify development of ISDN equipment. For example, it can enter a power-down mode for terminal equipment that receives its power through the ISDN interface. The p.l.l. also allows the chip to synchronize itself with any clock signal, satisfying the requirements to synchronize the entire ISDN network.

The TP3076/ST5075/6 programmable combos for digital terminals are second-generation p.c.m. coder and filter devices optimized for digital switching applications on subscriber line and trunk cards in digital 'phone applications. Using advanced switched-capacitor techniques, they combine transmit bandpass and receive low-pass channel filters with a companding p.c.m. encoder and decoder.

NS has also developed a version of its HPC microcontroller core that contains added circuitry to support ISDN system functions. Its HPC16400 communications controller contains specific hardware, such as two full-duplex HDLC (high-level data link control) channels, a serial decoder and a programmable uart. When used to implement ISDN in equipment at the user's premises, the HPC16400 can support ISDN standards such as X.25 LAPB and LAPD (Q.921 and Q.931).

In addition to these chips, which conform to CCITT standards, NS has also announced its TP3401 digital adapter for subscriber loops (DASL). SGS-Thomson has the right to second-source this device. This is a low-cost, burst-mode transceiver for two-wire PBX and private network loops up to 1.8km. It uses techniques such as scrambled alternate mark inversion decoding to assure low bit error rates on a wide variety of cable types. While this is a proprietary transmission scheme, it offers single twisted-pair wiring and is available at a lower cost than the S interface which only specifies 1km (even though the TP3420/ST5420A will support 1.5km) and so can be usefully employed in PABXs.

Mercury expands Centrex services

Mercury has announced that the capacity of its London Centrex switch has been expanded from 10 000 to 28 000 lines. The company also plans to provide Centrex services, whereby PABX facilities are provided by the local public telephone exchange, in other major cities around the country.

Mercury's is the first digital Centrex service in Europe and it has been available for customers on Mercury's London Cable Scheme since April 1987. Charges for the service consist of a one-off connection fee per service line plus monthly rentals.

Centrex is well suited to companies with several separate locations, and also to those that quickly need to alter their internal communications system in response to company growth or relocation.

Benefits to the customer include the elimination of the need for major capital expenditure. Features available on Centrex are enhanced by Mercury on a continuous basis so that customers have the ability to upgrade quickly and simply. External calls are charged but calls between extensions are free.

PTAT-1 installation begins

STC Submarine Systems has begun the first stage of the underwater installation of PTAT-1 (the first private transatlantic optical fibre telecommunications system), co-owned by Cable and Wireless in the UK and Private Transatlantic Telecommunications System Inc. in the USA.

Three shore ends, at Manasquan, New Jersey in the USA, Brean near Weston-super-Mare in the UK, and Devonshire Bay, Bermuda, have been installed. Laying of the first five deep water sections of the link will begin later this year as part of the overall programme which leads to the provision of the UK-USA-Bermuda section of the system by July 1989.

The link will comprise three working fibre pairs, two of which will link the UK and the USA direct, the third linking Bermuda and Ireland via branching units. An additional spare fibre pair may be switched into service on a section-by-section basis to enable the system to be maintained in service without the need for ship repairs.

The two-fibre pair spur to Courtmacsherry Bay, County Cork in the Republic of Ireland, due for completion in November 1989, will join the main transatlantic link at a branching unit 100km off the coast.

The fibre pairs will operate at 420Mbit/s at a wavelength of 1300 nanometres, giving a capacity of 5670 circuits per fibre pair before the use of circuit multiplication equipment. All cable for the system will be protected either by extra sheathing or by one or more layers of armour wires.

Repeaterless record

STC Submarine Systems is to supply the world's longest underwater cable link without submerged repeaters. The $10 million contract for the cable is between STC and the link's co-owners Mercury Communications, the Netherlands administration PTT Telecommunicatie, and British Telecom.

To be known as UK-Netherlands 12, the system will link Aldeburgh, Suffolk, with Domburg in the Netherlands, over a distance of 155km. Completion is scheduled for summer 1989. It will be the fourth submarine system between these two points, all of which STC has supplied.

The six fibre pair system will operate at a wavelength of 1500nm at 140Mbit/s and each fibre pair will be able to carry 1920 telephone circuits. This basic total capacity of 11 500 circuits can be further increased by upgrading terminal equipment to operate at 565Mbit/s.

The system employs 1535 nanometre distributed feedback (DFB) single-line lasers. These have a very narrow spectral width and will be used at this longer wavelength where the fibre attenuation is much lower.

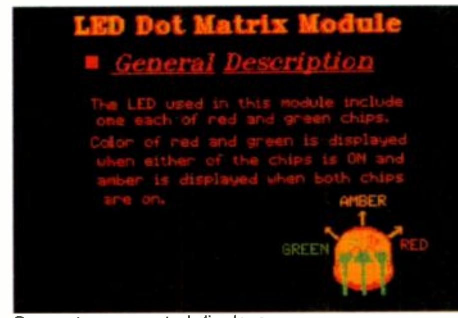
Telecomms Topics is compiled by Adrian Morant.


TOSHIBA LED DISPLAY PANEL

LED GRAPHICS: A NEW WINDOW ON THE WORLD

Large-screen LED video displays

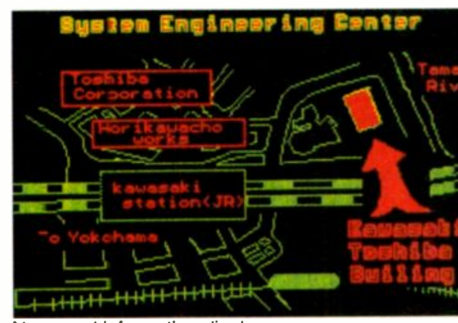
Combined text/graphic displays



Computer-generated displays

Advertising and promotional displays

Arrival and departure boards



News and information displays

Toshiba, the first name in LED modules, opens a new window on graphic display media with the latest breakthrough in LED technology.

As easy to use as conventional CRT displays, Toshiba's new LED dot-matrix modules provide clear, colourful display of letters and graphics for the coming generation of LED televisions.

Each module features an advanced gate array for interfacing with video equipment and personal computers. And with versatile capabilities such as superimposition and stop motion, these modules can handle virtually any computer-generated graphic display.

Toshiba LED modules also boast a powerful, high-speed 20 MHz input clock, and 16-gradient control for improved colour contrast. In addition, we've successfully developed a new flat LED which provides a clear image from any angle of view.

And in putting a system together, you can count on the support of Toshiba engineers with extensive experience in the field.

For new possibilities in LED graphic display, look to Toshiba — the leading light in LED technology.

electronica 88®
Munich, 8–12 November 1988
Toshiba booth is located in
HALL 25, STAND 25 A9

TLMM504A1U (New flat LED) TLMM502A1 TLMM501B2

In Touch with Tomorrow

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ENTER 51 ON REPLY CARD

LED screen is simulated

Fast Fourier transforms of sampled waveforms

A procedure for the accurate determination of frequency as low as half the frequency interval and higher than the Nyquist frequency

S.E. GEORGEOURA

A study of the results obtained by the FFT algorithm for actual experimental (and precisely known) digitally sampled waveforms has led the author to a better theoretical understanding of how the FFT works. The result is an extrapolation procedure which enables the accurate determination of unknown frequencies – to an accuracy far exceeding that defined by the frequency interval (F=(sampling freq.) ÷ number of points). Frequencies can be as low as F/2 for cosine waves, and can be higher than the Nyquist value of ½ sampling frequency.

One thesis that is here challenged is that the FFT 'assumes' the waveform to repeat itself before and after the sampled time window. This is, one would suppose, a hangover from Fourier series. It is suggested that the FFT algorithm 'considers' the waveform to be precisely limited to what is in the time window – with nothing happening before or after. This is verified in the case of square waves taken as a set of a small number of pulses whose pulse width is equal to the pulse separation.

Several articles have appeared in *E&WW* dealing with the Fast Fourier Transform[1-4]. In these one finds a 256 point Basic program and a 128 point machine code program, both for the BBC. The waveforms dealt with are simple, theoretically evaluated waveforms in which nothing of the complications occurring in an experimentally obtained waveform actually appear. Omer gives a brief mention of a "leakage" effect appearing[6].

Witten[5] gives a good description of the effect of sampling on the frequency spectrum. The main diagrams are reproduced as Fig.1 and are self-explanatory. Omer describes the spectrum obtained for sinewaves of frequency greater than the Nyquist limits as "meaningless"[6].

Starting with Larsen and Dyvik's 256 point basic program, the author has extended it to apply to any number of points (powers of 2) using the bit-reversal routine given by Dvorak and Musset[7]. He then followed Omer's example of setting up 'look-up' tables – and constructed bit-reversal machine code files and cosine files for 64, 128, 256, 512 and 1024 point transforms. Page is moved down to & 1300 in Mode 7 for the FFT calculations, and a lot of juggling in memory locations is done – in fact even saving the final result in an area of memory

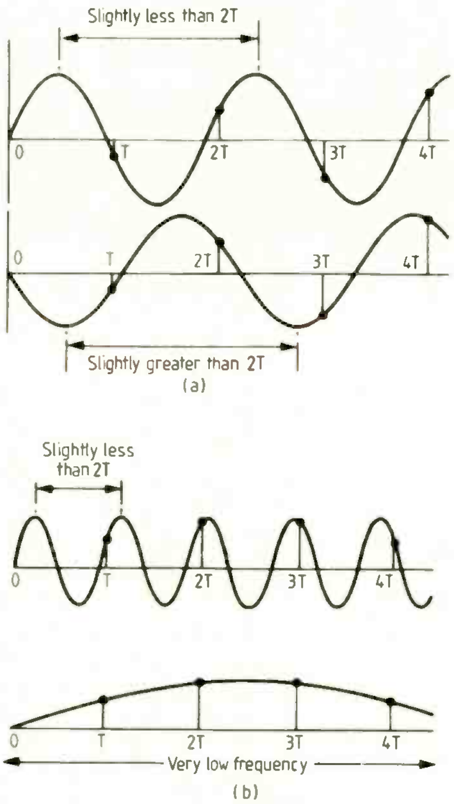
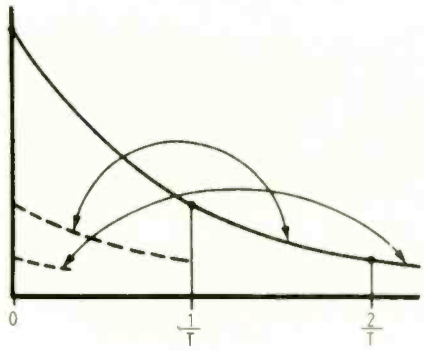


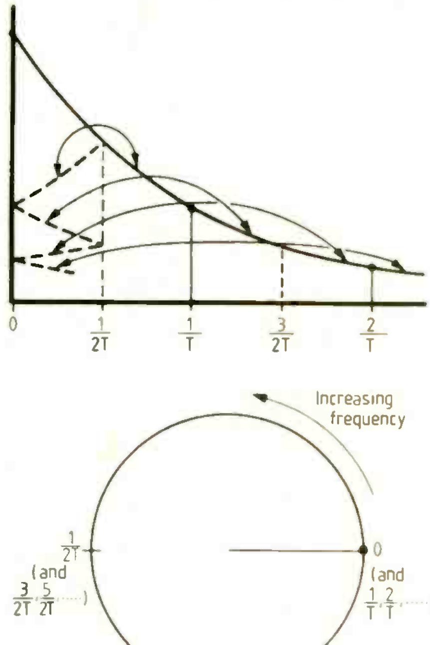
Fig. 1. Diagrams due to Witten which show the effect of sampling on the spectrum.

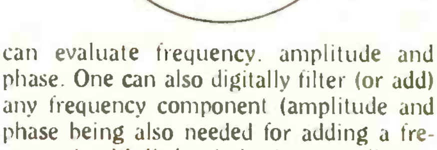
used up by the top part of the actual program. LOMEM is also altered at the start of the program to leave space for the final results. Page is then lowered to & 1200.

The plotting program uses values of Real, Imaginary and |Amplitude| which have been stored as integers between −100 and +100. This is restrictive, but at least enables the use of Mode 0 – for high resolution and for printing results on the graph. The data is also plotted. The four channels can be plotted singly or in any combination. A shortened version only plots the modulus of amplitude.

Both plotting programs can expand any section of the graph until a minimum of 32 points is plotted on the screen. In any scale one can view one section after another, so that one can scan the whole graph at high resolution. Using the extended version and a program which can be 'chained' from it one







can evaluate frequency, amplitude and phase. One can also digitally filter (or add) any frequency component (amplitude and phase being also needed for adding a frequency), with little windowing (usually restricted to the first two or three points in the restructured waveform).

The shortened version will evaluate amplitude but not phase. It can display the order of the harmonic of a given frequency component relative to a fundamental frequency, which is useful if we have previous information as to what harmonics we are looking for and is also useful if one seeks to make sense of some of the spectra which are sometimes called 'meaningless'.

Lastly, the shortened version can display the FFT of two waveforms obtained simultaneously, or concurrently.

EXTENDING THE UPPER LIMIT OF MEASURABLE FREQUENCY

The problem is to get some sense out of a supposedly meaningless spectrum which is obtained with a sampling frequency that is lower than the frequency to be measured. To do this, the author wrote a versatile program which enables one to use the same data to obtain the results that would have been obtained with a smaller sampling frequency, e.g. with sampling frequency f_s a given set of data points was obtained. The resulting datapoints with $f_s/2$ will be deduced by skipping every other datapoint, with $f_s/3$ by skipping two data points and taking the third, etc.

By doing this and doing the FFT calculations to note the calculated frequency f every time, the following result was obtained by inspection:

correct frequency = $m \times F_s \pm f$

where m = 0,1,2, ... an integer, F_s is the sampling frequency and f is the frequency calculated from the FFT spectrum. Sidebands are familiar enough so that $F_s \pm f$ is understandable. Do the higher orders come because we have modulated pulses? The above equation and the facility for determining a harmonic's order have enabled the determination of a 40kHz square wave harmonics with 33⅓kHz sampling frequency (Fig.2).

FOURIER TRANSFORM OF A DIGITALLY SAMPLED WAVEFORM

Suppose one is sampling with frequency f and N points are sampled. Consider a cosine wave with amplitude A, frequency f_0 and phase ∝, when it is first sampled. Since sampling starts at t = o and ends at $\tau = N(1/f)$, then these must be the limits of the (sampling) time window.

For the sake of generality, let the cosine function be switched on for a time $t_0 = n_0 (1/f)$ which is less than τ as in Fig.5. The frequency interval or the smallest increment in the frequency domain is

$$F = 1/\tau = f/n$$

$$f(t) = \begin{cases} A\cos(\omega_0 t + \alpha) \ldots\ldots 0 \leq t \leq 1/F_0 \\ 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{otherwise} \end{cases}$$

where $\omega_0 = 2\pi f_0$, $F = f/n_0$.

The Fourier transform is given by[8]

$$G(\omega) = \int_0^{1/F_0} f(t) e^{-i\omega t} dt$$

$$= \frac{A}{2} \int_0^{1/F_0} \left[e^{i(\omega_0 t + \alpha)} + e^{-i(\omega_0 t + \alpha)} \right] e^{-i\omega t} dt$$

$$= \frac{A}{2} \left[\frac{e^{-i((\omega - \omega_0)t - \alpha)}}{-i(\omega - \omega_0)} + \frac{e^{-i((\omega + \omega_0)t - \alpha)}}{-i(\omega - \omega_0)} \right]_0^{1/F_0}$$

We now write $\omega = 2\pi f = 2\pi F L$

$\omega_0 = 2\pi f L_0$.

(where L is an integer, L_0 is not necessarily an integer) and separate real and imaginary parts, giving

$$\mathrm{Re}G(\omega) = \frac{A}{2F_0} \left\{ \frac{\sin\left(\frac{2\pi F(L-L_0)}{F_0}\right)\cos\alpha + \left(1 - \cos\left(\frac{2\pi F(L-L_0)}{F_0}\right)\right)\sin\alpha}{\frac{2\pi F(L-L_0)}{F_0}} + \frac{\sin\left(\frac{2\pi F(L+L_0)}{F_0}\right)\cos\alpha - \left(1 - \cos\left(\frac{2\pi F(L+L_0)}{F_0}\right)\right)\sin\alpha}{\frac{2\pi F(L-L_0)}{F_0}} \right.$$

$$\mathrm{Im}G(\omega) = \frac{A}{2F_0} \left\{ -\frac{\left(1 - \cos\left(\frac{2\pi F(L-L_0)}{F_0}\right)\right)\cos\alpha + \sin\left(\frac{2\pi F(L-L_0)}{F_0}\right)\sin\alpha}{\frac{2\pi F(L-L_0)}{F_0}} - \frac{\left(1 - \cos\left(\frac{2\pi F(L+L_0)}{F_0}\right)\right)\cos\alpha + \sin\left(\frac{2\pi F(L+L_0)}{F_0}\right)\sin\alpha}{\frac{2\pi F(L+L_0)}{F_0}} \right.$$

It can be easily seen that

$$\mathrm{Re}G(-L) = \mathrm{Re}G(L)$$
$$\mathrm{Im}G(-L) = -\mathrm{Im}G(L)$$

which demonstrates the symmetry properties of the Fourier transform. Since negative frequencies are unphysical and since the 'correct' frequency is mf+LF then a frequency −LF will correspond to a positive frequency f − LF or NF − LF using the lowest non-zero value of m.

This now makes it possible to write the symmetry properties as

$$\mathrm{Re}G(N\text{-}L) = \mathrm{Re}G(L)$$
$$\mathrm{Im}G(N\text{-}L) = -\mathrm{Im}G(L)$$

Thus, for $0 \leq L \leq N/2$,

$$\mathrm{Re}G(L) = \frac{A}{2F_0}\left[\frac{\sin\frac{2\pi F(L-L_0)}{F_0}}{\frac{2\pi F(L-L_0)}{F_0}} \cos\alpha + \frac{\left(1 - \cos\frac{2\pi F(L-L_0)}{F_0}\sin\alpha\right.}{\frac{2\pi F(L-L_0)}{F_0}} \right]$$

$$\mathrm{Im}G(L) = \frac{A}{2F_0}\left[-\frac{1 - \cos\frac{2\pi F(L-L_0)}{F_0}}{\frac{2\pi F(L-L_0)}{F_0}} \cos\alpha + \sin\frac{2\pi F(L-L_0)}{F_0} \sin\alpha \right]$$

$$|G(L)|^2 = [\mathrm{Re}G(L)]^2 + [\mathrm{Im}G(L)]^2$$

$$|G(L)|^2 = \frac{A^2}{4F_0^2} \frac{\sin^2\frac{\pi F(L-L_0)}{F_0}}{\left(\frac{\pi F(L-L_0)}{F_0}\right)^2}$$

$$|G(L)| = \frac{A}{2F_0} \left| \frac{\sin\frac{\pi F(L-L_0)}{F0}}{\frac{\pi F(L\text{-}L_0)}{F_0}} \right|$$

The treatment above gives the frequency spectrum of a cosine wave of amplitude A and frequency $f_0 = L_0 F$, and phase ∝ at t=o.

No reference was made to an integer number of cycles in the sampled window. It is easy to see that instead of one single line in the frequency spectrum one has a whole distribution obeying a sinc/cosc function. This is in fact experimentally observed. The fluctuations in the real and imaginary parts are not apparent in the usual case in which $t_0 = \tau$ i.e. $F_0 = F$. This is because with $F = F_0$, the argument of sine/cosine is 2π (L-L_0) and this is a constant for all L. Thus only the 1/(L-L_0) behaviour is observed. If, however, F_0 is set equal to F/2 the oscillations are immediately obvious.

The inverse FFT of the above spectrum

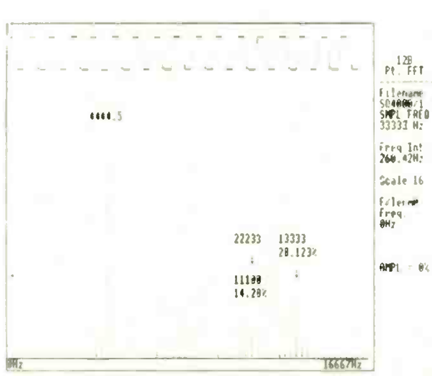


Fig. 2. 40kHz square wave harmonics when sampled at 33.33kHz.

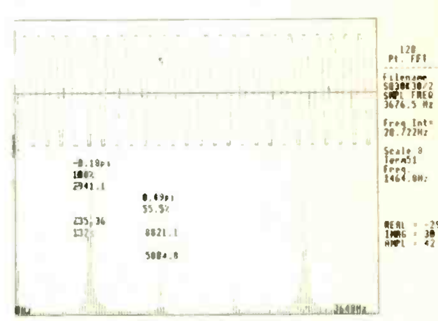


Fig. 3. 3kHz wave, sampled at 3676Hz, showing low-frequency alias at 735Hz (f). Correct frequency = $F_s - f$. Harmonics 2 and 3 coincide. Phase and amplitude incorrect, but frequencies are correct.

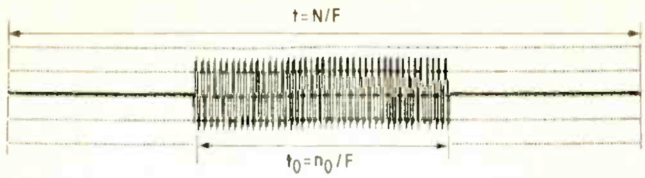


Fig. 5. Cosine function switched on for a period $t_0 = n_0(1/f)$ less than Y.

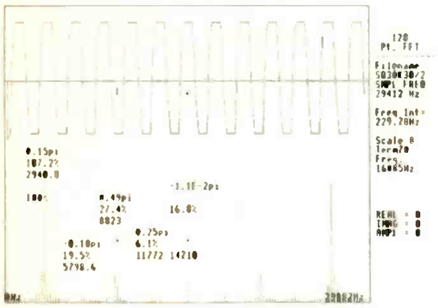


Fig. 4. 3kHz wave sampled at 29412Hz. Harmonics 1 and 2 underlined.

Fig. 9. 512-point FFT gives FREQ == 2943.9Hz (Freq. interval == 57.445Hz) and phase = 0.068 radians.

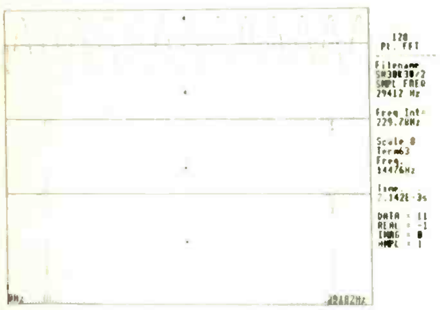


Fig. 6. A pure sine wave with F = F_0, no oscillation in real and imaginary parts visible.

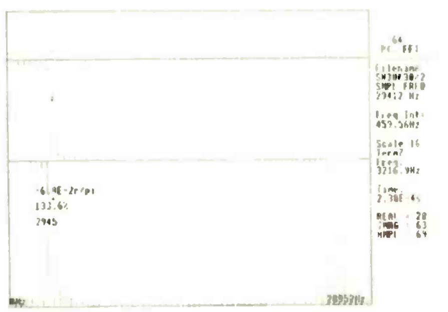
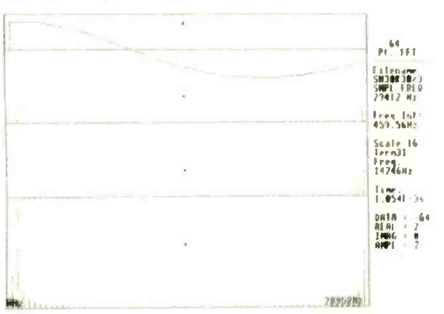


Fig. 10. 64-point FFT of same waveform as in Fig. 9. Freq = 2945Hz, phase = −0.068 radians. Amplitude depends on normalization. Result is almost identical with that from 512-point FFT.

Fig. 7. Pure sine wave with F_0 = F/2, showing oscillations.



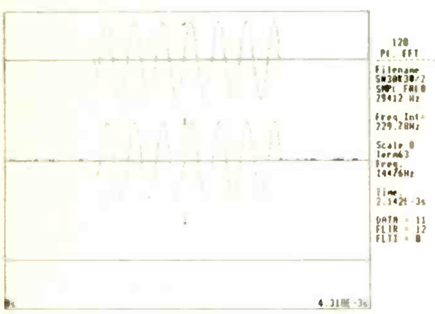


Fig. 8. Inverse FFT. Top waveform is input. Two lower plots show real and imaginary parts of reconstructed waveform.

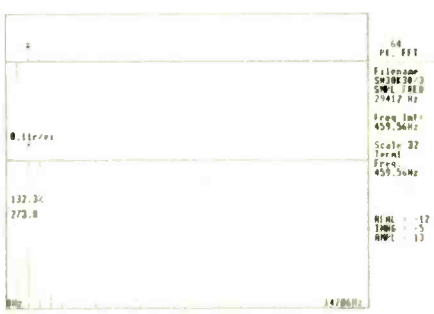


Fig. 11 and 12 show the effect of extending the lower measurable frequency limit. 300Hz is measured with a frequency interval of 459.56Hz. Less than one complete wave is sampled. Fig. 12 shows a frequency error of less than 10%.

yields the original waveform restricted to the same time interval t_0. Should one have expected a repetition of the waveforms outside the interval t_0 with discontinuities at the boundaries of the t_0 window.... as Omer may seem to suggest? (p.23, *E&WW* June, 1986).

The equations for ReG(L), ImG(L) and the symmetry properties at N-L relative to L enable the addition of a frequency component of defined $A, f_0, \propto$ (f_0 can be greater than the sampling frequency!) to a frequency spectrum. An inverse FFT will then yield the reconstructed waveform with the added frequency component.

PARAMETRIZATION OF FREQUENCY SPECTRUM

We consider only the case in which $F_0 = F$. For a given L_0 $(=f_0/F)$, the argument $2\pi(L-L_0)$ is a constant for all L. Since $\propto$ is also a constant then one can write,

$$ReG(L) = f_0/(L-L_0);\ ImG(L) = f_1/(L-L_0)$$

for $L_0 \neq$ integer.

This is the behaviour expected of a single-frequency component. If L_0 is an integer then all terms in ReG(L) and ImG(L) will be zero except for the $L = L_0$ term because of the denominator

$$(L-L_0)\left(\frac{\sin x}{x} \xrightarrow[x\to 0]{} 1\right)$$

This corresponds to the case in which the time window contains a whole number of cycles.

One should, however allow for the possibility of some background term which may result from the sampling procedure, rounding off error, experimental error, etc. If this is assumed to vary little over, say, two sampling intervals, then in the neighbourhood of a 'pole' one can assume its effect to be simply the addition of a constant term.

$$ReG(L) = A_0 + f_0/(L-L_0);ImG(L) = A_1 + f_1/(L-L_1)$$

for $L_0 \neq$ integer.

When f_0, f_1 and L_0 are determined, then the chosen frequency component can be digitally filtered by subtracting the pole term from each frequency component.

DETERMINATION OF FREQUENCY AND AMPLITUDE

This is most easily determined from the modulus or (energy part) of the amplitude. If F_1 is the largest local value of the spectrum corresponding to an integer $L = L_0\%$ and F_2 is the larger of the two neighbouring values then, using the properties of the sinc function the peak value is a small distance a_0 (<1) from $L_0\%$ given by

$$a_0 = F_2/(F_1+F_2)$$

$a_0 > 0$ if F_2 is the value of $|G(L)|$ at $L = L_0\% + 1$

and

$a_0 < 0$ if F_2 is the value of $|G/(L)|$ at $L = L_0\% - 1$

$$L_0 = L_0\% + a_0$$

If one looks at the real and imaginary parts as well then one can set $L_0\%$ to be that value for which the functions have a sign at $L_0\% - 1$ which is opposite to that at $L_0\%.a_0$ is then always negative i.e. $L_0 = L_0\% - a_0$. In each case the frequency is FREQ = L_0F.

Since the background terms A_0 and A_1 will affect the answer then only the pole terms in the above parametrization should be used. Moreover, to increase resolution the effect of a nearby 'pole' should also be subtracted before determining a_o.

The amplitude f_a is determined by remembering that

$$(F_1)_{\text{corrected for background, etc}} = f_a \frac{\sin \pi a_o}{\pi a_o}$$

An outstanding feature of this method is that the value of the FREQ obtained is almost independent of the number of Fourier points analysed, as seen in Figs 9 and 10.

EXTENDING THE LOWER LIMIT OF MEASURABLE FREQUENCY

It is usually accepted that one should have at least one whole cycle in the time window, and this corresponds to the smallest frequency reading of f/N.

Using the present theoretical derivation one can measure a_o for $Lo<1$ by using the 'pole' behaviour for $L>1$ rather than for values of L on either side of Lo. In this case, if F_1 is the value of G(L) at $L=1$ and F_2 is the value at $L=2$ then

$$a_o = \frac{F_2}{F_1 - F_2}.\ \text{FREQ} = (1-a_o)F$$

and f_a is still $F_1/(\sin \pi a_o/\pi a_o)$

This cannot be used for less than about half a wave in the sampled window as, for smaller sections of a wave, it becomes difficult to differentiate a sine wave from a straight line. Of course the same extension does not apply for the case of a square wave, as it will be indistinguishable from a pulse. Figs 11 and 12 show the results.

MEASUREMENT OF PHASE

By dividing ImG(L) by ReG(L) one obtains, using the previous parametrizations

$$\left(\frac{ImG(L)}{ReG(L)}\right) = \frac{f_1}{f_o}$$

$$= -\frac{(1-\cos 2\pi(L-L_o))\cos\alpha + \sin 2\pi(L-L_o)\sin\alpha}{\sin 2\pi(L-L_o)\cos\alpha + (1-\cos 2\pi(L-L_o))\sin\alpha}$$

Since $2\pi(L-L_o) = 2\pi a_o \pm$ integer multiple of 2π, then

$$\frac{f_1}{f_o} = -\frac{(1-\cos 2\pi a_o)\cos\alpha + \sin 2\pi a_o \sin\alpha}{\sin 2\pi a_o \cos\alpha + (1-\cos 2\pi a_o)\sin\alpha}$$

For $L=L_o$, $\tan\alpha = f_1/f_o$, but in general

$$\tan\alpha = \frac{f_1 \sin 2\pi a_o + (1-\cos 2\pi a_o)f_o}{f_o \sin 2\pi a_o - (1-\cos 2\pi a_o)f_1}$$

The BBC gives the answer to arctan as a number between $-\pi/2$ and $+\pi/2$. The sign of the numerator (corresponding to the sign of the sine of the phase) then determines which quadrant the angle α is in. The phase printed on the graph is in the form of number $\times\pi$. If a frequency component is added, then the phase is also fed in as a number $= \alpha/\pi$. (α = phase at $t = o$ of the particular frequency component. To calculate relative phases of components see later.)

When a determination of FREQ, f_a and α has been made for each frequency component, then one can filter out the individual components one at a time and analyse the 'residue'. This may give us some data relative to experimental error/accuracy, noise etc. – or it may show the discrepancy between the theory developed and experimental results. The error is greatly magnified as the discrepancy is usually of the order of a few percent of maximum amplitude but is made equal to 100% in the plotted waveform.

NORMALIZATION

In the software used $G(L)_{max}$ is set equal to 100%. Three methods of normalization are useful.

(i) Pulse-type – data analysed as it is. This gives a transform with $G(0) = 100\%$ and hence gives the expected pulse – type transform (generally accepted as a sinc function of the form sin x/x.

(ii) Peak-to-peak – useful for repetitive waveforms with the zero value of the data being adjusted as ½ × (maximum + minimum values of data). G(0) can now be used for confirm the value of α obtained. Since every complete wave will contribute zero to G(0) then only the incomplete wave in the data will be responsible for the value of G(0) Hence

$$G(0) = \frac{fa}{4\pi}\left[\sin(2\pi L_o + \alpha) - \sin\alpha\right]$$

(iii) Average – use if G(0) is much greater than all other values of G(L). By setting $G(0) = 0$ all other G(L)s are scaled to a higher value and the spectrum can be more accurately analysed.

DIGITAL FILTERING

Two examples are shown in Figs 13 and 14 where the 50Hz mains frequency (appearing because of the use of unscreened leads) have been filtered. In the electro-cardiogram example, odd multiples of 50Hz upto the 9th harmonic were found and filtered out. The expanded plot shows in greater detail the relevant e.c.g. pulses.

The second example in Fig.14 is that of a single pulse. The effect of filtering out two different parts of the spectrum and the corresponding reconstructed pulse are shown.

PULSES

Before considering square waves, pulses are dealt with, since square waves can be viewed as a special case of a succession of equally spaced pulses, with the pulse separation equal to the width of the pulse.

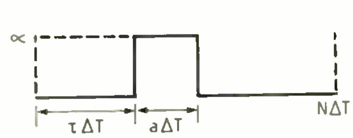


Fig. 15. Single pulse of consideration.

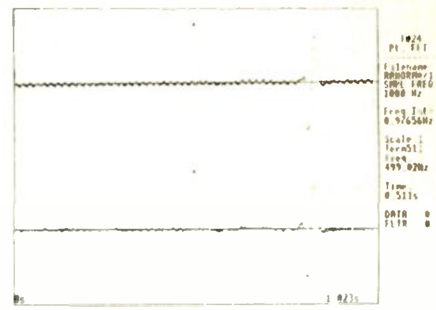
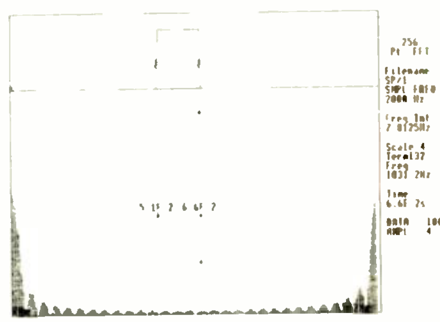
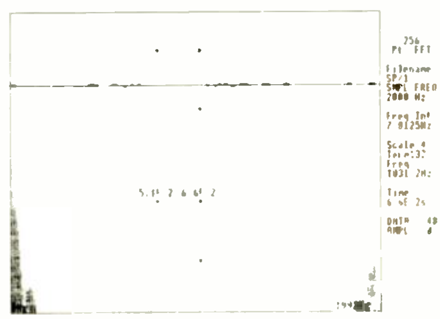
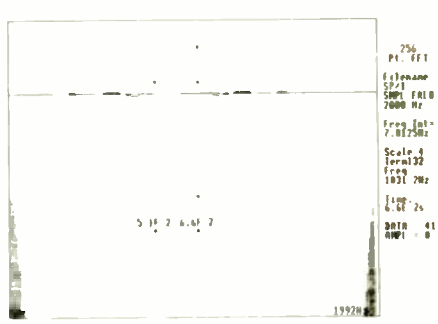


Fig. 13 and 14 show examples of 50Hz filtering. Fig. 13 shows an electrocardiogram and Fig. 14 is a single pulse with different parts of its spectrum filtered to show the effect of the reconstructed pulse.







Single pulse

For the above f(t) in the time window, where ΔT is the sampling interval ($=1/f_s$, the Fourier transform is

$$ReG(L) = \frac{\alpha a}{2FN} \frac{\sin\left(\frac{\pi La}{N}\right)}{\left(\frac{\pi La}{N}\right)} \cos\left[\frac{2\pi L(\tau + a/2)}{N}\right]$$

$$ImG(L) = \frac{\alpha a}{2FN} \frac{\sin\left(\frac{\pi La}{N}\right)}{\left(\frac{\pi La}{N}\right)} \sin\left[\frac{2\pi L(\tau + a/2)}{N}\right]$$

where $F = f_s/N$, as before.

$$|G(L)| = \frac{\alpha a}{2FN}\left|\frac{\sin\left(\frac{\pi La}{N}\right)}{\left(\frac{\pi La}{N}\right)}\right|$$

for $-N/2 \leq L \leq N/2$.

A comparison is made in Fig.16 of this theoretical, well known transform of a single pulse with that obtained by the FFT program. The 'fit' is almost perfect. With the value of G(L) normalized to 100% at L=0, the difference between the FFT and the sinc prediction varies by at most 1. Yet notice the difference this 'slight' difference makes to the reconstructed waveforms! The two printouts with filename SP/ST compare theory with actual FFT. SP/FFT and SP/SINC give the reconstructed (inverse FFT) pulses.

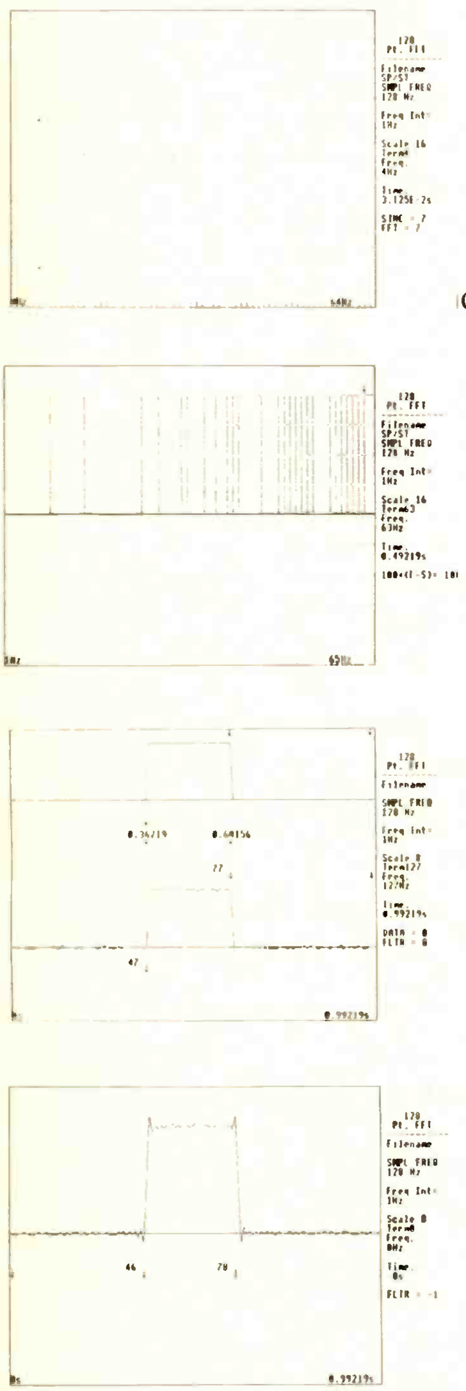


Fig. 16. Comparison of FFT and sinc prediction.

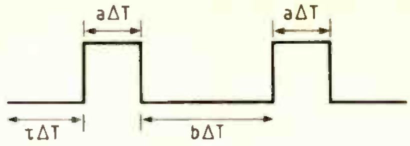


Fig. 17. Double pulse.

SPECIAL CASES

Two pulses. Using the result for one pulse, one obtains

$$\mathrm{Re}G(L) = \frac{\alpha a}{2FN}\frac{\sin\left(\frac{\pi La}{N}\right)}{\left(\frac{\pi La}{N}\right)}\left[\cos\left(\frac{2\pi L(\tau+a/2)}{N}\right) + \cos\left(\frac{2\pi L(\tau+a+b+a/2)}{N}\right)\right]$$

with ImG(L) given by a similar expression with sine replacing cosine. The modulus of the amplitude is then

$$|G(L)| = \frac{\alpha a}{FN}\left|\frac{\sin\frac{\pi La}{N}}{\frac{\pi La}{N}}\right| \cdot \left|\cos\left(\frac{\pi L(a+b)}{N}\right)\right|$$

Three pulses. Using the same procedure as above

$$|G(L)| = \frac{\alpha a}{2FN}\left|\frac{\sin(\pi La/N)}{(\pi La/N)}\right| \cdot \left|1+2\cos\left(\frac{2\pi L(a+b)}{N}\right)\right|$$

One pulse with a = N/2.

$$|G(L)| = \frac{\alpha a}{2FN}\frac{\sin\left(\frac{\pi L}{2}\right)}{\left(\frac{\pi L}{2}\right)}$$

This is a sinc function with zeros at L = 2,4,6 .... If one ignores the value of G(0), then the values of G(1):G(3):G(5) .... are in the ratio of 1:⅓:⅕: .... as expected for a repetitive square wave.

Two pulses with a = N/4, b = N/4. Here the sinc function has zeros for L = multiples of 4, but the cosine term which multiples it has zeros for odd L. Thus the non zero terms are for L = 0,2,6,10,14,.... Ignoring L = 0, then the non-zero terms all odd multiples of 2, with amplitudes in the expected ratio of 1:⅓:⅕:⅐....

SQUARE WAVES

Frequency. The extrapolation method given previously for a cosine waveform gives, still, a very accurate evaluation of frequency. The same frequency (with very small error) is obtained with 128 points as with 1024 points, provided the neighbouring frequencies can be resolved, i.e. their separation is ≮ 5 frequency intervals.

Amplitude. One occasion, a variation f up to ±5 is noticed in the values of the amplitudes. This can be corrected in the case of a square wave by using the frequencies obtained and by also finding the value of a – which is the number of datapoints between two points. By putting the amplitude as

$$A = 100.\frac{\sin\left(\frac{\pi La}{N}\right)}{\left(\frac{\pi La}{N}\right)}$$

where frequency = Lx frequency interval and normalizing these amplitudes so that the fundamental has an amplitude of 100, one obtains a consistent amplitude for each frequency for 64→1024 point FFT.

Phase. The phase that has been determined in all the above cases is the phase at t=0. Let us suppose that if $\propto = 0$ for the fundamental then the m[th] harmonic has a phase value of γ_m. When the value of $\propto$ is not zero, then $\omega_0 t \rightarrow \omega_0 t + \propto$. This effectively translates $t = t + d/\omega_0$

Thus for the m[th] harmonic

$$\omega_m t + \gamma_m \rightarrow \omega_m t + \frac{\omega_m \alpha}{\omega_0} + \gamma_m$$

The quantity is the phase obtained in the FFT calculation.

This phase now has values $\beta_m = m\propto + \gamma_m$. Using the results derived earlier: $\propto = -0.49\pi$; $\gamma_3 = \beta_3 - 3\times(-0.49\pi) = 1.02\pi$; $\gamma_5 = 2.03\pi$; $\gamma_7 = 3.03\Omega$. The βs are the phases printed on the graph. For cosine terms, a phase of π, 3π,... corresponds to a minus sign: 2π, 4π... to a plus sign. Thus the amplitudes are now, taking the phase into account, 100(1, –⅓,+⅕,–⅐...) as is the well known result of a square wave.

Reference and notes

1. T. Larsen and G. Dyvik – Fast Fourier transforms using a microcomputer – *E&WW* September. 1985 p.80 etc.
2. G.K. Dyvik – Fast Fourier transforms – *E&WW* December, 1985 p.74.
3. W. Omer – Faster Fourier transforms – *E&WW* June, 1986 p.23.
4. W. Omer – Faster Fourier transforms *E&WW* July, 1986 p.57.
5. I.H. Witten – Digital storage and analysis of speech: 1. storing waveforms digitally – *WW*, July, 1981 p.45.
6. Omer ref.4 p.57 3rd column 1st para.
7. S. Dvorak & A. Musset – Basic in action. Butterworth 1984.

8. The result obtained for a cosine wave could have been obtained directly by realizing that f(t) is really the product of two functions **f**=A cosωt and

$$f_p = \begin{cases} 1\ldots \text{for } 0 \leq t \leq 1/F_0 \\ 0\ldots \text{otherwise} \end{cases}$$

From the well known theorems of Fourier integrals, the Fourier transform **G(ω)** = the convolution integral of **G(ω)** and $G_p(\omega)$.

$$G(\omega) = \int \mathbf{G}(\omega) G_p(\omega - y)dy = \mathbf{G}(\omega) \otimes G_p(\omega)$$

where $\mathbf{G}(\omega) = \delta(\omega - \omega_0) + \delta(\omega + \omega_0)$ and $G_p(\omega) = \sin(\omega a/2)/(\omega a/2)$.

This immediately gives the result shown earlier, but does not yield all the other details of real and imaginary parts etc., since these result from the added effect of sampling.

9. M. Rousseau & J.P. Matthieu – Problems in Optics. Pergamon Press, 1973

SATELLITE SYSTEMS

25 years of geostationary orbits

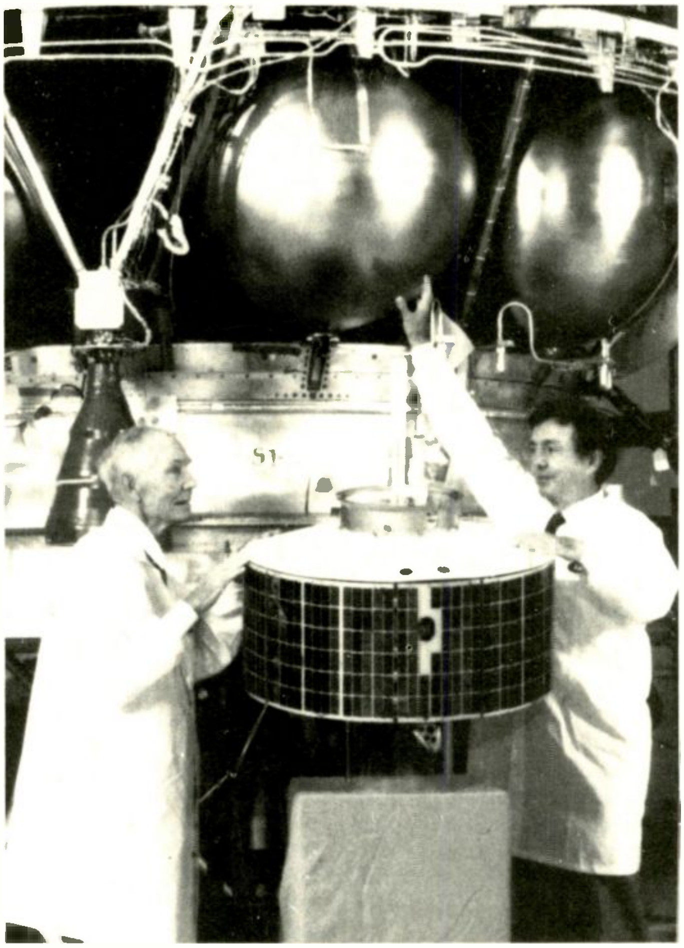
The first communications satellite to get successfully into a geostationary orbit and operate therefrom was Syncom III, launched a quarter of a century ago. This spin-stabilized spacecraft and the technique for placing it in the g.s.o. were the work of Dr Harold Rosen (see photograph) and his team at Hughes Aircraft Company in the USA.

It was a case of third time lucky. The first attempt to launch a Syncom was made in February 1963, but the apogee kick motor exploded and destroyed the satellite. Syncom II was more fortunate and in July of the same year was placed in an orbit which was almost but not quite geostationary. A few months later Syncom III achieved the goal of operating from a true geostationary orbit.

Before that date the use of the g.s.o. was nothing more than a theoretical possibility, proposed by Arthur C. Clarke in this journal some eighteen years earlier ('Extra-terrestrial Relays', *Wireless World*, October 1945). After the early experimental spacecraft of the late 1950s, the first working communications satellite was Telstar, launched in 1962. But this was not geostationary, being in low Earth orbit, and was only visible to ground stations for about 25 minutes at a time.

It was the success of Syncom III that persuaded Comsat to utilize the geostationary orbit for the planned Intelsat world communications system. Comsat asked Hughes to build another spin-stabilized satellite for full operation in a permanent service. Called Early Bird, this satellite started operation in 1965 (see May and June issues of that year) and was later designated Intelsat I.

A crucial factor in Harold Rosen's success in putting a spacecraft into the g.s.o. was his use of a transfer orbit. In general, this is an elliptical path designed to transfer a spacecraft from one, low-altitude, orbit to another, higher-altitude, orbit with the smallest possible expenditure of mechanical energy. Obviously the less power needed from the launching vehicle the lower will be the cost of launching the spacecraft and the lower will be the cost of the resulting communications service.



Pioneer Dr Harold Rosen (left) with the prototype of his Syncom, the first geostationary communications satellite. A colleague, Tom Hudspeth, points to one of the fuel tanks of the new Intelsat VI which stands behind in the Hughes plant at El Segundo, California. Syncom, weighing only 35kg, would fit inside this tank. Intelsat VI is 120 times heavier at 4240kg.

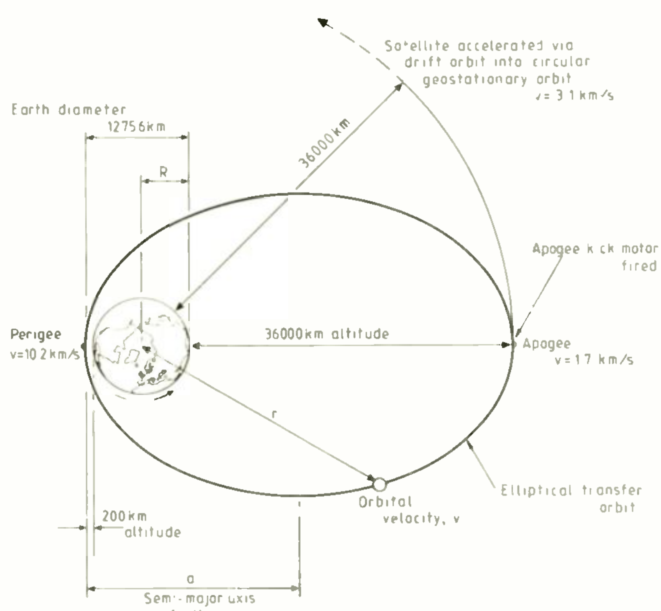


Fig.1. Principle of elliptical transfer orbit, as used by Harold Rosen to put Syncom into a geostationary orbit and now standard practice. The orbit shown here is an ideal one in the equatorial plane. For simplicity the drift orbit phase is not included.

In the g.s.o. case, the transfer orbit is an ellipse which touches a circular low Earth orbit at one point (altitude about 200km) and the circular geostationary orbit at another point (altitude about 36 000km). The first point becomes the perigee of the transfer orbit while the second point becomes its apogee (see Orbital elements, November 1987 issue, p.1158). Figure 1 shows the general principle with values corresponding roughly to a present-day launching of a comsat by an Ariane-3 rocket.

After lift-off the Ariane rocket climbs almost vertically in an easterly direction, burning out its booster and first and second stages, till it reaches an altitude of just over 200km. At this point, about six minutes after lift-off, it has travelled approximately 1000km eastwards round the Earth in a plane fairly close to the equatorial plane. The rocket is now also gradually turning over so that it is travelling more or less horizontally and parallel with the Earth's surface. This trajectory, virtually part of a low Earth orbit, continues for a further 10 minutes and a distance round the Earth of about 5000km, or 45°.

If the rocket were indeed in a low Earth orbit it would of course continue to travel round indefinitely at a constant altitude of about 200km. The equation of motion of such a circular orbit is $v^2 = gR^2/r$, where v is the orbital velocity (here 7.8km/s), g is the acceleration due to gravity ($9.8m/s^2$), R is the radius of the Earth and r is the distance between the rocket and the Earth's centre. But in fact, with all three rocket stages now fired, the vehicle has already increased its speed beyond the 7.8km/s necessary to keep it in the circular orbit specified by the above equation. The effect of this acceleration is to throw the rocket outwards, away from the Earth, so that it moves from part of a circular orbit into an elliptical orbit, as shown in Fig. 1. Centripetal acceleration is v^2/r.

At about 18 minutes after lift-off and some 6000km along this new track, the first satellite (if there are several being carried) separates from the rocket and continues to travel onward in the same elliptical path. Initially it has a velocity in the region of 10km/s but gradually slows down over several hours as it approaches the apogee – rather as a cricket ball thrown upwards slows down as it nears the top of its trajectory. At the apogee the orbital velocity is only about 1.7km/s. In this region the spacecraft does not 'need' as much velocity to satisfy the equation of motion for an elliptical orbit (see below) because at this great distance the Earth's gravitational force is so much less, in accordance with the inverse square law.

As the satellite returns towards Earth it speeds up again under the increasing attractive force of the Earth's gravity. Returning to the perigee some 10½ hours after lift-off, it reaches an orbital velocity of 10.2km/s. Here again, this high velocity is 'needed' to balance the very large gravitational force at the low altitude of 200km.

The satellite is allowed to remain in this elliptical transfer orbit as long as required by the pre-arranged launching procedure. In the case of the recent ECS-5 comsat launch (September issue, p.905) this period was just over 36 hours, or more than three complete orbits. Here the plane of the transfer orbit was not exactly in the equatorial plane as indicated in Fig.1 but at a small incination of 7°. The equation of motion of such an elliptical orbit is

$$v^2 = \frac{gR^2(2a - r)}{ra}$$

where v, g, R and r are as defined above and a is the semi-major axis of the ellipse (see Fig.1). The orbital period here is

$$T = \frac{2\pi a^{3/2}}{\sqrt{gR^2}}$$

and in the example shown in Fig.1 works out to approximately 10½ hours.

To propel the satellite from this elliptical transfer orbit to its final geostationary orbit an apogee kick motor is fired by telecommand at one of the times when the spacecraft is at the 36 000km apogee. With ECS-5 this was done after three complete elliptical orbits, as the satellite reached the apogee for the fourth time. The resulting acceleration to a higher speed again 'throws the spacecraft outwards' and it now moves into a drift orbit and finally into a circular geostationary orbit (inclination = 0°) at an orbital velocity of 3.1km/s. In this way the manoeuvre is completed with the least possible expenditure of energy and propellant fuel in both the launching rocket and the satellite's apogee kick motor.

ECS-5 was launched at 23.13h UTC on July 21 and the apogee kick motor was fired at 12.23h UTC on July 23, using up 3.5kg of the total 122kg of hydrazine fuel carried in the spacecraft. The satellite reached its initial position of 16°E in the geostationary orbit in mid-August.

● A cursory mention of centrifugal force in an earlier item on celestial mechanics (February 1987, p. 159) gave rise to some lively correspondence with a reader on the question of whether such a force exists in the mechanics of orbiting satellites. I should have added in my piece that it is valid to conceive of centrifugal force as existing within a rotating frame of reference (e.g. as experienced by a particular or person whirling round inside a centrifuge) but not in an inertial frame of reference (looking at the various forces from the larger world outside the system). So it all depends on where the observer is.

Cheaper vehicle insurance

A satellite communications scheme that could reduce insurance costs for the world's road transport industries has been demonstrated in Helsinki, Finland. It was set up experimentally by a manufacturer of anti-theft devices for lorries, Peterwell Finland KY, using the Inmarsat satcoms system. Peterwell's equipment not only sounds an alarm if a vehicle is tampered with but also disables various parts of the lorry's controls and mechanisms.

Insurance firms had already told this company that they would offer substantially reduced premiums if they could be sure that the anti-theft equipment installed was actually in use. The purpose of the Helsinki demonstration was to show how a satellite scheme could provide that assurance.

The anti-theft equipment, installed in a Volvo truck, was connected to an Inmarsat Standard-C data communications terminal which transmitted a sequence of data each time the equipment was turned on or off. The signal was uplinked to a comsat over the Atlantic Ocean and downlinked to an Earth station in the UK, from which it was sent over normal international telecom channels back to the Peterwell office in Helsinki. Here the data was processed and displayed as a graphical status report on a v.d.u. screen.

Other information was included in the data signal, such as the temperature in the truck's cargo area. It seems possible that this could be expanded to give information on such things as position, mileage, fuel and load statistics.

● Even though its second-generation satcom system has not yet begun operation, Inmarsat has already announced plans for Inmarsat-3. This is likely to use more advanced satellites with multiple spot-beams and the international co-operative has asked manufacturers to make proposals for such spacecraft, to be available in orbit by 1994. Meanwhile an arrangement has been made for China to provide tracking, telemetry and command services for the coming Inmarsat-2 satellites in the Pacific Ocean area. These services will require a 24-hour dedicated tracking station and a separate in-orbit testing station, both to be operated by China Satellite Launch and Tracking Control General.

Tracking Phobos

An interferometric radio telescope with a very long baseline (see August issue, p.779) will be used by NASA to assist in its current scientific space mission to Phobos, one of the two natural satellites or moons of the planet Mars (the other is Deimos). The purpose is to measure the position and movement of Phobos by the radio interferometric technique in conjunction with Doppler and range tracking.

Scientists are interested in Phobos because its orbit appears to be decaying. They think that tidal forces – the unequal gravitational attractions between different parts of two bodies – are making the moon spiral very slowly towards Mars and eventual destruction. Optical tracking is not really accurate enough to detect this phenomenon. Only active radio tracking, with a transmitter actually planted on Phobos, will measure the orbit's rate of decay.

The Soviet Union launched two scientific spacecraft in July this year, Phobos 1 and Phobos 2, and these are now on their way to Mars. In about April 1989, while orbiting the planet, these spacecraft are intended to put down landers, carrying transmitters, on to the surface of Phobos. NASA's tracking system, part of its deep space network, will also be used to assist in these landings before being transferred to the main scientific task.

On Earth, signals from the lander transmitters sitting on Phobos will be picked up by widely-spaced antennas for the interferometric system. These are NASA's 70 metre dish antennas in California, Spain and Australia, plus a Russian radio telescope in the Crimea. One of the difficulties in measurement will be that Phobos has a very short orbital period. At an altitude of 6000km, it completes an orbit round Mars in only 7 hours 37 minutes. As a result the interferometric and other radio tracking of the lander transmitters will only be possible for about 17 minutes of each orbit round the planet.

From October until the end of this year the interferometer technique is being checked under space flight conditions. Scientists and engineers from 14 countries and from ESA have taken part in developing scientific instruments for the two Phobos spacecraft.

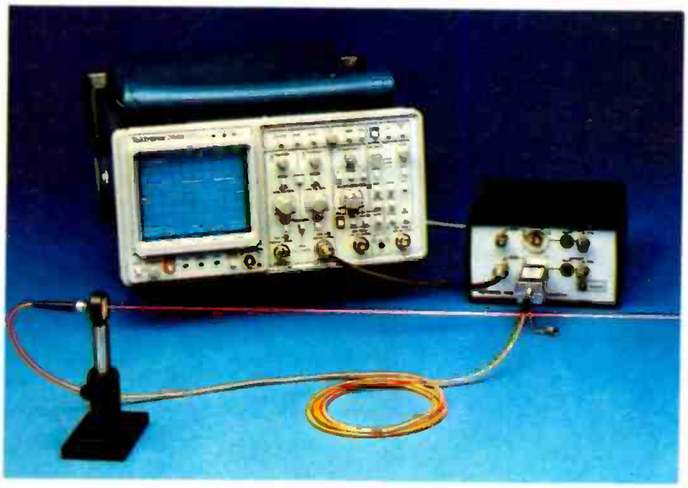
Satellite Systems is written by Tom Ivall.

NEW PRODUCTS

Polishing machine for optical fibre connectors

A high-yield polishing machine designed to produce optical-fibre connectors has been introduced into the UK by K-Tech.

It can be used with all major connector styles, including FC/PC, DIN, ST and SMA. The machine can accommodate up to 12 connectors at a time to make convex or flat end-face finishes. Polishing time is 6.5min for 12 connectors. K-Tech, 16-18 Barton Road, Bletchley, Milton Keynes MK2 3JH. Tel: 0908 76353.



Optical signal measurements

Electro-optic engineers can accurately measure optical signals using any conventional oscilloscope in conjunction with the 1103 Tekprobe power supply.

When the unit is used with the P6701 and P6702 optical electrical converters and the P6751 spatial input head all oscilloscopes can perform calibrated optical measurements on both fibre-based and free-space signals. The Tekprobe sends calibrated voltage signals to the oscilloscope so users can make average and pulse-optical power measurements. It also facilitates the simultaneous display of electrical and optical waveforms on dual-channel oscilloscopes. Tektronix UK Ltd, Fourth Avenue, Globe Park, Marlow, Bucks SL7 1YD. Tel: 06284 6000.

Custom design service

A free custom design service for Corstat and Corshield static protection packaging products is now available.

The company stocks a number of standard sizes and designs for the three types of containers it manufactures: inplant handlers, bin boxes for storage and transit packs. Corstat is designed to protect all static-sensitive devices and components from discharge including p.c.bs, sub-assemblies, i.cs and transistors. Corshield protects against electrostatic discharge but, because of the metal foil inserted into the construction, it also provides protection against electromagnetic and r.f. interference. Conductive Containers Ltd, Western Road, Bracknell, Berks RG12 1QY. Tel: 0344 59911.

Variable size instrument cases

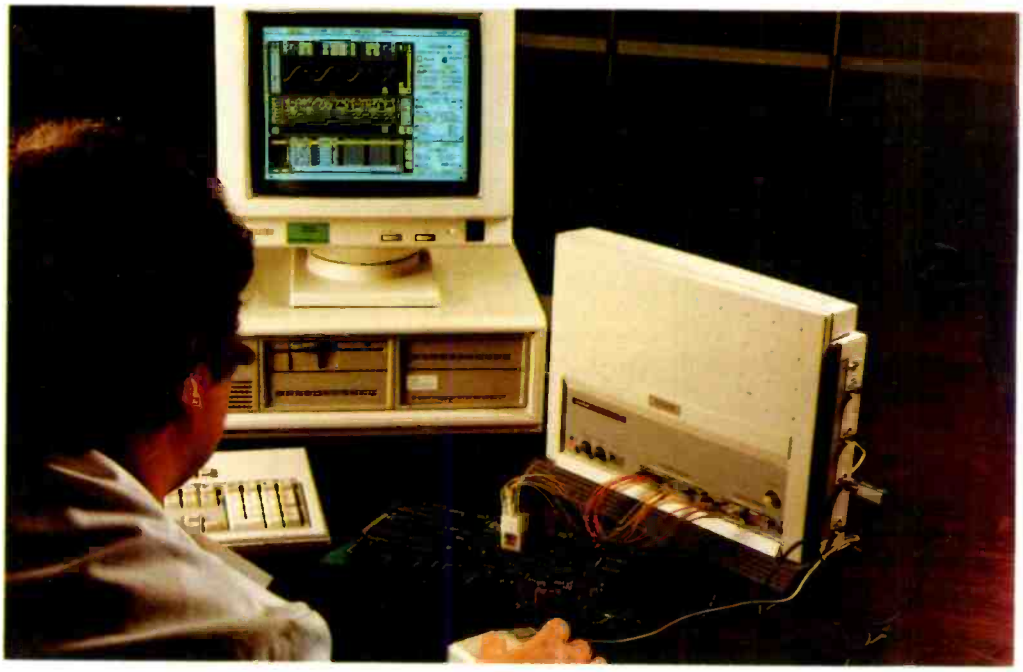
Flexibility is brought to the design of prototype and production runs by the Powerbox Macro range of rack mounting and tabletop instrument cases.

Radiatron Components supply the cases in flat-pack form to be screwdriver assembled to the required size. Individual full-rack cases can be built in two depths (12.8 and 16.73mm) in heights from two to eight modules. The enclosure systems have integral heat sinks and guide channels to hold p.c.bs, and special grooves to hold tapped strips for component mounting. Radiatron Components Ltd, Crown Road, Twickenham, Middlesex TW1 3ET. Tel: 01-891 6839.

Single unit analogue and digital analysis

One PC controlled unit able to perform analogue and digital analysis is announced by Megger Instruments.

OmniLab 9240 combines a 100MHz digital oscilloscope with a time-aligned 200MS/s 48-channel logic analyser and synchronized analogue and digital stimulus generators. Both analogue and digital traces are time-correlated on to a single display and the stimulus generators allow capture, editing and play back of signals. New select triggering combines the features of oscilloscope and logic analyser techniques with ram truth tables and min/max time qualifications to simplify the capture of rare events such as missing pulses, bus contentions and buried noise glitches. Megger Instruments Ltd, Archcliffe Road, Dover, Kent CT17 9EN. Tel: 0304 202620.

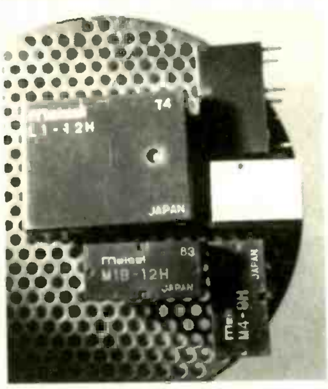


NEW PRODUCTS

Dot matrix replacements for led displays

Designers can improve the performance and appearance of equipment without mechanical or electronic design alterations using a range of replacement displays from Siemens.

The displays are dot-matrix direct drop-in replacements for the Siemens DL1414, DL2416 and DL3416 four digit modules and the Hewlett-Packard equivalents. They are available with red, high-efficiency red or green light outputs. The 5 × 7 matrix format enables the size of the available character set to be doubled to 128. Siemens Ltd, Siemens House, Windmill Road, Sunbury-on-Thames, Middlesex TW16 7HS. Tel: 0932 752323.



Telecomm relays

Miniature type 47 relays suitable for a range of telecommunication applications are available from Devlin Electronics following the company's appointment as distributor for Meisei.

The range comprises six different types with nominal coil voltages from 5 to 48V d.c. and coil resistances of between 45 and 3900ohm. Power consumption is 0.56W. The gold clad, silver palladium alloy contacts have a maximum switching voltage and current of 125V and 1.25A. The relays offer a mechanical life in excess of 20million operations. Devlin Electronics Ltd, Unit 1, Sherrington Way, Basingstoke, Hants RG22 4DQ. Tel: 0256 467367.

Real-time image processing

Real colour and real-time image processing are offered by Oxford Framestore Applications' advanced image analysis system.

The system is able to capture real colour images at video rate, and can average images in real time to sixteen bit accuracy. Real time subtraction and video peak hold to eight bits extends potential applications to low light level and thermal imaging, security, X-ray and electron microscope image noise reduction, scientific data collection and particle tracking. Oxford Framestore Applications Ltd, 3 Membury Way, Grovelands Park, Wantage, Oxon OX12 0BP. Tel: 02357 66078.

Signal generator

A non-volatile memory capable of storing up to 40 different instrument set-ups is included in the new SMX signal generator available from Feedback Test and Measurement.

The SMX is a modular generator with four fixed frequencies (0.3, 1, 3 and 15kHz) and offers a frequency range of between 100kHz and 1000MHz. The generator's 10Hz incremental setting makes it suitable for carrying out narrowband testing. A.m., f.m. and pulse modulation are all available. Other features include IEEE488 bus interface for remote control which is possible for listener, talker and service functions. The standard unit is overload protected up to 30W. Full self-diagnostic facilities have been included and test points include all essential points of signal generation and r.f. signal levels, without having to open the unit or use external measuring devices. Feedback Instruments Ltd, Park Road, Crowborough, East Sussex TN6 2QR. Tel: 0892 653322.

Airflow sensor protects equipment

Sensitive equipment is protected from damage by using an airflow sensor to monitor the velocity and temperature of cooling airflows to warn of degration or failure in a cooling system.

The solid state device from Cambridge Aeroflow has a fast response time and no moving parts. The sensor has already proved its use in computer systems and other electronic equipment. The output will drive computer logic or can activate alarms, relays or other circuits. Normally closed versions are available as well as manual reset versions. Supply voltages are 11 to 25V, and dissipation is less than 0.8W. The device can either supply or sink up to 100mA at 30V and thermal response time is better than 3s. Cambridge Aeroflow Ltd, Unit 23, Bankside, Kidlington, Oxford OX5 1JE. Tel: 0865 841464.

Message mode on data printer

Up to 15 stored messages can be pre-programmed and printed out on demand using the IPP144-40E data printer from ITT Instruments.

Each stock message can be 40 characters long and can include up to six spaces for variable data input. Texts are located or edited from a programmer, terminal or PC through a serial interface, and are stored in a battery maintained c-mos ram. Message mode texts are called up by a number code via a second serial or b.c.d. interface, and can be printed out with the date and time from the built-in clock. The unit can also function as a conventional data printer. ITT Instruments, 346 Edinburgh Avenue, Slough, Berks SL1 4TU. Tel: 0753 824131.

Signal source, multimeter and thermometer in one unit

A portable d.c. signal source from Universal Instrument which is suitable for adjusting and calibrating industrial instruments, transmission lines, thermocouples for thermometers and recorders can also operate as a four-digit multimeter and thermometer.

The Hioki model 7010 is powered by rechargeable batteries or an a.c. adapter and generates voltage and current signals in the range 0 to ±8.1V and 0 to ±81mA. The unit also produces six types of thermoelectric power output for types K, E, J, T, R and S. It has a l.c.d., rotary function switches and digital step or continuous control of output levels and polarity. Universal Instrument Services Ltd, Unit 62, GEC Site, Cambridge Road, Whetstone, Leicester LE8 3LH. Tel: 0533 750123.

NEW PRODUCTS

Slim fans for cooling

Fans which are suitable for high density packaging applications including computer disc drive assemblies are available from Dialogue Distribution.

They are designed to operate within a temperature range of −10 to +70°C and have a life expectancy of 40,000hr when operated at 40°C. They measure 25mm deep, with a frame size of 120mm square and have an airflow capacity of 114m³/hr. Dialogue Distribution Ltd, Wicat House, 403 London Road, Camberley, Surrey GU15 3HL. Tel: 0276 682001.

Audio-frequency pre-amp for car radios

All the functions for a complete audio-frequency pre-amplifier for car radios — from source selector right through to a quad fader output are included in the Philips TEA6300.

The i.c. eliminates the need for manual potentiometers that often require as many as eight to ten wipers and, unlike electronic potentiometers, uses a switched op amp principle which introduces no audible noise when the controls are activated. The performance of the

TEA sound fader control circuit is high enough to process signals from compact disc players, a.m./f.m. tuners, and cassette players using Dolby B and C noise reduction. An extra mute function is available that can silence all channels while a radio is searching for a station.

The TEA6300 gives 20dB of amplification, and provides a nominal 0.5V output signal into a 10kohm load resistance. It can connect directly to two of the company's TDA1514 amplifier i.cs; a radio using this arrangement can drive a load of 6W into each of four channels, or 20W into each of two channels. Mullard Ltd, Mullard House, Torrington Place, London WC1E 7HD. Tel: 01-580 6633.

Power meter for broadcast applications

Applications of Marconi Instruments' new power meter extend into broadcasting, communications and radar.

These areas have been brought under the domain of the 6960A by the inclusion of a 3W sensor; automatic signal averaging facilities; a kW annunciator; and increased simplicity of operation. The sensor has a measurement range of −15 to +35dBm over the frequency range of 10MHz to 18GHz. The maximum hold facility allows users to make unattended measurements on amplifiers, transmitters etc. and to retain the maximum reading obtained. Nine non-volatile memories in the 6960A incorporate automatic functions which can be chosen by from the front panel keyboard. Marconi Instruments Ltd, Longacres, St Albans, Herts AL4 0JN. Tel: 0727 59292.

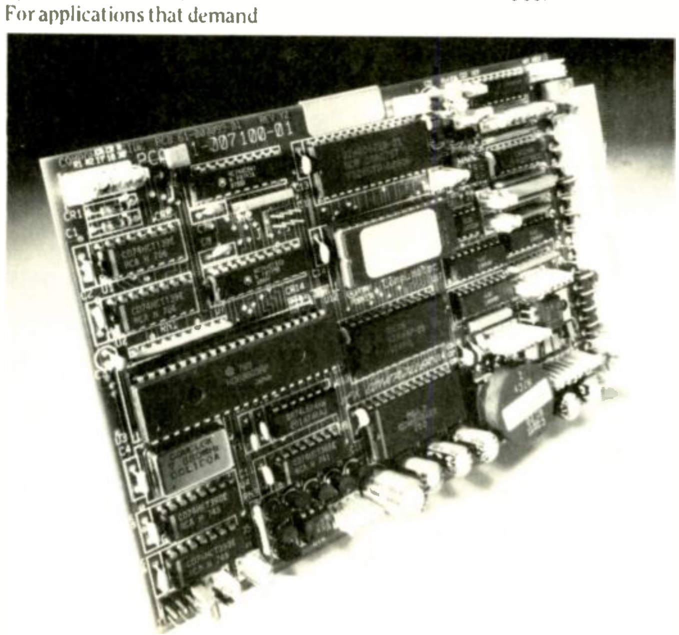
Ozone-friendly aerosol

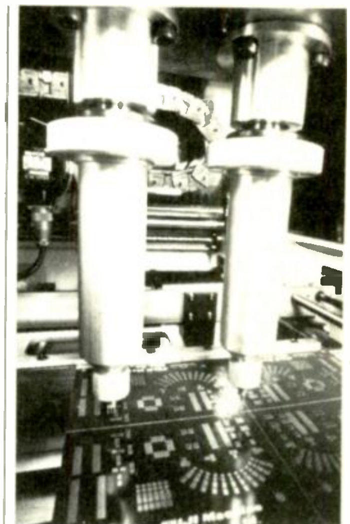
An ozone-layer-friendly aerosol for electrical applications has been introduced by Chemtronics UK. DPL penetrates, lubricates, displaces water and restores electrical values. It is available in aerosol liquid form for mass application. Chemtronics UK, 16 Swanscombe Business Centre, London Road, Swanscombe, Kent DA10 0LH. Tel: 0322 846886.

Single axis indexer card

A command language that is specifically for motion control purposes is featured in Digiplan's IFX intelligent single-axis indexer.

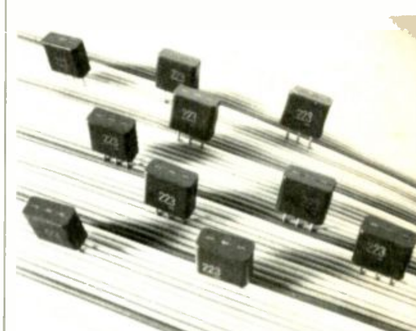
The indexer is easily programmed over a standard RS232C link and is equipped with on-card program storage. As many as seven motion control programs, each containing up to 256 characters, can be loaded. For applications that demand simultaneous control of several axes of movement, up to eight of the indexers are daisy-chained together. The unit generates all clock and direction signals necessary to control motor velocity, acceleration, position and direction. Parker-Digiplan Ltd, 21 Balena Close, Creekmoor, Poole, Dorset BH17 7DX. Tel: 0202 690911.





High-speed glue dispenser

Optical correction produces accuracy at high speed in the latest Fuji II glue dispenser for surface mount p.c.bs. The unit can be integrated into a Fuji automated component placing line or used as a stand alone system. It can take boards sized from 100 × 60mm to 475 × 356mm. Astro Technology Ltd, Astro House, Little Park Farm Road, Segensworth West, Fareham, Hants PO15 5TD. Tel: 04895 77233.



E.m.i. filters for power supply applications

In power supply applications the MTY223NB series of miniature e.m.i. rejection filters from EEC Electronics provides high attenuation over a wide band of frequencies from 10 to 1000MHz.

The filters measure 9 × 4.2 × 8mm and are made up of a combination of Melf tubular ceramic capacitors, Cerachips and magnetic ferrites bead cores. They are available with capacitances ranging from 270 to 33,000pF. The noise rejection band is determined by the capacitance value chosen. ECC Electronics (UK) Ltd, 9 Blenheim Road, High Wycombe, Bucks HP12 3RT. Tel: 0494 450716.

NEW PRODUCTS

Signal generator

Low distortion and a frequency spectrum down to 100Hz are offered by the Model 360A 100MHz general purpose signal generator from Quartzlock Instruments.

Harmonic distortion is −40dBc and modulation distortion is about 0.7%. Non-harmonic distortion is −80dBc and output level accuracy at 1MHz is ±2dB. The unit is also available with enhanced specifications including an harmonic distortion figure of less than −50dBc. The carrier range of this model is 110MHz and the modulation level control has a resolution of ten times that of the general purpose model. Either model is suitable for use by unskilled personnel and applications include quartz filter testing and h.f. receiver and transmitter testing. Quartzlock Instruments, Moor Road, Staverton, Devon TQ9 6PB. Tel: 080426 282.

Sweep generator for up to 26.5GHz

Communications, radar systems and components operating above 20GHz can be tested by Marconi Instruments' 6313 programmable sweep generator.

The frequency range covered by this instrument is from 0.01 to 26.5GHz. The model has a digital sweep capability to provide fast, accurate control of the sweep frequency via the GPIB port. This allows sweep repeatibility and sweeps of 400 points can be achieved in 100ms. Calibration is carried out in approximately 17min and five calibration stores are available for full-band and restricted-frequency calibration. Marconi Instruments Ltd, Long-acres, St Albans, Herts AL4 0JN. Tel: 0727 59292.

Automated inspection system

Surface defects on silicon wafers can be visually inspected by the Model 9000 in-line process control system from ADE Corporation.

A robotic arm wafer handler transports the wafer onto a vacuum chuck within the station. The operator is able to rotate and tilt the wafer under a light source, inspecting for visible faults. The defect code is then entered into a key pad, routing the wafer to the proper cassette for further processing. The system accommodates five functional stations and is configurable to meet a variety of applications. It includes a PC controller and an optional SECS II communication interface via a RS232 port. ADE Corporation, 77 Rowe Street, Newton, Massachusetts 02166, USA. Tel: 617 969 0600.

Better surveillance in low light

The blur-free image capture of moving subjects at low light levels by the Starsight VL intensified c.c.d. camera improves surveillance and security measures.

This camera, the HR604/MCP, uses a Philips NXA1011 sensor, fibre-optically coupled to a Mullard XX1500 second generation MCP intensifier. The tapered optical fibre coupling block is bonded to the c.c.d. sensor but pressure coupled to the intensifier for serviceability. For ultra-fast shuttering times, the intensifier is gated to reduce the image motion blur down to about 1μs. Prostab International Ltd, Boyn Valley Trading Estate, Boyn Valley Road, Maidenhead, Berks SL6 4EJ. Tel: 0628 784931.

Decade resistance boxes

A range of ten precision decade resistance boxes measures from 1 to 111ohm with a choice of 4, 5, 6 or 7 decades.

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- **Fully Computer Compatible.** *Yaesu's CAT system is a standard feature and a RS232 interface is available plus other interfaces for popular HOME computers. With this feature memories can be expanded and the unit can be remote controlled via a modem.*
- **Clock Function.** *Clock function allows time logging and auto switch on/off of the receiver.*
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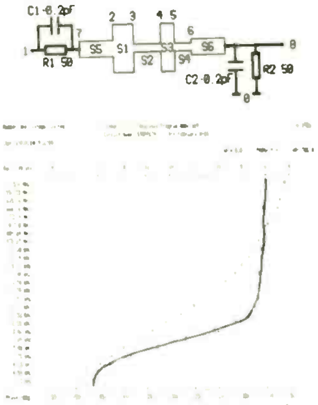

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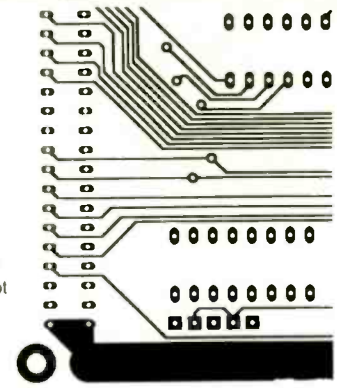

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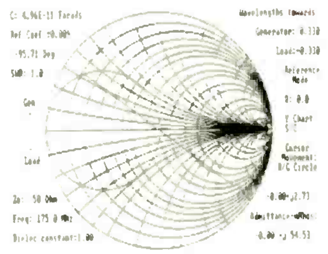

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RADIO COMMUNICATIONS

Meteors in uniform

The resurgence of interest in meteor-scatter burst techniques for medium-distance, point-to-point and ground-to-air communications or the recovery of data from unattended remote sensors has been reflected in a Royal Signals trial carried out last year between Krefeld and Berlin (a path length of roughly 500km). As described by Major C.J.Whittaker in the Spring 1988 issue of *The Journal of The Royal Signals Institution*, the trials once again showed that meteor trials could provide reliable low data rate circuits, resistant to jamming as well as auroral or polar cap ionospheric disturbances at costs significantly below satellite systems suitable for rapid-deployment applications.

Disadvantages include the absence of an instantaneous or speech capability, other than for short voice-synthesized commands, and an average data rate roughly equivalent to manual morse code.

The 1987 "MCC520" trials used a duplex link on frequencies in the range 40-50MHz, bi-phase p.s.k. mode and transmitter powers up to 500 watts. Over a three-day period in one of the least favourable months for meteors, an average data rate of 25bit/s was achieved – slightly higher than the 20bit/s reported by RAE for the 1986 "Blossom-A" experiments.

Major Whittaker ascribes the renaissance in the 1980s of commercial and military interest in meteor burst communications (m.b.s.) to the advent of v.l.s.i. and digital techniques and the slow-down in available communication satellites and their increasing cost, at a time when h.f. communications was still in decline for long-distance communications. Meteor trails can provide communications over distances of about 500 to a maximum of 2000km. Waiting time between usable trails increases significantly for path lengths below about 500km. The system can use frequencies between about 20 and 120MHz, but the lower frequencies are subject to ionospheric disturbances and interference while waiting time increases as frequencies rise. In practice about 35 to 55MHz is optimum. A complete m.b.s. system between two users would cost about £80 000.

The scattering geometry of a specific trail is such that the m.b.s. signals are receivable only within a restricted "footprint" of the order of 50 by 20km. This permits frequency re-use as well as offering important advantages in that interception or jamming is extremely difficult if not impossible from sites outside the footprint. It is also predicted that m.b.s. would be much less affected by high-altitude nuclear explosions than satellite or h.f. circuits. Paths would be partially open within a few minutes of the explosion and full recovery within about five hours. Bulk encryption of burst data has been shown to work. Future possibilities might include spread-spectrum techniques and dispersed receiver terminals in different "footprint" areas linked by terrestrial circuits to increase data rate.

Despite the increasing use of high data-rate and burst systems, a Royal Signals training advisory and control team (TACT) study has concluded that there will be a firm requirement for morse radio-telegraphists extending into the 21st century. But, the study notes, at present about half of the 1500 Royal Signals telegraphists are overtrained and under-employed as radio-operators and are "very dissatisfied individuals". It has recommended that the total should be reduced to about 800 with morse training to 15 instead of 18 words per minute (keyboard to 36 w.p.m.) with only a few operators trained to 20 w.p.m.

How secret is secret?

When *Proc. IEEE* (March 1979) published a 30-page tutorial paper "Privacy and authentication: an introduction to cryptography") by Whitfield Diffie and Martin Hellman (supplementing their 1976 "New directions in cryptography" (*IEEE Trans. Information Theory*, November 1976), it sparked off a row during which the National Security Agency sought to introduce new restrictions on the publication by American scientists and engineers of defence-sensitive papers. Diffie and Hellman stressed that the study of cryptography, once of interest primarily to military and diplomatic communities, is now of vital importance far beyond these limited areas. Electronic mail, electronic transfer of funds, huge databases of sensitive medical and personal histories stored in computers with dial-up capabilities, even subscription and pay-as-you-view television, have ensured that cryptography touches almost everyone in society. There is now a vast amount of information available to an eavesdropper, with technology making eavesdropping easier.

Diffie and Hellman were particularly concerned to publicize the advantages of the then new public-key (two-key) ciphers, as opposed to the Data Encryption Standard (D.E.S.) algorithm established for secure commercial use by the US National Bureau of Standards. They showed for the first time in public that secure communication is possible without any transfer of a secret key between sender and receiver, so starting off a decade of controversy that continues unabated to this day.

The D.E.S. algorithm was submitted originally by IBM in response to an invitation to industry for an encryption system suitable for government and commercial communications that would remain secure despite the algorithm being made public. D.E.S. provides only a 64-bit key although it is recognized to be an extremely good cipher with an unfortunately small key. At first NSA denied that it had influenced NBS in adopting a key of only 64 bits, but a US Senate committee in 1977 ascertained that the original submission by IBM included what amounted to a 768-bit key. There was a general feeling that D.E.S. would have a limited lifetime of about ten years.

In its May 1988 issue, *Proc. IEEE* devotes 100 pages to a special section on cryptology, including seven specialist papers. Paradoxically, these show that while nobody has yet revealed publicly any weakness in the D.E.S. algorithm that could be exploited other than by something significantly better than an exhaustive supercomputer attack, several of the public-key proposals have fatal weaknesses, including the Merkle-Hellman trapdoor-knapsack systems. Only the RSA (Rivest, Shamir, Adleman) algorithm, the use of which requires much greater computer power than D.E.S., remains a significant contender. At present the very attractive features of public-key cryptosystems are bought at the expense of speed: RSA chips work at only a few thousands bits per second maximum; D.E.S. chips are available for many million bits per second. But this difference is not theoretically inherent in two-key ciphers.

In *Electronics Letters* (21 July, 1988) Yang Xi Yian of Beijing University of Posts and Telecommunications shows that a public-key system based on matrix rings, proposed recently by his colleague, Xiao Rong, can be broken. He has, himself, in 1987 proposed new public key systems (*Electronics Letters*, Vol.23, pp560-1, 934-5) which he believes have not been broken and has invited cryptanalysts to attack his systems by any method in order to determine whether they really are secure.

A radically different concept was proposed in 1982 by Brassard, Breidhart and Wiesner, called quantum cryptography and based on the uncertainty principle of quantum physics. This could not be broken by the established principles of cryptanalysis; however, the concept has yet to be translated into a practical cryptosystem.

The need to subject high-grade ciphers to skilled attack by the best available cryptanalysts was proven by the Poles in July 1941. Wladyslaw Kozaczuk in his book "Enigma" relates how, at that time, Marian Rejewski and Henryk Zygalski, the highly-skilled cryptanalysts of the Polish Z team (who earlier had made the original breaks into Enigma) and were then working with Gustave Bertrand at the secret "Cadix" station near Nimes in the unoccupied zone of France, broke the high-grade Polish Lacinda (LCD) rotor machine in a few hours. This caused consternation because LCD was being used on the important covert radio link to the Polish radio centre at Stanmore, near London. Fortunately LCD had not been broken by the Germans.

Radio Communications is written by Pat Hawker.

RESEARCH NOTES

Fifth force – the evidence grows

British and American physicists have recently come up with what looks like sound evidence for a fifth fundamental force of nature. This fifth force, if it really does exist, would add to the long established forces of gravity, electromagnetism and the so-called strong and weak nuclear forces.

The first direct evidence of a fifth force came in 1922 when the Hungarian physicist Roland von Eötvös made accurate measurements of the periodicity of pendulums made of different materials. Eötvös found apparent discrepancies in the value of g, the gravitational constant, but put them down to experimental errors.

In 1985, a team at Purdue University re-analysed Eötvös's results and concluded that the 'discrepancies' were in fact evidence of a new force that acted against gravity, but over a much shorter range, typically a few hundred metres. Moreover the different effects of the new force on different materials could be explained on the assumption that it acted only on nuclei and not on the whole atoms.

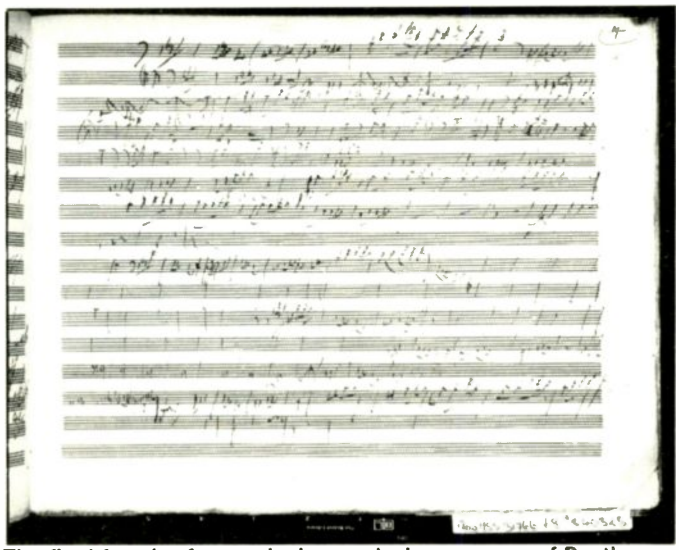
Evidence has continued to accumulate for the fifth force, though none of it has been wholly conclusive. One experiment down a mine in Queensland set out to measure the rate at which gravity decays with depth. As one nears the centre of the earth the pull of gravity should decay progressively because there's less earth underneath. But in this experiment it didn't seem to decay nearly fast enough.

Last year the opposite approach was tried up a 600m television tower in North Carolina when yet further anomalies were observed. Could it be, as some physicists had suggested, that there was not only a fifth force but a sixth one as well?

All these experiments, whilst interesting, could be faulted on the grounds of accuracy. In the case of the mine, there was some doubt over the density of the rock; up the television tower there was a distinct possibility of r.f. interference to the equipment! Now, however, a new experiment has been conducted that seems to eliminate these potential sources of error.

Gorman and Cooper of Scott Polar Research Institute at Cambridge working in conjunction with a group at the Los Alamos National Laboratory experimented down a borehole drilled through solid ice in Greenland. Because of the purity of the ice, measurements of gravity could be made with great accuracy and seemed to indicate an extra force equal to about 2% of the downward force of gravity.

If, as now seems likely, one or more extra forces do actually exist, they may turn out to be just what physicists have been yearning for in their attempts to describe gravity in terms of quantum theory. This in turn could lead very neatly to a grand mathematical theory unifying all the forces of nature.



The final frontier for musical o.c.r. devices: a page of Beethoven, from the sketchbooks for his Pastoral symphony (Additional manuscript 31766, folio 8; by kind permission of the Board of the British Library).

Optical music recognition

Optical character recognition (o.c.r.) is now an established technique. Many commercial systems are available in which printed words are scanned and 'read' off the page. Usually the object of the exercise is to convert the video input signal into a standard form that can be processed by a computer. In the case of printed text the problems are those of unambiguously identifying the complete alphanumeric set when presented in different character founts at different angles and spacings.

As a variation on this exercise, Richard Bacon and Nicholas Carter of Surrey University's physics and music departments set out to devise a system that would intelligently recognize the essential features of a musical score. In a recent paper (*Phys. Bull.* 39, 1988) they describe the problems involved and how they are being overcome.

The first obvious difficulty is the huge range of frequently-used symbols. This, say the Surrey researchers, rules out the use of ordinary o.c.r. programs. Then there's the question of position. Musical pitch is denoted by the position of a note on the stave which consists of five parallel lines. But what if, as is often the case, these stave lines are more or less completely obscured by the notes?

Bacon and Carter have developed an alogorithm which cleverly decides where the stave lines ought to be. This involves searching for pieces of the lines in an original manuscript and trying to join together sections with similar gradients and intercepts. It then selects five equidistant lines with similar gradients and defines a stave.

Notes and other musical symbols are identified by similar algorithms that look for blobs, vertical lines, curved lines etc. and then try to relate them to the nearest valid musical symbols. The greatest problem faced by the Surrey team is in defining the maximum error allowable, beyond which a valid symbol would go unrecognized. What, for example, does an optical music recognizer do with a note-head that is not precisely placed between two stave lines? Or how does it sort out supposedly parallel semiquaver beams that merge and overlap, a common fault in printed music?

These and other practical difficulties have now been overcome to the extent that the system can recognise most standard musical symbols. It is also resilient enough to cope with good quality handwritten music, for which it was never designed.

Altogether this new development seems set to revolutionize music publishing, as witness the support it has received from Oxford University Press and the Performing Rights Society. But don't ever expect it to turn Beethoven's scribbles into fair copy. Even human readers draw the line there.

Steady grind for silicon carbide

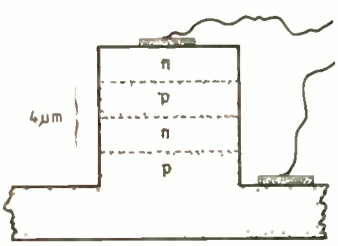
Those of us brought up on valve technology are perhaps understandably inclined to think twice before applying a soldering iron to anything solid-state. Eventually, though, it seems likely that we'll have a range of semiconductors capable of working at temperatures that would easily melt valves. (See Research Notes, March and June 1988).

The materials that have done most to make this possible are boron nitride and silicon carbide, the latter of course being a pure crystalline form of the grit more commonly associated with emery paper.

Over the last three decades various research teams have demonstrated solid state devices based on silicon carbide. These devices have included rectifier diodes, tunnel diodes and fets. Bipolar transistors that depend for their operation on minority carriers came much later because of their need for much greater purity. Silicon carbide has proved almost impossible to process without some contamination because at 1600°C even the atoms of the container diffuse into the carbide melt!

RESEARCH NOTES

This problem has now largely been overcome by a team of physicists working in Leningrad. In their latest report (*Electronics Letters* vol. 24 No 16) they describe a container-free liquid-phase epitaxy process in which a droplet of molten silicon carbide is suspended in an r.f. field. This techniques which has previously been used experimentally to produce high temperature fets and blue leds, has now been applied successfully to a four-layer thyristor-type structure.



This device, which has characteristics similar to those of a conventional silicon p-n-p-n stack, shows considerable promise especially in its switching speed.

With aluminium contacts, noone is of course promising practical devices that will operate at 1600°C. Nevertheless this latest success demonstrates the potential for commercial devices that will work in environments quite inhospitable to silicon.

Superconductor sandwich

That the transition temperatures below which superconducting materials lose their electrical resistance are determined by their structure is given further support in a report (*Nature* vol.334 No 6182) by H. Ihara and nine colleagues at the electrotechnical laboratory at Tsukuba, Japan.

Working on superconducting oxides based on the metal thallium, the researchers extended the previously known relationship between transition temperature and the number of layers of copper in the superconductor's crystalline structure. Ihara's material (a new kind of thallium-barium-calcium-copper oxide) is the first thallium superconductor to be made in bulk that has four copper layers to every one of thallium. It begins to lose its electrical resistance at about 120K (−153°C).

Earlier work on thallium superconductors containing two layers of thallium per unit cell of crystal showed that the transition temperature is related to the amount of copper: 80K with one layer, 110K with two, and 120K with three. The first of these was reported by Z.Z. Sheng and A.M. Hermann earlier this year and was the first superconducting ceramic based on thallium rather than a rare-earth metal such as lanthanum or yttrium. Since then, researchers have identified two main classes of thallium superconductor, with either one or two layers of thallium in each unit cell.

Ihara's material, with four copper layers and one thallium layer, has about the same transition temperature as the three-copper, two-thallium material. But the clear relationship between copper and transition temperature in materials with a given amount of thallium raises hopes that a two-thallium, four-copper system might be a superconductor at even higher temperatures.

Chips by X-ray lithography

X-rays, because of their short wavelength, have long held out the promise of fine-line lithography and hence the creation of chips with sub-micron patterns. The problem has always been that of generating X-ray beams with sufficient intensity and precision.

IBM researchers using a large scientific electron storage ring at the Brookhaven National Laboratory, New York, have now demonstrated what they believe to be the most advanced practical X-ray lithographic techniques yet reported. Using new tools and processes they have created experimental half-micron chips that demonstrate the practicability of future 64Mbit rams.

At the heart of the experiment was a source of X-rays produced by synchrotron radiation within the electron storage ring. Synchrotron radiation occurs when electrons move at high velocities in circular paths in a magnetic field; it is powerful and precise.

On this chip fabricated by X-rays, the bright strips are metal tracks less than a micron wide, crossing over another signal line.

To make practical use of this precision X-ray source the IBM researchers also had to develop a new lithography system for an exposure station connected to the Brookhaven storage ring. In this station, X-rays were passed through a mask with the desired pattern to expose a 6.5cm^2 area of a silicon wafer coated with a photosensitive material. Nine test chips, including two memories, were patterned this way.

Although preliminary work was done using a large experimental storage ring, future work to develop this technology will make use of a smaller, specialized ring being designed and manufactured by the Oxford Instruments Group in Britain.

Ultimately it's hoped that X-ray lithography will replace the ultraviolet (u.v.) and optical lithography now used to make l.s.i. chips. Not only can X-rays shape far smaller circuit patterns than u.v. and optical lithography because of the wavelength of X-rays, they can also expose a larger area of silicon at once. Chips made using these techniques could thus be made much larger and so hold more devices. X-ray lithography is also less sensitive to the surface contaminants that plague today's technology because X-rays can pass through small dirt particles.

Rusty bolts exonerated

Readers of this column may recall descriptions of the 'rusty bolt' syndrome and various attempts to cure it. What these refer to is the tendency for structural components of a transmitting mast to generate transmissions of their own when in the vicinity of two or more transmitters operating on unrelated frequencies. This co-siting is, of course, the norm both in broadcasting and at private base stations, and can lead to intermodulation products that may interfere with nearby receivers.

The origin of these intermodulation products is of course well known and may lie in any non-linear junction, not just the much-maligned rusty bolt. But whilst the phenomenon has been extensively studied in the field, it hasn't proved easy to make quantitative comparisons of different types of mechanical fixtures, so as to facilitate good antenna design.

A team from the University of Kent working in conjunction with the Home Office Directorate of Telecommunications (*Electronics Letters* vol.24 No16) has now developed a computer-controlled system that will enable different structures to be tested in the laboratory. It consists of two power amplifiers producing separate signals between 150 and 250MHz. After combination these two signals are fed into a test chamber which can accommodate metal structures up to 1m×20cm wide. The signals are then terminated and filtered so as to release any intermodulation products into a receiver.

Tests using this highly accurate and fully enclosed system have produced some interesting results. Contrary to popular belief, for example, the archetypal rusty bolt is not the worst offender: if the joint is tight the effect may actually be minimal. Much worse as a generator of intermodulation signals is galvanized mild steel rope. But a whole 35dB worse still – and to be avoided at all costs – is mild steel chain. Loose joints with small areas of contact appear to be the real horrors while nasty-looking corrosion may be much less important or even incidental.

Research Notes is compiled by John Wilson of the BBC World Service science unit.

TELEVISION BROADCAST

H.d.tv will be price-sensitive

In the 1970s, the Japanese broadcasters, both NHK and commercial, sent innumerable delegations and representatives to the UK to assess the prospects for teletext, a service that could never have been launched if the UK had not then believed in public service broadcasting concepts. The Japanese visitors invariably wanted to know how much "market research" had been carried out by the IBA before the decision had been taken to launch the Oracle (and presumably also the BBC Ceefax) service. They politely refrained from expressing open disbelief when it fell to my lot to admit that there had been no prior market research of the type they had in mind, at least by the IBA.

I have no idea as to the extent to which NHK has carried out market research in Japan on its 1125-line, widescreen h.d.tv system. But I feel sure it will have studied carefully the North American survey of 7000 members of the public and special interest groups when these were given their first opportunity to view 1125-line pictures, with the MUSE-E bandwidth-reduction system, as an example of an "advanced television system", in direct comparison with 525-line NTSC pictures, carefully adjusted to provide optimum picture quality rather than as normally seen in most North American homes. Both were shown at optimum viewing distance.

A report on this research by Dr Stephen Lupker, Dr Natalie Allen (both University of Western Ontario) and Dr Paul Hearty (Canadian Department of Communications) in *Combroad* (September 1988) indicates that, as might be expected, most viewers preferred the h.d.tv system (even with MUSE) and would be prepared to pay for suitable sets provided that h.d.tv signals were readily available.

But they showed quite clearly that "although there is considerable demand for advanced television, success in introducing a.tv will be highly dependent on factors such as cost of equipment, availability of programme material and quality of reception... when costs are considerable (e.g. $1500) viewers become increasingly demanding, with expressed purchase interest eroded by any factor that promotes dissatisfaction (e.g. motion quality, set size, colour quality, depth portrayal etc). Thus it is possible that the cost of an intermediate-quality system would provoke consumer requirements out of proportion to the capacities of the system... although there is a considerable demand, it will prove difficult to satisfy consumers with regard to both video/audio quality and factors such as price, availability and transmission quality... large-scale initial adoption of a.tv is also unlikely if the availability of signals in the appropriate format is severely curtailed... purchase interest drops as availability becomes increasingly constrained."

Expressed purchase interest decreased sharply in most of the five test cities in Canada and the USA from the 74 percent "if sets are in your price range" to about 34 percent if sets were to cost $1500 and only 22 percent if sets cost $2500.

Viewing habits

According to the EBU, British viewers spent an average of 218 minutes (3 hours 38 minutes) daily in front of a television set during 1987, up 13 minutes since 1984. French viewers averaged 175 minutes, up from 120 minutes in 1982. Italian viewers averaged 178 minutes, up from 145 minutes in 1984. However by placing a camera in the television set to record viewer behaviour, a recent West German experiment found a third of the viewers left the set on without watching, another third were busy doing something else at the same time, and only about one third were found to be paying undivided attention to the programme.

I recall that when, in the mid-1970s (before the development of the hidden camera technique), on the basis of some German research on children's viewing habits, I ventured to suggest in *Independent Broadcasting* that inattention to the screen was not confined to young children, it provoked a highly indignant letter to my masters from the then managing director of Thames Television suggesting that I was trying to ruin ITV by discouraging advertisers! Later, hidden camera research in the UK showed only too clearly that family viewing is a highly disjointed, intermittent affair. Unfortunately, it also confirmed the American finding that only violent action seems to gain viewers' undivided attention. Which is why so many American "drama" programmes flit from violence to violence within the short attention-span of many viewers.

Nowadays, commercial television companies have other worries. The German research shows that while commercials were being transmitted, over half of the viewers "zapped" to other channels. Similarly, the majority use "fast forward" on commercials ("zipping") when they watch home videotaped programmes. An American-developed device is claimed to recognize and cut out commercials on recordings. One notices that even in the tightly-regulated UK, the IBA now permits an average of seven minutes of commercials per hour, with a maximum of 7½ minutes in any one clock hour; this compares with the six minutes average and 6½ minutes maximum that was rigorously maintained until quite recently. With deregulation we may have commercials interrupted by programmes!

Cable expands slowly

Although broadband cable networks in the UK franchise areas are now expanding at a rate of well over 10 000 homes-passed per month, the take-up by viewers remains low and the "churn rate" (percentage of homes ceasing to subscribe) quite high. On April 1 this year, 307 453 homes were passed by broadband cable but only 44 565 homes were connected, a take-up of 14.5 percent. This compares to 168 436 homes passed with 21 873 connected (13 percent) a year earlier. The rate of cabling has been rising much faster than the take-up. In view of the high cost of buried cables in the UK, it is not surprising that there has been so much industry agitation for the licensing of microwave video distribution systems, despite the slow growth of m.v.d.s. in the USA and the original Government ruling that all new cable systems must be capable of carrying at least 25-30 channels.

A large majority of UK cable subscribers are still connected to the old limited-capacity "upgraded" networks, freed from the obligation to carry BBC and ITV channels. These still account for almost 200 000 subscribers and help to raise the take-up for both old and new networks to a more respectable 18.7 percent.

• Westminster Cable Television with 6500 subscribers has become the first to link with BT's Prestel service, permitting access to interactive videotex services via existing remote control keypads and television sets with services charged on a pay-per-use basis.

New technology

NHK has developed an experimental super-sensitive h.d.tv camera pick-up tube with a new high-gain avalanche rising amorphous photoconductor (HARP) target which is expected to result in a camera ten times as sensitive as one with an equivalent Saticon picture tube. Currently h.d.tv cameras need to be operated with the iris opened two or three stops wider than cameras for existing tv standards (*SMPTE Journal*, July 1988).

NEC is developing a new gallium arsenide technology to reduce fabrication costs of d.b.s. and communications/radar receivers for use above 10GHz. It is claimed that a GaAs/Al-GaAs self-aligned heterojunction bipolar transistor has only about 1/300th of the phase noise of a GaAs fet oscillator and makes possible the implementation on a chip of a complete d.b.s/communications receiver front-end. The device is roughly tuned by positioning a bonding wire on an aluminium tuning line on the chip, with fine tuning by adjusting the bias voltage. It is claimed the technology offers the possibility of a maximum oscillator frequency above 100GHz by reducing stray capacitances.

Television Broadcast is written by Pat Hawker.

Modelling microwave propagation

The extensive programme of work being carried out under the COST 210 project, of importance to d.b.s. as well as to analogue and digital terrestrial microwave links, is now well into its fifth year. COST 210 is a project of the European co-operation in the field of scientific and technical research programme, as set up in 1971 within the OECD and European Community. This project was formally initiated on 7 June, 1984, as a five-year project to determine "the influence of the atmosphere on interference between radio communication systems at frequencies above 1GHz". It is concerned particularly with interference between terrestrial and satellite systems and with mutual intereference between satellite systems using relatively small antennas.

COST 210 has involved 25 organizations in ten countries. UK participants are BTRL, IBA, Polytechnic of Wales, Portsmouth Polytechnic, RAL, RD/DTI, RSRE and the universities of Bradford and Essex. Chairman of the management group is M.P.M.Hall (RAL). The three working groups have been investigating (1) interference in clear air; (2) interference due to hydrometeor scatter; and (3) interference reduction techniques.

The work has included a critical assessment of existing CCIR models and interference procedures and the development of more reliable new models. The ultimate aim is a fully self-contained prediction procedure, including computer source listings for application in European areas. A number of the UK studies have involved 1.3, 11 and 24 GHz transhorizon paths across the North Sea and the English Channel as well as a number of monostatic radar experiments. Clear air studies on 1.3GHz paths have been mainly centred on BTRL at Martlesham Heath on links subject to considerable tropospheric propagation to Denmark, West Germany, Holland and the Channel Islands. Work at 11GHz has included study of the paths across the English Channel between Winchester and Lannion, Brittany; and Winchester and the Cap d'Antifer.

Among the many experiments that have been contributing to COST 210 have been a series of flights across the English Channel in a specially equipped Norman Islander (G-AXJ) to enable RAL's French woman-scientist, Dr M.F. Levy, to obtain a large number of reflector measurements to reveal the fine structure and radiowave coupling mechanisms of transhorizon ducts. Flights have been made from Eastney to Cap d'Antifer (152km path) with the refractive index measurements automatically correlated with accurate height measurements.

Professor E. Vilar (Portsmouth Polytechnic) has been involved with the investigation of transhorizon propagation on the 11GHz Winchester-France paths by such mechanisms as scattering by atmospheric turbulence, scattering from hydrometeors (mostly rain), rapid changes in the vertical profile of the refractive index etc. Rain scatter can result in signals as strong as those from ducts but usually over a much briefer period.

The Directorate of Telecommunications of the Home Office, in association with Essex University, designed an experimental system to gather angle-of-arrival data on a 93km path at 2GHz to validate a reflecting layer model that takes into account the actual underlying terrain profile. The project, including BT studies on paths from Martlesham, may help resolve some of the problems experienced in digital transmission of audio, video and data signals over long microwave paths.

Outback radio by satellite

Hearings of the Australian Broadcasting Corporation began in August for the award of licences to provide remote commercial radio services (RCRS) by means of the Aussat domestic satellite alongside the existing RATS (remote area tv service) and the commercial (RCTS) services, both associated with the Australian homestead and community broadcasting satellite system (HACBSS). A few services may be in operation early 1989.

But, according to *Broadcast Engineering News*, satellite broadcasting to remote areas has so far been a commercial failure, with the outback markets too small to sustain transmission costs without substantial government or state subsidies. It is claimed that the use of B-MAC, "the most expensive d.b.s. system available", has not made it easier. The experience of RCTS channels has not been encouraging despite State subsidies ranging up to 70 percent of the transponder charges. Leasing a B-MAC channel on Aussat costs $(A)125 000 without subsidy. The B-MAC format, selected in 1984, provides four extra audio channels per tv channel, but so far they have been virtually unused.

The commercial Golden West Network (GWN) based in Perth operates a State-subsidized RCTS service and has applied to operate a stereo and a mono RCRS service using its existing 96MHz f.m. service for Perth as the sustaining backbone, for an estimated maximum audience of 55 000 listeners. GWN is making effective use of its satellite television channel to distribute programme material to remote terrestrial stations, reaching 100 000 people of whom 10 000 view on 2000 HACBSS earth terminals.

H.f.audiences

Bert Steinkamp (Radio Nederland Wereldomroep) in considering "The future of external broadcasting" (*EBU Review, Programmes, Administration, Law*, July 1988) suggests that "even if shortwave has its shortcomings as a mode of transportation, the medium is far from defunct". Radio Nederland, following the example of Deutsche Welle, is developing a new audience among the many Dutch holidaymakers who flock to the coasts of southern Europe: "Our publicity has persuaded about a third of these to take a shortwave receiver with them to create an entirely new group of listeners who had never before listened to shortwave at home... External broadcasting should not be identified as shortwave only... My personal feeling is that there might be a gradual vacating of a.m. transmitters for domestic services in favour of f.m., f.m. stereo and ultimately (digital) satellite. External broadcasters would be well advised to use such seemingly redundant (medium wave) facilities where distances permit. *Not* to forestall developments in the direction of still more advanced technology but simply to retain audiences."

He notes that there were more than 2200 h.f. transmitters (with another 164 under construction) in 1986, a growth of about 12 percent in the past decade, while very high power transmitters (200kW or more) had increased by more than 40 percent.

IEEE Trans. on Broadcasting (June 1988) is a special issue devoting some 230 pages to short-wave broadcasting.

• BBC External Services has changed its name to BBC World Service.

In brief

The increasing interest of eastern European broadcasters in digital audio, noted several times previously in this column, is underlined by recent sales of Sony digital equipment to Gostelradio (USSR), Bulgarian Radio, Polish Radio and Television, Radio Prague, Radio Bratislava, Hungarian Radio, Radio Ljubljana (Yugoslavia) and the Czech CD record firm Supraphon. Gostelradio has just taken delivery of two complete CD mastering systems; it has also bought three PCM3324 digital multitrack recorders and two PCM-2000 recorders. Mike Bennett of Sony Broadcast believes that eastern European radio is entering an exciting new era of digital audio and is making rapid progress in a spirit of glasnost.

RDS data has been broadcast on all transmitters of France-Inter since June 1987 providing automatic programme identification and automatic frequency search. An increasing number of mainland-European f.m. transmitters can now be identified by RDS.

• The BBC claims that "The Daily Service", broadcast since 24 June, 1928, is the world's longest-running radio programme.

Radio Broadcast is written by Pat Hawker.

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LQ800 (80 col) £439 (a)
LQ1000 £589 (a)

TAXAN
KP815 (160 cps) £249 (a)
KP915 (180 cps) £369 (a)

JUKI
6100 (Daisy Wheel) £259 (a)

NATIONAL PANASONIC
KX P1080 (80 col) £149 (a)

STAR NL10 (Parallel Interface) £209 (a)
STAR NL10 (Serial Interface) £279 (a)
STAR Power Type £229 (a)

BROTHER HR20 £329 (a)

COLOUR PRINTERS

Dotprint Plus NLQ Rom for Epson versions for FX, RX, MX and GLP (BBC only) £28 (d)

PLOTTERS
Hitachi 672 £459 (a)
Graphics Workstation (A3 Plotter) £599 (a)
Plotmate A4SM £450 (a)

PRINTER ACCESSORIES

We hold a wide range of printer attachments (sheet feeders, tractor feeds etc) in stock. Serial, parallel, IEEE and other interfaces also available. Ribbons available for all above plotters. Pens with a variety of tips and colours also available. Please phone for details and prices.
Plain Fanfold Paper with extra fine perforation (Clean Edge):
2000 sheets 9.5" × 11" £13(b) 2000 sheets 14.5" × 11" £18.50(b)
Labels per 1000s. Single Row 3½" × 1 7/16" £5.25(d) Triple Row 2-7/16" × 1 7/16" £5.00(d)

MODEMS

All modems carry a full BT approval

MIRACLE TECHNOLOGY WS Range

WS4000 V21/23 (Hayes Compatible, Intelligent, Auto Dial/Auto Answer) £149 (b)

WS3000 V21/23 Professional As WS4000 and with BELL standards and battery back up for memory £245 (b)

WS3000 V22 Professional As WS300 V21/23 but with 1200 baud full duplex £450 (a)

WS3000 V22 bis Professional As V22 and 2400 baud full duplex £595 (a)

WS3022 V22 Professional As WS3000 but with only 1200/1200 £350 (a)

WS3024 V22 Professional As WS3000 but with only 2400/2400 £450 (b)

WS2000 V21/V23 Manual Modem £95 (b)

DATA Cable for WS series/PC or XT £10 (d)

DATATALK Comms Package
* If purchased with any of the above modems * *£70 (c)

PACE Nightingale Modem V21/V23 Manual £75 (b)

(Offer limited to current stocks)

RT256 3 PORT SWITCHOVER SERIAL INTERFACE
3 input/1 output or 1 input/3 output manual channel selection. Input/output baud rates, independently selectable 7 bit/8 bit, odd/even/none parity. Hardware or software handshake. 256K buffer, mains powered £375 (b)

PB BUFFER
Internal buffer for most Epson printers. Easy to install. Inst. supplied
PB128 128K £99 (c)

SOFTY II

This low cost intelligent eprom programmer can program 2716, 2516, 2532, 2732, and with an adaptor, 2564 and 2764. Displays 512 byte page on TV – has a serial and parallel I/O routines. Can be used as an emulator, cassette interface.
Softy II £195.00 (b)
Adaptor for 2764/2564 £25.00

PLEASE WRITE OR TELEPHONE FOR CURRENT PRICES

DISC DRIVES

5.25" Single Drives 40/50 switchable:
TS400 400K/640K £114 (b)
PS400 400K/640K with integral mains power supply £129 (b)
5.25" Dual Drives 40/80 switchable:
TD800 800K/1280K £199 (a)
PD800 800K/1280K with integral mains power supply £229 (a)
PD800P 800K/1280K with integral mains power supply and monitor stand £249 (a)
3.5" 80T DS Drives:
TS351 Single 400K/640K £99 (b)
PS351 Single 400K/640K with integral mains power supply £119 (b)
TD352 Dual 800K/1280K £170 (b)
PD352 Dual 800K/1280K with integral mains power supply £187 (b)
PD853 Combo Dual 5.25"/3.5" drive with p.s.u. £229 (a)

3M FLOPPY DISCS

Industry Standard floppy discs with a lifetime guarantee. Discs in packs of 10

5¼" Discs				3½" Discs	
40 T SS DD	£10.00 (d)	40 T DS DD	£12.00 (d)	80 T SS DD	£20.00 (d)
80 T SS DD	£14.50 (d)	80 T DS DD	£15.50 (d)	80 T DS DD	£25.00 (d)

FLOPPICLENE DRIVEHEAD CLEANING KIT

FLOPPICLENE Disc Head Cleaning Kit with 28 disposable cleaning discs ensures continued optimum performance of the drives. 5¼" £12.50 (d) 3½" £14.00 (d)

DRIVE ACCESSORIES

Single Disc Cable £6 (d)
10 Disc Library Case £1.80 (d)
50 × 5¼" Disc Lockable Box £9.00 (c)
Dual Disc Cable £8.50 (d)
30 × 5¼" Disc Storage Box £6 (c)
100 × 5¼" Disc Lockable Box £13 (c)

MONITORS

RGB 14"
1431 Std Res £179 (a)
1451 Med Res £225 (a)
1441 Hi Res £365 (a)

MICROVITEC 14" RGB/PAL/Audio
1431AP Std Res £199 (a)
1451AP Std Res £259 (a)
All above monitors available in plastic or metal case.

TAXAN SUPERVISION II
12" – Hi Res with amber/green options. IBM compatible £279 (a)
Taxan Supervision III £319 (a)

MITSUBISHI
XC1404 14" Med Res RGB, IBM & BBC compatible £219 (a)

MONOCHROME
TAXAN 12" HI-RES
KX1201G green screen £90 (a)
KX1203A amber screen £95 (a)

PHILIPS 12" HI-RES
BM7502 green screen £75 (a)
BM7522 amber screen £79 (a)
8501 RGB Std Res £139 (a)

ACCESSORIES
Microvitec Swivel Base £20 (c)
Taxan Mono Swivel Base with clock £22 (c)
Philips Swivel Base £14 (c)
BBC RGB Cable £5 (d)
Microvitec £3.50 (d)
Taxan £5 (d) Monochrome £3.50 (d)
Touchtec – 501 £239 (b)

UVERASERS

UV1T Eraser with built-in timer and mains indicator. Built-in safety interlock to avoid accidental exposure to the harmful UV rays. It can handle up to 5 eproms at a time with an average erasing time of about 20 mins. £59 + £2 p&p.
UV1 as above but without the timer. £47 + £2 p&p.
For Industrial Users, we offer UV140 & UV141 erasers with handling capacity of 14 eproms. UV141 has a built in timer. Both offer full built in safety features UV140 £69, UV141 £85, p&p £2.50.

EXT SERIAL/PARALLEL CONVERTERS

Mains powered converters
Serial to Parallel £48 (c)
Parallel to Serial £48 (c)
Bidirectional Converter £105 (b)

Serial Test Cable

Serial Cable switchable at both ends allowing pin options to be re-routed or linked at either end – making it possible to produce almost any cable configuration on site.
Available as M/M or M/F £24.75 (d)

Serial Mini Patch Box

Allows an easy method to reconfigure pin functions without rewiring the cable assay. Jumpers can be used and reused £22 (d)

Serial Mini Test

Monitors RS232C and CCITT V24 Transmissions, indicating status with dual colour LEDs on 7 most significant lines. Connects in Line £22.50 (d)

CONNECTOR SYSTEMS

I.D. CONNECTORS

(Speedblock Type)

No of ways	Header Plug	Recep tacle	Edge Conn
10	90p	85p	120p
20	145p	125p	195p
26	175p	150p	240p
34	200p	160p	320p
40	220p	190p	340p
50	235p	200p	390p

D CONNECTORS

No of Ways

	9	15	25	37
MALE:				
Ang Pins	120	180	230	350
Solder	60	85	125	170
IDC	175	275	325	—
FEMALE:				
St Pin	100	140	210	380
Ang Pins	160	210	275	440
Solder	90	130	195	290
IDC	195	325	375	—
St Hood	90	95	100	120
Screw Lock	130	150	175	—

TEXTOOL ZIF

SOCKETS
24-pin £7.50
28-pin £9.10
40 pin £12.10

EDGE CONNECTORS

	0.1	0.156
2 × 6 way (commodore)	—	300p
2 × 10 way	150p	—
2 × 12 way (vic 20)	—	350p
2 × 18 way	—	140p
2 × 23 way (ZX81)	175p	220p
2 × 25 way	225p	220p
2 × 28 way (Spectrum)	200p	—
2 × 36 way	250p	—
1 × 43 way	260p	—
2 × 22 way	190p	—
2 × 43 way	395p	—
1 × 77 way	400p	500p
2 × 50 way (S100conn)	600p	—

EURO CONNECTORS

DIN 41612	Plug	Skt
2 × 32 way St Pin	230p	275p
2 × 32 way Ang Pin	275p	320p
3 × 32 way St Pin	260p	300p
3 × 32 way Ang Pin	375p	400p
IDC Skt A + B	400p	
IDC Skt A + C	400p	

For 2 × 32 way please specify spacing (A + B, A + C).

MISC CONNS

21 pin Scart Connector 200p
8 pin Video Connector 200p

AMPHENOL CONNECTORS

36 way plug Centronics (solder) 500p (IDC) 475p
36 way skt Centronics (solder) 550p (IDC) 500p
24 way plug IEEE (solder) 475p (IDC) 475p
24 way skt IEEE (solder) 500p (IDC) 500p
PCB Mtg Skt Ang Pin
24 way 700p 36 way 750p

GENDER CHANGERS

25 way D type

Male to Male £10
Male to Female £10
Female to Female £10

RS 232 JUMPERS

(25 way D)

24"	Single end Male	£5.00
24"	Single end Female	£5.25
24"	Female Female	£10.00
24"	Male Male	£9.50
24"	Male Female	£9.50

DIL SWITCHES

4-way	90p	6-way	105p
8-way	120p	10-way	150p

RIBBON CABLE

(grey/metre)

10-way	40p	34-way	160p
16-way	60p	40-way	180p
20-way	85p	50-way	200p
26-way	120p	64-way	280p

DIL HEADERS

	Solder	IDC
14 pin	40p	100p
16 pin	50p	110p
18 pin	60p	—
20 pin	75p	—
24 pin	100p	150p
28 pin	160p	200p
40 pin	200p	225p

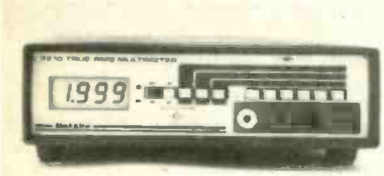
ATTENTION

All prices in this double page advertisement are subject to change without notice.
ALL PRICES EXCLUDE VAT
Please add carriage 50p unless indicated as follows: (a) £8 (b) £2.50 (c) £1.50 (d) £1.00

TECHNOLINE VIEWDATA SYSTEM. TEL: 01-450 9764

Using 'Prestel' type protocols. For information and orders – 24 hour service, 7 days a week

DIGITAL MULTIMETERS from £89



- 3½ DIGIT 0.5" LCD
- 7000 HR BATTERY LIFE
- 0.1% BASIC ACCURACY
- TRUE RMS
- 1000V DC 750V AC
- 10A AC/DC
- DIODE/RESISTANCE TEST
- CONTINUITY BUZZER

from £99 FREQUENCY COUNTERS

- 100MHz, 600Mhz, 1GHz, 1.5GHz MODELS
- 3 GATE TIMES
- RESOLUTION TO 0.1Hz
- ½" BRIGHT LED DISPLAY
- MAINS/BATTERY
- TCXO OPTION
- LOW PASS FILTER

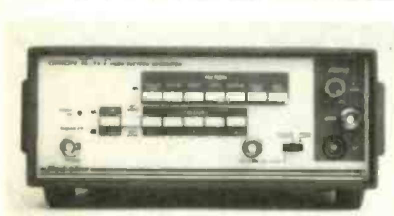
UNIVERSAL COUNTER-TIMERS from £219

- FREQUENCY DC — 100MHz
- RESOLUTION TO 0.001Hz
- RATIO
- PERIOD
- TIME INTERVAL
- COUNT
- STOP WATCH
- RPM
- SIGNAL CONDITIONING

from £110 FUNCTION GENERATOR

- 500KHz and 2MHz MODELS
- SINE, SQUARE, TRIANGLE, TTL
- EXTERNAL AM
- EXTERNAL SWEEP
- 0-30V OUTPUT
- ±15V DC OFFSET
- 50 Ω and 600 Ω O/P's
- 0, -20dB, -40dB ATTENUATOR

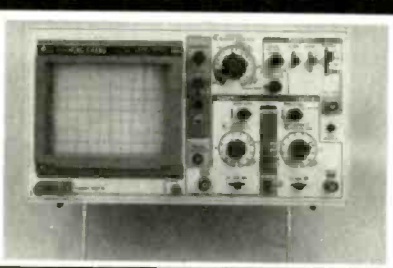
PAL PATTERN GENERATOR £199



- FULL SELECTION PATTERNS
- VHF/UHF
- RF, COMP, VIDEO, IRGB O/P's
- 5.5, 6.0, 6.5 MHz SOUND
- SEPARATE OR MIXED SYNCS
- 1V OR TTL IRGB
- VARIABLE VIDEO O/P
- INT/EXT SOUND

OSCILLOSCOPES

- 20MHz DUAL TRACE, COMPONENT TESTER. £295
- 15MHz DUAL TRACE BATTERY OPERATION £399
- 35MHz DUAL TRACE SWEEP DELAY £399
- 50MHz DUAL TRACE SWEEP DELAY £579



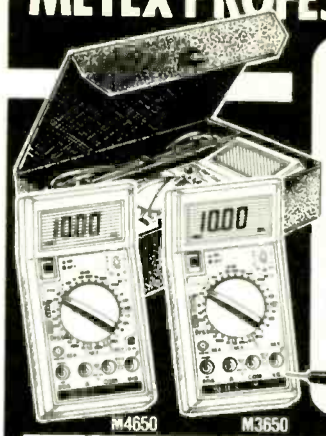
PRICES EXCLUSIVE OF CARRIAGE AND VAT. ALL PRODUCTS CARRY 1 YEAR GUARANTEE.
FOR ILLUSTRATED DATA SHEET, PRICES, TECHNICAL ADVICE OR DEMONSTRATION CONTACT:

BLACK STAR LIMITED
4 HARDING WAY, ST IVES,
HUNTINGDON, CAMBS PE17 4WR.
Tel: (0480) 62440 Telex: 32762

Black★Star

ENTER 59 ON REPLY CARD

METEX PROFESSIONAL DMM'S



EDUCATION AND QUANTITY PRICES ON REQUEST

3½ and 4½ 12mm LCD Digital multimeters: 5 ranges AC and DC volts: 6 Resistance Ranges to 20M ohm: AC/-DC to 20 Amps: Hfe Transistor test: Diode Test: Continuity: Auto polarity and zero: Plus extra features as below. Size 176 x 90 x 36 mm (3800 172 x 88 x 36): All with Test Leads: Fused: Hard carry case and instructions.

ALL MODELS WITH FREE HARD CARRY CASE

MODEL	DIGITS	RANGES	EXTRA FEATURES	BASIC	PRICE
3800	3½	32	Low AC/DC 0/20 micro amp ranges	0.5%	£35.00
3610	3½	30	LED continuity indicator	0.3%	£39.09
3630	3½	30	5-Range Capacitance Test	0.3%	£45.17
3650	3½	30	2-Range frequency counter 5-Capacitance	0.3%	£52.13
4630	4½	30	Data Hold 5-Range Capacitance	0.05%	£60.83
4650	4½	30	Data Hold, 2-Range Freq. 5-Capacitance	0.05%	£69.52

Add 15% VAT UK only - UK POST/INS etc. FREE (EXPORT EXTRA)

OPEN 6 DAYS A WEEK — CALLERS WELCOME

INSTRUMENT CATALOGUE Ref TG UK Send SAE A4 £1.00

AUDIO ELECTRONICS

TELEPHONE 01-724 3564
301 EDGWARE ROAD, LONDON W2 1BN
ORDER BY POST OR TELEPHONE

ENTER 40 ON REPLY CARD

With 40 years' experience in the design and manufacture of several hundred thousand transformers we can supply:

AUDIO FREQUENCY TRANSFORMERS OF EVERY TYPE

YOU NAME IT! WE MAKE IT!

OUR RANGE INCLUDES:

Microphone transformers (all types), Microphone Splitter/Combiner transformers, Input and Output transformers, Direct Injection transformers for Guitars, Multi-Secondary output transformers, Bridging transformers, Line transformers, Line transformers to B.T. Isolating Test Specification, Tapped impedance matching transformers, Gramophone Pickup transformers, Audio Mixing Desk transformers (all types), Miniature transformers, Microminiature transformers for PCB mounting, Experimental transformers, Ultra low frequency transformers, Ultra linear and other transformers for Valve Amplifiers up to 500 watts, Inductive Loop transformers, Smoothing Chokes, Filter, Inductors, Amplifiers to 100 volt line transformers (from a few watts up to 1,000 watts), 100 volt line transformers to speakers, Speaker matching transformers (all powers), Column Loud-speaker transformers up to 300 watts or more.

We can design for RECORDING QUALITY, STUDIO QUALITY, HI-FI QUALITY OR P.A. QUALITY. OUR PRICES ARE HIGHLY COMPETITIVE AND WE SUPPLY LARGE OR SMALL QUANTITIES AND EVEN SINGLE TRANSFORMERS. Many standard types are in stock and normal dispatch times are short and sensible.

OUR CLIENTS COVER A LARGE NUMBER OF BROADCASTING AUTHORITIES, MIXING DESK MANUFACTURERS, RECORDING STUDIOS, HI-FI ENTHUSIASTS, BAND GROUPS AND PUBLIC ADDRESS FIRMS. Export is a speciality and we have overseas clients in the COMMONWEALTH, EEC, USA, MIDDLE EAST, etc.

Send for our questionnaire which, when completed, enables us to post quotations by return

SOWTER TRANSFORMERS
Manufacturers and Designers

E. A. SOWTER LTD. (Established 1941). Reg. No. England 303990
The Boat Yard, Cullingham Road, Ipswich IP1 2EG.
Suffolk. PO Box 36, Ipswich IP1 2EL, England.
Phone: 0473 52794 & 0473 219390 —
Telex: 987703G

ENTER 38 ON REPLY CARD

APPOINTMENTS

Advertisements accepted up to 12 noon 28th October for December issue.

DISPLAYED APPOINTMENTS VACANT: £27 per single col. centimetre (min. 3cm).
LINE ADVERTISEMENTS (run on): £6.00 per line, minimum £48 (prepayable).
BOX NUMBERS: £15.00 extra. (Replies should be addressed to the Box Number in the advertisement, c/o Quadrant House, The Quadrant, Sutton, Surrey SM2 5AS).
PHONE: PETER HAMILTON on 01-661 3033 (Direct Line).
Cheques and Postal Orders payable to REED BUSINESS PUBLISHING and crossed.

Leicester Polytechnic

School of Electronic and Electrical Engineering and Textile and Knitwear Technology

Senior/Principal Technician

Salary Negotiable up to £9,000 p.a.

A professional with a minimum qualification of HNC/HND is required to join an established project, to apply machine vision to Automated Inspection in the Apparel Industry.

You will be required to set up a rig for inspecting garments, run tests and evaluate its performance under supervision. Substantial programming (in 'C' and 6,800 series assembler) will be required.

The appointment will initially be for one year from 1st September 1988, with the possibility for a second year.

Application form and further details available from the Personnel Office, Leicester Polytechnic, P.O. Box 143, Leicester LE1 9BH. Telephone: (0533) 551551 ext. 2303. Closing date 2nd November 1988.

EQUAL OPPORTUNITIES POLICY Applications are welcome from people regardless of their race, ethnic origin, religion, sex, marital status or disability: disabled applicants will be guaranteed an interview if suitably qualified and or experienced, and supported by a recognised agency e.g. a D.R.O.

Wanted urgently Practical people for the Third World.

Many people want to help the Third World. But relatively few can offer the kind of help wanted most: the handing on of skills and professions which lead to self-reliance.

You could make this priceless contribution by working with VSO.

Current requests include:

- Electronics Instructors ☐
- Studio Electronic Engineer ☐
- Hospital Electronics Engineers ☐
- Lecturers in Power and Communication ☐
- Ultra-sound Technician ☐
- Refrigeration/Radio/TV Engineers ☐
- Electrical Engineers for instruction/installation ☐
- Maintenance and repair Technician ☐

For more details, please complete and return to: Enquiries Unit, VSO, 317 Putney Bridge Road, London, SW15 2PN. Tel. 01-780 1331.

Conditions of work: • Pay based on local rates • Posts are for a minimum of 2 years • You should be without dependants • Many employers will grant leave of absence.

I'm interested. I have the following training/experience:

Name

Address

CALL 01-780 1331 NOW FOR 24hr VSO ENQUIRY SERVICE

EWW/11/88

VSO

Helping the Third World help itself.

30p S.A.E. appreciated — Charity No.313757

AMANUENSIS

HARDWARE/SOFTWARE ENGINEERS

We have a large number of local and national clients requiring the following skills at all levels.

HARDWARE: Contact Peter Dunkley at the office or (0223) 314229 (home).
Microprocessors 68XX series (in particular 6809)
Design of analogue or digital circuitry
Radio/Data communications
CAD and multi/single layer pcb design
Image analysis and video A-D conversion
Networking, X25, DEC, ICL, HP, IBM mainframes and PCs
Computer systems and peripheral maintenance
Project/Development Management
Sales/Marketing/Applications Engineers/Field Service or Test

SOFTWARE: Contact Richard Woodward at the office or (0223) 355480 (home)
Operating Systems: Unix, VMS, MS-DOS
Languages: C, Modula 2, Pascal, Fortran, BCPL
Applications: Oracle, DBaseIII+, CAD/CAM/CAE
Assemblers: 680×D, 80×86, 8085, Z80, 8086
Comms: WANS, LANS, Telecoms.
Any combination of the above skills are in constant demand.

AMANUENSIS EXECUTIVE SERVICES LIMITED
20 NEWMARKET ROAD CAMBRIDGE CB5 8DT ☎ 0223 354978

LAND MOBILE RADIO SALES PERSON

Must be willing to travel throughout the UK, some technical background would be an advantage. Can be based anywhere in the UK.

Good salary/commission and company car.

Please reply with CV to:

COMMUNIQUE

COMMUNIQUE (UK) LTD
COMMUNICATION HOUSE
PURLEY AVENUE
LONDON NW2 1SB

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A·C·E

STATE OF THE ART BROADCAST TELEVISION EQUIPMENT

Following the successful launch of our new product range at the International Broadcast Convention –

WE HAVE OPPORTUNITIES IN:

SYSTEMS TEST ENGINEERING

If you have at least two years' experience in analogue and digital systems test within a broadcast environment –

WE CAN OFFER:

Salaries up to £14,000
5 weeks holiday
Excellent career opportunities.

Please send CV or ring:
Susan White, A.C.E., Hanworth Trading Estate, Hampton Road West, Feltham, Middlesex TW13 6DH. Tel: 01-894 5622

A Carlton Company

683

COMMUNICATIONS TECHNICIAN

Salary on a scale from £7,365 to £8,997 inc. of fringe allowance (pay award pending).

Is required for Police Headquarters, Welwyn Garden City, to assist with the installation and inspection of the Force Communications Equipment. This includes temporary radio aerials, emergency generators, telephones, telex and associated equipment in use throughout the county. You will evaluate and advise on new equipment and will participate in user trials, and will be required to erect temporary radio aerials on the roof of various buildings and large vehicles and therefore should not suffer from vertigo.

Possession of appropriate qualifications would be an advantage, but more importantly you should have relevant experience in communications. A clean driving licence is essential.

A generous relocation package may be available in appropriate circumstances. If you would like to know more, please contact the Personnel Department, Police Headquarters, Stanborough Road, Welwyn Garden City, Herts. Tel: (0707) 331177 ext. 1347.

Closing date: 4th November 1988.
An equal opportunities employer.

London Fire Brigade

The London Fire and Civil Defence Authority is now responsible for fire and emergency planning services in the Greater London area and its responsibilities include the London Fire Brigade

Assistant Radio Officer

£11,916 - £14,544

You would assist the Brigade Radio Officer in maintaining an efficient and effective radio network. You must have proven experience in the installation, repair and maintenance of fixed and mobile VHF radio telephone equipment, and hold a City and Guilds Telecommunications Technicians Certificate or equivalent and have GCE "O" level in mathematics and technical drawing. Good oral and written communications skills are essential.

Application forms and further details from the Recruitment Section on 01-587 4860/4875 (ansaphones), Personnel Department, Room 607, Queensborough House, 12-18 Albert Embankment, London SE1 7SD.

Please quote Ref: FB.210.

Closing date 4th November 1988.

The Authority has a positive equal opportunities policy and welcomes applicants from all sections of the community, particularly those presently under-represented e.g. women, black and ethnic minorities and people with disabilities.

This post is open to job sharing unless otherwise stated.

LFCDA

London Fire & Civil Defence Authority

Electronic Engineers

If you are an experienced, Support, Design, Development, Production, Test, Quality, Project Engineer or Trainee/Graduate, within the following disciplines: Telecomms, Datacomms, Computers, Electronics, Process Control, Medical Scientific Instrumentation or Broadcast, send your CV to Capital Appointments Ltd, Freeport, 74 Willoughby Lane, London N17 0BR or telephone 01-808 3050 for an application form.

CAPITAL

291

SALES ENGINEER

An experienced, self-motivating sales engineer, based in the South East of England, is required to develop sales of OEM equipment to the Sound and Communication industry.

AKG is already well established in this area and the position offers the right person considerable potential for advancement.

Salary negotiable. Company car provided. Reply with CV to,

T. Peacock, AKG Acoustics, Vienna Court, Catteshall Road, Godalming, Surrey GU7 1JG.

AKG acoustics

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Hardware/ Software/ Systems £9,000 - £25,000

As a leading recruitment consultancy we have a wide selection of opportunities for high calibre Design, Development, Systems and supporting staff throughout the U.K. If you have experience in any of the following then you should be talking to us for your next career move.

ARTIFICIAL INTELLIGENCE • IMAGE PROCESSING • ANALOGUE DESIGN • MICRO HARDWARE & SOFTWARE • GUIDED WEAPONS • C • PASCAL • ADA • RF & MICROWAVE • ELECTRO-OPTICS • SIMULATION • C ^{3}I • REAL TIME PROGRAMMING • SYSTEMS ENGINEERING • ACOUSTICS • SONAR • RADAR • SATELLITES • AVIONICS • CONTROL • ANTENNA • VLSI DESIGN

Opportunities exist with National, International and consultancy companies offering excellent salaries and career advancement.

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STS Recruitment

STS Recruitment, Telephone: (0962) 69478 (24hrs), 33 Staple Gardens, Winchester, Hampshire SO23 8SR.

BROADCAST ENGINEERS

Ref: 40/88

Required for work in the Broadcast Engineering and Production Departments of the SSVC, which provides Radio, Television and Training Services for the British Forces and their dependants in the UK and abroad.

Candidates (preferably aged 22-35) should be educated to HND standard in electronic and electrical engineering and have had at least three years' work experience in broadcast or related industries.

The work, often overseas, includes the operation, maintenance and installation of the full range of professional radio and television studio equipment and, in some areas, medium wave and VHF transmitters.

The salary offered is tax free when on overseas service, plus generous overseas allowances and other fringe benefits. There are promotion prospects to higher grades and opportunities for training and transfer to other departments of the SSVC.

For further information and an application form please contact:
Mrs A. R. Sive, Assistant Personnel Manager
Telephone: 02407 4461, ext 221

670

SSVC

The Services Sound and Vision Corporation
Chalfont Grove, Narcot Lane, Chalfont St Peter, Gerrards Cross, Bucks SL9 8TN.

UNIVERSITY DATA CENTRE

THE JOHN RADCLIFFE HOSPITAL

COMPUTER ENGINEER

A Service and Installation Engineer is required to be responsible for the communications network at the University Data Centre. Experience with computer switching systems (PACX), and the service and installation of microcomputers or other digital type equipment is essential. Minimum qualifications: ONC in Electrical and Electronic Engineering. Salary on the Whitley Council MPT II Scale, £8,985-£11,208 (under review) according to age and experience. (The University is an equal opportunity employer). Please telephone or write if you are interested in this vacancy, Oxford 817486.

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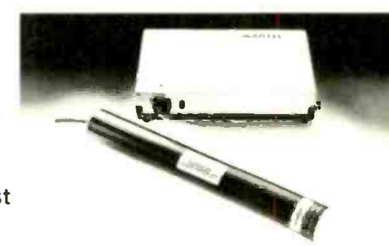

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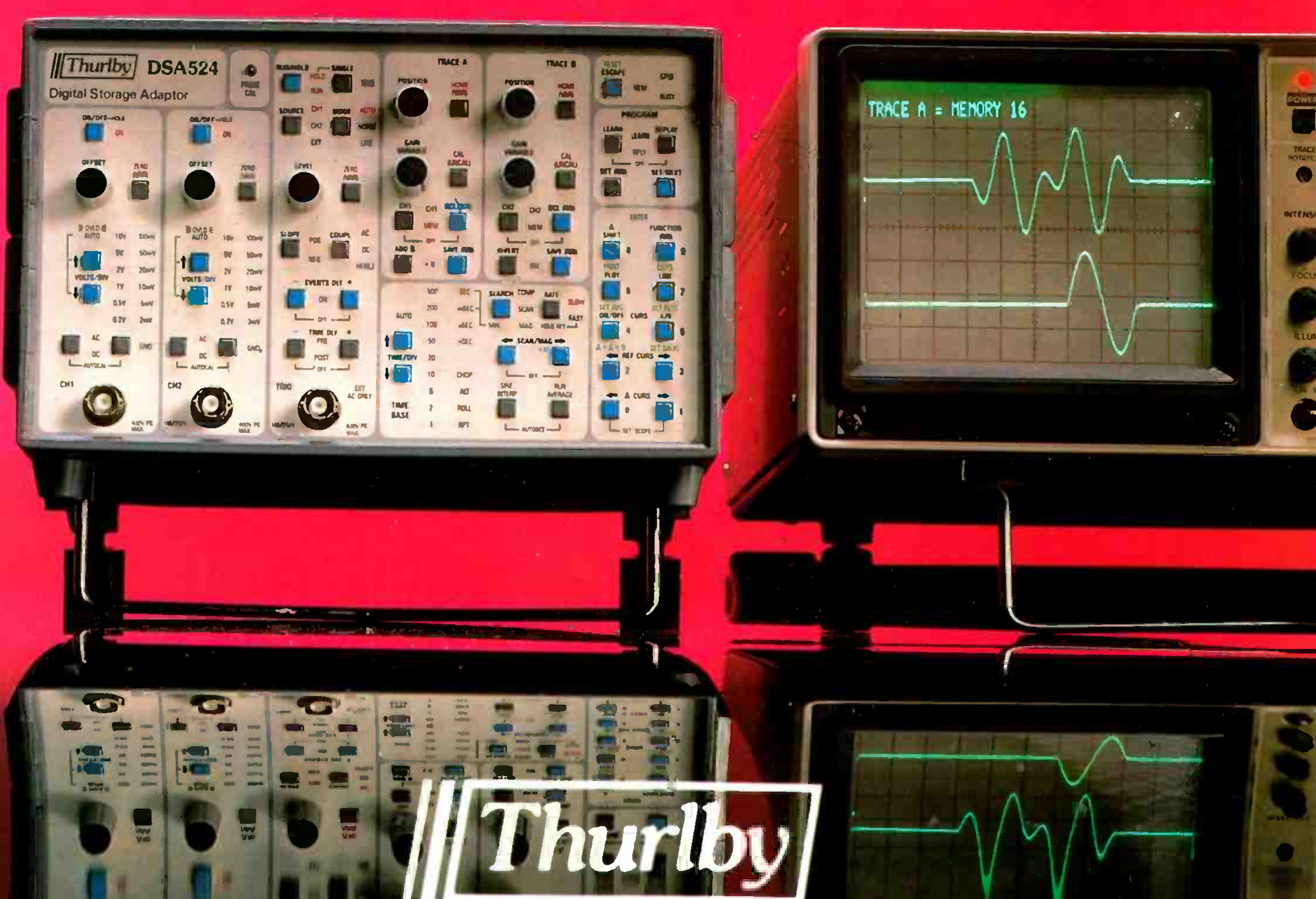

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