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Spectrum analysis techniques

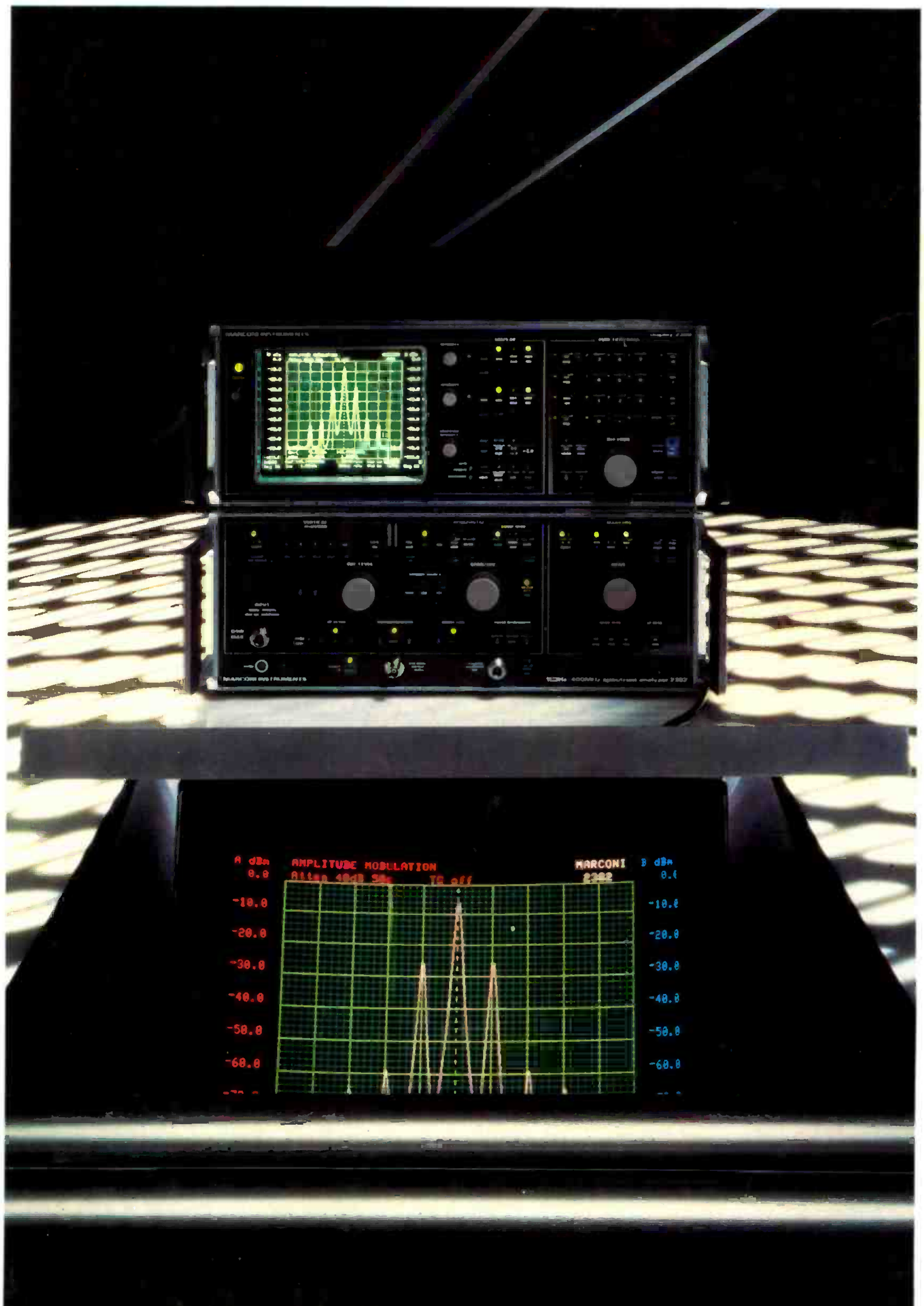
Development of an h.f. receiver

Image acquisition system

Reducing quantizing error

Micro-processor tone decoder

Multi-to-single-element transform



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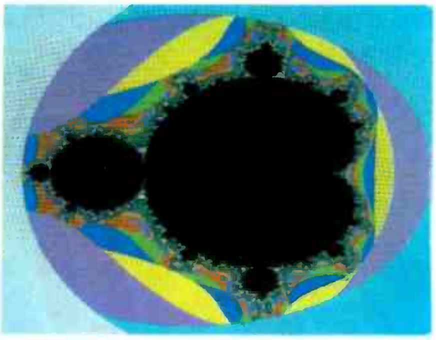

Mandelbrot pattern generated by John Adams' graphics board described on p.368.

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COMMENT

Guest editorial, contributed by Bob Giddy, General Manager, NEC Electronics (UK) Ltd.

Eastern promise

It could be argued that the British industrial machine has not always benefitted from this country's membership of the EEC. For the UK electronics industry to succeed in Europe, the entrenched forces of the other European multi-nationals must give up some of their long-held territory – a gesture they are unlikely to offer voluntarily, particularly in those sectors regulated by local PTTs.

In the US, hawking British electronics is a little like trying to sell sand to the Arabs – many companies have tried it, but have not prospered.

The third largest, and fastest growing, market area is the Pacific basin excluding, for the moment, Japan. Most of this area, particularly Thailand, the Philippines and Taiwan, is part of the US capital investment zone. These countries are cash-rich with low overheads and are already recipients of technology transfers. As such, they are heavily dependent upon United States investment and thus are difficult market areas for British companies.

It is clear that new marketing areas must be sought in which new rules can be applied. We must find markets that are able and willing to absorb our products. If "necessity is the mother of invention," then need is the father of demand.

The UK has a good record for innovation and design. Its reputation for reliable manufacturing has not, until recently, been so good. A partnership with a nation possessing complementary skills to our own would surely be fruitful.

The solutions I proposed to these two problems of finding new markets and partners may seem foolhardy on the surface, but we do have precedents.

As partners, I suggest the Japanese. There are many similarities between the countries and our people. We are islanders and consider ourselves somehow different to continentals. We are, or have been, successful in developing markets. We are monarchies, with consequent political stability. The British are famous (or notorious) for compromise – the Japanese will avoid conflict if at all possible. In both countries, a man's word is reputed to be his bond.

The Japanese have a truly awesome reputation for manufacturing technology. It is claimed and recognized, even by the Japanese, that they are not innovative. Perhaps this is why they modelled their education system upon our own and may be why they so admire and respect British innovation and design skills. The Japanese need to develop strategic friendships: their spectacular successes have brought them problems of trade friction, dumping disputes etc. They are looking for joint-venture partners, not partners of the purely commercial kind, of which the result is just another distributor. The partnership must offer joint benefit, as in the British Leyland/Honda venture, where each partner's skills complemented the others.

As a solution to the problem of a new market area, the Comecon countries have a great deal to offer (I did say it might appear foolhardy). The population of these countries is greater than that of Europe and about the same as that of North America; if China is included, then it is about 2.5 times that of the US. To cultivate the Comecon market would clearly be politically sensitive and sale of some types of equipment would not be permitted. It must be said that it is difficult to see how the sale of a few computers, or even a complete communications system, is going to destabilize the military status quo. However, these equipments, if they are to be marketed successfully, must be free of restrictions on vital components – a very real problem when a product is obtained from US companies.

The germination and growth of such a partnership, targetted at new markets, would take time to establish. To allow for this lead-time, the next generation of equipments should be of overriding interest. In my own field of semiconductors, for example, we should aim at the rapidly evolving field of computers and communications. As before, it will be semiconducting technology that will define the architecture of the equipment. Starting at the very beginning, we should explore areas of interest, be it research, design, manufacturing, or some of each. We should share the reponsibilities and agree the form in which the marketing of these future products is to be carried out. In other words, the two partners must be intrinsically locked together, thus avoiding the usual importer/exporter relationship. The partners would possess complementary skills which would be harnessed and directed towards working to a common goal.

Our two nations are a world apart, but that does mean they are well placed to see both sides.

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Advances in spectrum analysis

Undoubtedly the most versatile item of test equipment used by r.f. and microwave engineers, the modern spectrum analyser provides a host of functions that would have been impossible a few years ago.

STEVE GLEDHILL

The origins of spectrum analysis can be traced back to the work of French mathematician Baron Jean-Baptiste Fourier in the early part of the nineteeth century. He showed that any waveform, however complex, can be generated by adding together sine waves. The converse of this is also true, any complex waveform can be broken down into individual sine waves. Spectrum analysis is thus Fourier analysis, breaking down a signal into its component frequencies.

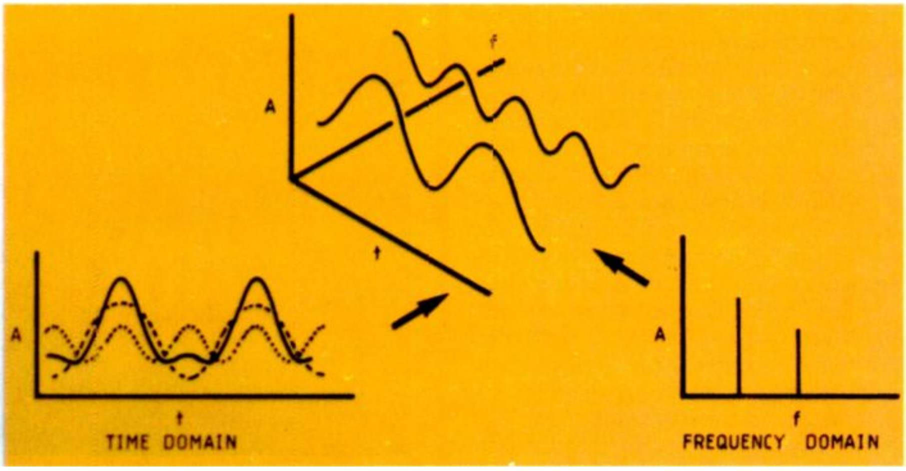
A spectrum analyser is undoubtedly the most versatile item of test equipment used by r.f. and microwave engineers. It not only separates a signal into its component parts but also measures power and frequency, determines distortion, noise and intermodulation, identifies spurious signals, and evaluates modulated signals.

Before studying spectrum analysis further, examine more closely what a spectrum analyser does and compare it with the measurements that can be made by an oscilloscope. Figure 1 shows a three-dimensional graph with three mutually perpendicular axes calibrated in terms of amplitude, frequency and time. The signal shown consists of a sinewave with a second harmonic. The process of signal analysis is to display the components of such a signal. Two-dimensional displays are used, as three-dimensional displays are not practical.

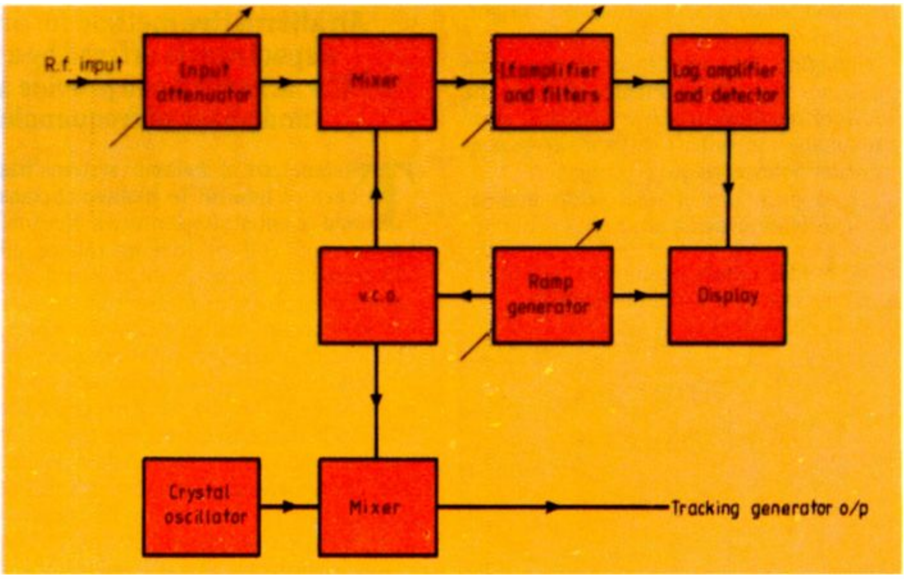
A time-domain display of amplitude versus time is the familiar type of oscilloscope trace. Only a single waveform would be seen when the signal in Fig. 1 is viewed – the waveform with the solid line – but there are in fact two sinusoids present, as shown by the dotted lines. As oscilloscope shows the total waveform and does not therefore separate out the individual components.

Analysing the same signal in the frequency domain, as would be seen on a spectrum analyser, reveals the two separate components. The amplitude and frequency of the fundamental is represented by a single vertical line and the second harmonic by a shorter line, clearly seen to the right of the fundamental.

Oscilloscopes are not so widely used by r.f. and microwave engineers because the frequency range of oscilloscopes is limited; they are hardly ever used at frequencies above 1GHz.



1. Signal analysis, the relationship between frequency, time and amplitude.



2. Heterodyne spectrum analyser block diagram.

The display of amplitude against frequency is much more useful because spurious signals, sidebands and noise can also be detected. Oscilloscopes are not able to isolate such subtleties of complex signals.

A further advantage of a spectrum analyser is its high sensitivity; it can measure very low level signals down to less than $0.1\mu V$ simply because it is selective rather than broad-band. It can also display low-level signals at the same time as high-level signals because logarithmic amplitude scales are used; an oscilloscope, which has a linear vertical scale, does not have this capability.

IMPLEMENTATION

All r.f. and microwave spectrum analysers have the same basic system configuration based around the principle of a swept, tuned, superhet radio receiver. Other techniques are encountered for very low frequency spectrum analysis but all higher frequency instruments have a basic block diagram similar to that shown in Fig.2. In practice the implementation is more complex and there are many more frequency conversion stages.

Before the input signal is applied to the mixer it passes through an input attenuator so that the sensitivity of the instrument can be changed. An input filter is generally also included at this stage to avoid i.f. feed-through. An input amplifier may also be incorporated.

The mixer converts the input signal to a fixed intermediate frequency, at which point a range of band-pass filters can be switched in to change selectivity. Further amplification is included at the i.f. stage to increase sensitivity. Most instruments have a vertical scale calibrated in decibels, and to accomplish this the signal at the i.f. stage is passed through a logarithmic amplifier. The signal is then applied to a detector before being applied to the vertical scale of the display.

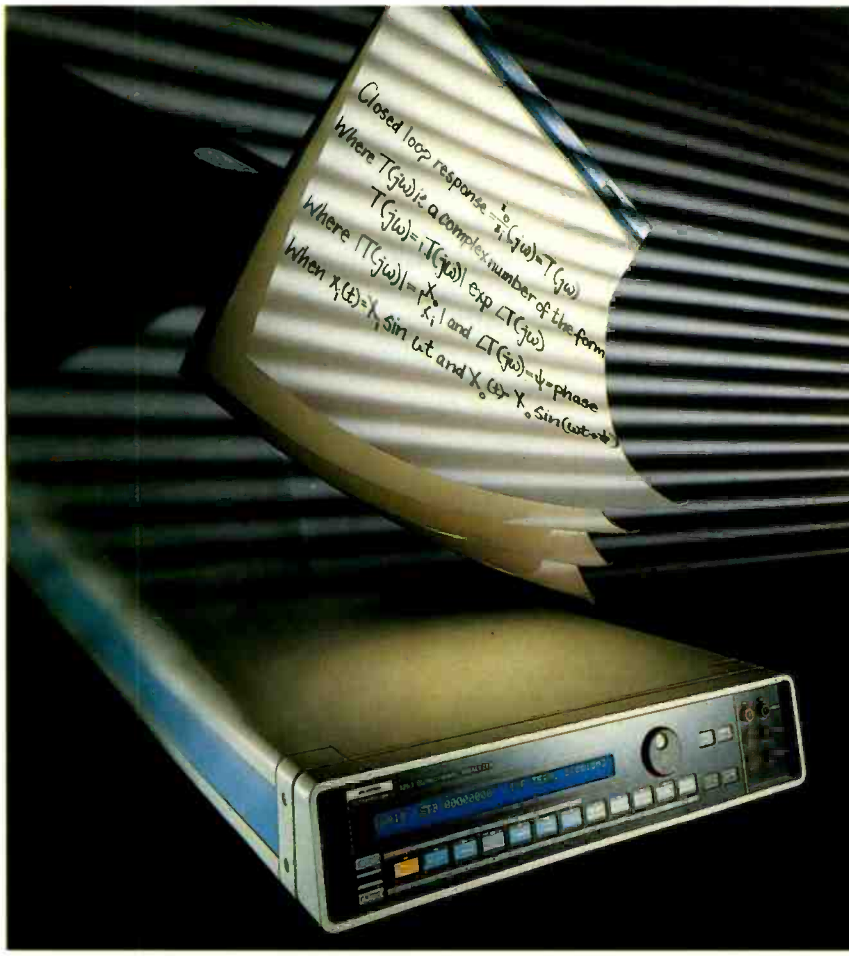
Video filtering may be incorporated after the detector. A low-pass video filter to reduce the statistical variability of displayed noise helps to reveal coherent signals which may otherwise be obscured by noise.

The horizontal input of the display is driven by a variable-amplitude ramp generator also applied to the voltage-controlled oscillator that feeds the mixer. As the ramp voltage is increased the receiver tunes to progressively higher frequencies and the trace on the display moves from left to right. A spectrum display is thus generated.

Changing the amplitude of the ramp generator fed to the oscillator changes the width of spectrum which is analysed, since the voltage-controlled oscillator sweeps over a greater or lesser frequency range.

The applications of a spectrum analyser are greatly increased if a tracking generator

3. A modern high resolution spectrum analyser, Marconi Instruments 2385.



Frequency analysis

An alternative method for analysing the frequencies within a spectrum is offered by a frequency response analyser (f.r.a.) which can provide a precise measurement of gain and phase of frequencies within a given spectrum.

The analysis of dynamic systems has been of interest to mathematicians and scientists for centuries. Newton, Laplace and Volterra, among others, all addressed the problem of relating the observable behaviour of dynamic systems to some form of mathematical descriptor. The origins of the practical approach to dynamic analysis are, however, much more recent. The advent of radar in the 1940s, and the consequent development of the remote-operating weapon delivery system, demanded the provision in quantity of high-accuracy, fast-responding servo-controlled actuation systems. Verification of the performance of such systems under operational conditions was not possible; hence, complex test procedures were devised to determine their acceptability for operational use. The principles of practical dynamic analysis were founded.

In 1954 Solartron, in collaboration with the then Admiralty Research Laboratories at Teddington, developed the first commercially-available general purpose dynamic analysis instrument; the VP250 Resolved Component Analyser, the forerunner of today's frequency response analyser. The instrument is still in use in many major testing laboratories throughout the world. Since then Solartron have carved a niche for themselves and are, they say, the only producers of stand-alone frequency response analysers in the world.

The f.r.a. works rather like a synthesized radio receiver; it can sweep through the frequencies within a range and record the amplitude and phase response of a system. This is displayed (in words and numbers) on the front panel and can also be recorded on a plotter, or transferred to a computer for further analysis and storage.

Two new instruments have been introduced, one of which is aimed at reducing the cost of the analyses; the other increases the frequency range and facilities.

A typical mode of operation involves the use of an internal generator to stimulate the system under test. The waveform frequency can be automatically swept between user-defined limits with a logarithmic spacing of frequency increments. A 'vernier' facility allows the operator to vary the frequency, amplitude or d.c. bias manually in order to find a resonant peak, or a null position and then set an offset for subsequent measurement. A modulator is included for the testing of transducers and systems which require an a.c. carrier.

It is also possible to synchronize the instrument to be triggered by an external signal, such as a tachometer output when testing rotating machinery. The 1253 gain-phase analyser has two input channels with amplifiers which automatically range the signal to ensure the best resolution and optimum signal/noise ratios for the incoming signals. It operates over the frequency range 1mHz to 20kHz. Gain and phase measurement accuracies are 0.1dB and 1.0° respectively. Input signals are digitised to 15-bit resolution using Solartron's patented pulse width technique, which ensures data integrity and provides a stable four-digit display. In common with other instruments in the range, this analyser uses a single-sine correlation analysis technique to provide fast and precise measurements of both amplitude and phase. The correlation technique rejects the harmonic components of a non-linear system response, accurately measuring the fundamental component of a signal even when it is buried in noise. A common analyzer measures the gain and phase response of the system, thus minimizing channel mismatching problems for two-channel measurement. The process inherently rejects harmonics. Noise is removed by integrating the signal over a number of cycles. Each input can be programmed to demodulate signals from systems operating with an a.c. carrier.

The 40-character display provides the menus for setting up the instrument as well as measured data and status information. Data is presented in either polar or Cartesian coordinates along with the appropriate variable (frequency, amplitude, or bias). Results can be calibrated and scaled with a constant or vector. The vector can be a previous measurement and readings can be made relative to a reference point, or systematic errors can be nulled.

Measurement sequences can be stored in program files internally so that regular tests can be repeated. Keyswitch protection of routine measurement sequencies prevents unauthorized alteration. The internal battery-backed memory can also store up to 400 measurements for output to a printer or plotter through the RS232/423 or GPIB interfaces included. The GPIB interface also offers automatic, remote, operation.

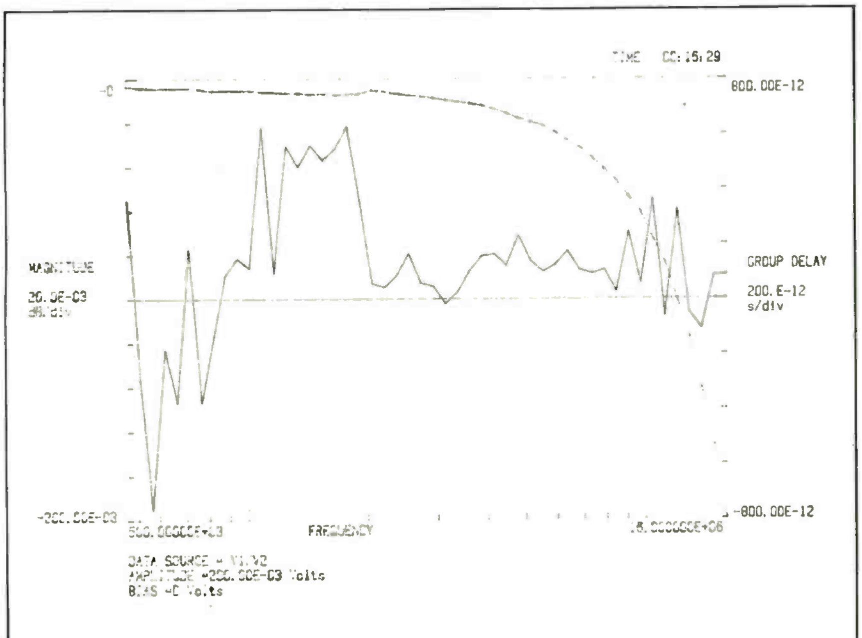
The instrument offers a simplified level of frequency analysis which should find applications in production testing, quality assurance, the testing of goods supplied and in educational establishments.

Solartron hopes that the comparatively low cost of the 1253 (£4800) will open up new markets and make the instrument a general-purpose tool for use by a variety of laboratories and test facilities.

Enhanced frequency range and resolution are offered by the second instrument, the 1255 (£8900), which has all the above facilities and offers a 12-decade frequency range, from 1μHz up to 20MHz and a 130dB dynamic range, making it ideal for testing of video amplifiers, filters, crystals, and communications equipment, and for many applications in electrochemistry, solid state physics and mechanical testing.

The instrument features two independent channels operating in parallel and offering basic gain and phase accuracy of 0.02dB and 0.2° respectively, and a frequency resolution of 1:65,536,000.

In addition to frequency response measurements the 1255 measures group delay and can modify any results using standard arithmetic operators. Up to nine programs can be stored in permanent eprom storage with keyswitch protection.



A general-purpose analyser is the Advantest TR4131 which covers 10kHz to 3.5GHz. Input sensitivity is −116dBm with a dynamic range of over 70dB. Available through Chase Electronics, Tel: 01 878 7748.

is included, especially for r.f. types. A tracking generator provides a swept signal whose instantaneous frequency, is always the same as the input tuned frequency so that the frequency response of components, devices or systems can be measured over a wide dynamic range. Figure 3 shows a modern high, resolution spectrum analyser with built-in tracking generator.

MEASUREMENTS

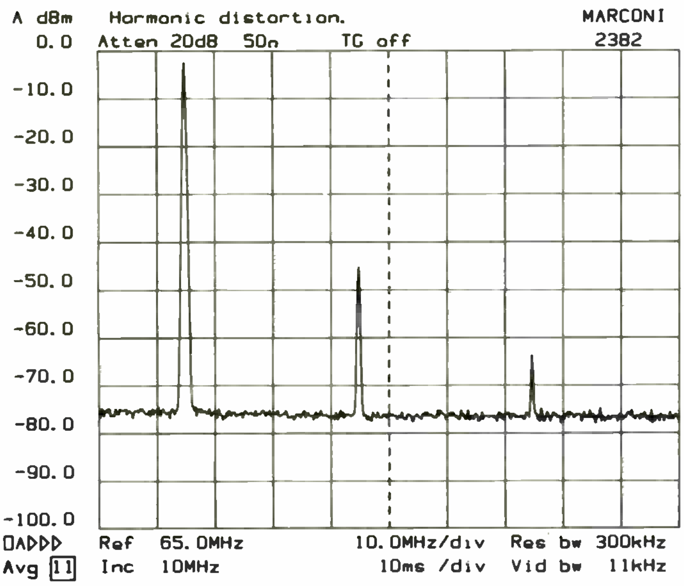
When measuring distortion the harmonics of a signal are displayed individually, as shown in Fig. 4. The amplitude of the fundamental and each of the harmonics can be measured and the total harmonic distortion calculated. This figure, and the other screen displays mentioned in this article, was obtained by connecting a digital plotter to the instrument to obtain a high quality hard copy.

A typical display of frequency modulation is shown in Fig.5, where a 1kHz modulation tone has been applied to a narrowband f.m. transmitter. Spectrum occupancy can be measured from such a display. Bessel zeros can also be determined. A Bessel zero occurs when the amplitude of the carrier or a sideband falls to zero, a crucial measurement for the calibration of f.m. systems. Amplitude modulation depth, distortion and spurious f.m. can all be readily determined.

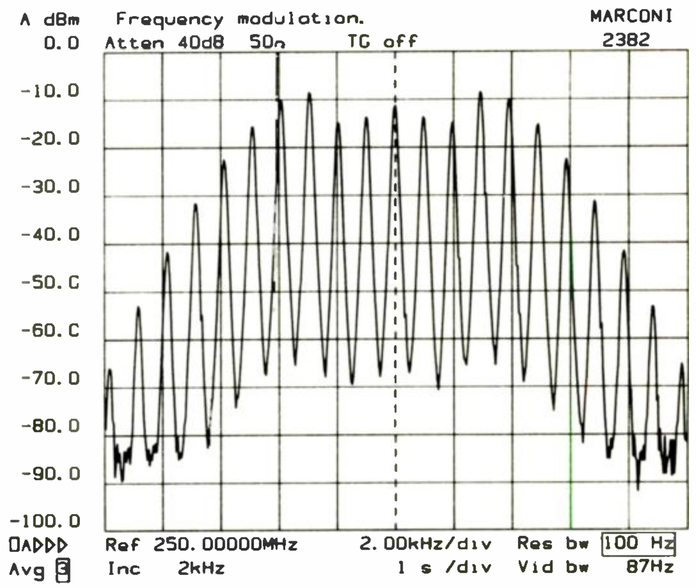
The detection and measurement of spurious signals is of great importance. Synthesizers, for example, can generate a number of unwanted products and these need to be determined. Spurious signals and noise can be generated by all types of electrical and electronic equipment, and interference may be caused if such signals are radiated from the equipment, or if the noise is conducted along mains cables or other connecting cables. Spectrum analysers are widely used to track down such unwanted radiated and conducted signals.

OPERATIONAL ADVANCES

Spectrum analysers have become easier to use over the last 20 years. Earlier instruments were highly complex and the operator had to be skilled and needed a great deal of



4. Typical spectrum analyser display of harmonic distortion.



5. Typical spectrum analyser display of frequency modulation.

patience. It is instructive to study the areas where the operation of spectrum analyzers has been improved in recent designs.

When using a sweeping spectrum analyser it is essential to sweep at the correct speed. Sweeping too fast causes distortion due to group delay variations in the filter system of the analyser such that the displayed signal amplitude and frequency is incorrect. Modern instruments incorporate microprocessor-controlled sweep speed controls so that the instrument always sweeps at the correct speed. Where high resolution is required the sweep speed may need to be as slow as 100 seconds, and it is easy to appreciate the gross errors that would occur if a sweep of 100ms for example was used for such a measurement. Sweep speed is also a function of video bandwidth if video filtering is used after the detector for noise smoothing.

Another area where microprocessor control is now used is in the selection of sensitivity. To increase the sensitivity of an analyser the user can either reduce the r.f. input attenuator or increase the i.f. gain. Reducing the input attenuator may overload the input mixer, which would cause distortion in the instrument. The alternative is to increase the i.f. gain, but this could increase the noise to an unacceptable level. The choice of which control to operate is not immediately obvious and is even more involved when one considers that the optimum noise and distortion trade-off not only changes for different signal levels but also when different bandwidth filters are selected. Automatic optimization of r.f. and i.f. gain is thus an important innovation, since it prevents the operator from inadvertently introducing distortion in the measuring instrument.

Older instruments initially used long persistence tubes to display slow sweeps. Storage tubes were introduced as a better alternative but they are expensive and unsatisfactory for slow sweeps. Digital storage is now used, giving added advantages: for example, a live trace can be compared with a stored one, or two traces can be subtracted. Electronic graticules can also eliminate parallax error. A further advantage of modern digital displays is that control settings can also be shown on the screen for ease of reading and interpretation.

Perhaps the three most significant improvements that the microprocessor has provided are easier front panel operation, synthesized tuning and programmability. Modern instruments can be controlled from a digital keyboard so that set-ups can be rapidly changed. Complete front panel control settings can be held in non-volatile memory. Synthesized tuning is a great benefit because not only can the tuned frequency be entered from a keyboard but the frequency of tuning is referred to a crystal oscillator for increased accuracy and resolution with a reduction of frequency drift. Synthesized tuning has other advantages: sideband noise is now significantly better because of the use of phase-locked oscillators.

Programmability is increasingly important. Modern spectrum analysers can be fully remotely controlled, usually using the General Purpose Interface Bus (GPIB). Screen information can be dumped for further detailed analysis, for archiving purposes or for the determination of the amplitude and frequencies of the individual signals.

SPECIFICATION ADVANCES

Many spectrum analyser users have not necessarily been aware of the amplitude inaccuracy of their instruments. There are many sources of uncertainty in the measurement chain from the input attenuator through to the logarithmic amplifier and display. To make matters worse the values change with temperature and frequency. In an attempt to improve accuracy, screwdriver pre-set controls have been incorporated on the front panel, but even when set correctly uncertainties can exceed ±3 or ±4dB. Without setting up, the uncertainties can be even larger.

Microprocessor control is now used to improve accuracy and screwdriver pre-set controls can be eliminated. The self-calibration routine which is used in the instrument shown in Fig.3. is very comprehensive. Pressing a key on the front panel initiates the process which includes:

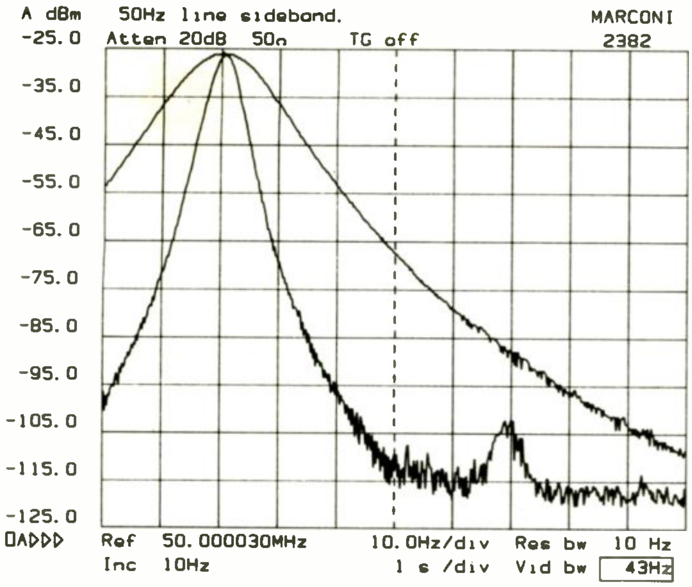
- setting the amplitude and frequency of each of the 12 resolution filters
- measuring and correcting for the attenuation of the r.f. input attenuator steps
- correcting the amplitude response of the system by sweeping through the entire frequency range by routing the built-in precisely levelled tracking generator into the input.

The advantage of this self-calibration technique is that total level accuracy is improved to a remarkable figure of ±1dB for all levels and frequencies and for any span or resolution bandwidth.

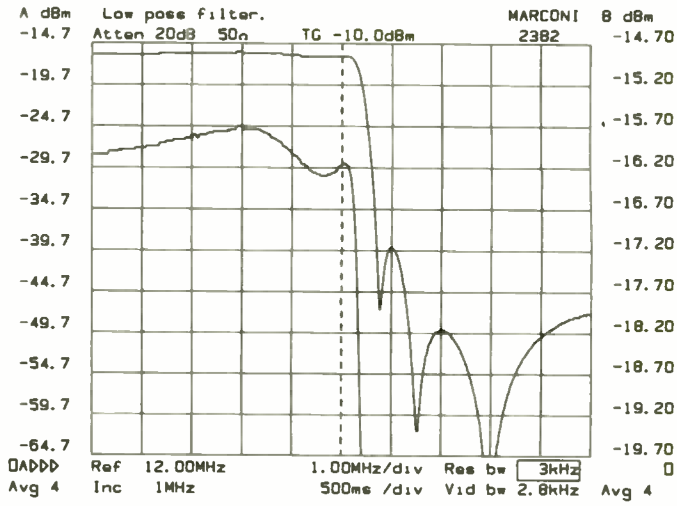
Spectrum analysers are used to assess the purity of oscillators by measuring close-in noise and power supply ripple. When carrying out such close-in measurements, it is essential to use a narrow resolution filter. A filter that is too wide will swamp low level signals close to the carrier; Fig.6 illustrates this. A signal of 50MHz is analyzed with a span of 10Hz/division; two traces are shown. The wider response was taken using a 10Hz resolution bandwidth which, up to now, has been the narrowest available on most spectrum analysers. The narrower response used the 3Hz filter. The 10Hz filter could not resolve the low level 50Hz component but the 3Hz filter clearly shows it.

Improved filter resolution will obviously be a very important consideration when specifying spectrum analysers, but the shape factor of the filter as well as the minimum resolution bandwidth is also critical. The shape factor is the ratio of the 60dB bandwidth to the 3dB bandwidth.

There is a further bonus from having a narrower filter – spurious signals which would otherwise be obscured by the internal noise floor can be seen. A quality spectrum analyser typically has a noise figure of around 20 to 25dB and a 10Hz filter would thus limit the noise floor to typically −135dBm; a 3Hz filter would reduce the noise floor by 5dB to around −140dBm. This



6. A 3Hz filter enables close-in hum sidebands to be measured. The 10Hz filter would have masked this signal.



7. Dual vertical scale used to view simultaneously the overall frequency response of a filter as well as the pass-band ripple.

aspect may be important for measurements such as synthesizer purity and checking for spurs.

Many spectrum analyser users will be surprised to realise that, until recently, a first class instrument could only claim a −70dBc or −80dBc intermodulation performance. Modern mixer technology and careful r.f. design can improve this figure to typically greater than −90dBc. An additional benefit of a modern design is that gain compression can effectively be eliminated so that the operator need not normally worry whether distortion is generated within the instrument.

A notable facility is the ability to display a signal with two different vertical scales at the same time. Adjusting a complex filter for optimum pass-band ripple and maximum out-of-band attenuation can be time consuming because adjustments can affect both characteristics. A dual vertical scale, as illustrated in Fig.7, allows the operator to simultaneously read out of the display store with two vertical resolutions. In this example a 12.4MHz low-pass filter is analysed with one scale of 5dB/division and the other of 0.5dB/division.

SOFTWARE FEATURES

It has been shown how the man-machine interface has been improved and automatic optimization of controls has made measurements more foolproof. Specification points such as accuracy, resolution and intermodulation performance have been improved. A final area of improvement is due to the software features in an instrument. These further improve the man-machine interface and also provide a number of functions to increase efficiency and reduce operator time.

Steerable markers are particularly significant: a control is used to move a dot over the display so that the frequency and amplitude of any chosen point can be determined. A 'delta marker' facility is particularly useful, which displays the difference in amplitude and frequency between two points on the screen to simplify measurements such as harmonic distortion or modulation frequency.

Markers can also be controlled by key strokes from the front panel. Functions known as 'peak find' and 'next peak' enable the operator to direct the marker to the peak signal on the screen and to then identify successively lower amplitude signals. This is particularly valuable when measuring harmonic distortion, since the amplitude of each of the harmonics can be rapidly ascertained; such a facility is essential when used in a remote control application.

The reference level and frequency of tuning of a spectrum analyser can be controlled with markers. Once a marker has identified a signal of interest the operator can simply press 'Marker sets reference level' and 'Marker sets reference frequency' buttons to bring the chosen signal to the top of the screen and to the centre of the screen. This is a great advantage over the previous manual method. Signal tracking, another software feature, can be used to keep a signal of interest at the centre of the screen by re-tuning the instrument if the signal of interest is drifting in frequency.

Often it is necessary to make adjustments to a device in order to meet a particular specification. Many operators have resorted to using a grease pencil to draw limit lines on the screen, but modern software makes this unnecessary, limits can now be entered from the keyboard and the tolerance lines displayed electronically.

Software manipulation of a sweep is also useful. Modern instruments can change the traditional linear frequency display to a logarithmic display to aid interpretation and analysis. Software can also digitally compensate for the loss and frequency response of cables and probes. One technique, which requires a built-in tracking generator, is to connect the cable or probe to the tracking generator output socket and to carry out a frequency sweep and store the response values in a digital memory. When subsequent measurements are made the values in the memory are used to correct the measured value so that a corrected or normalized display is given. A further software facility is A−B, one trace subtracted from another to assist when comparing two similar signals.

The modern spectrum analyser provides a host of functions and a specification that would have been impossible a few years ago. The new generation of instruments are lower in cost than their predecessors because advanced manufacturing techniques and complex automatic testing have reduced costs significantly. A wider range of instruments is available now to cater for higher and lower performance and for different frequency ranges, so that expensive unwanted frequency coverage can be avoided.

S.J. Gledhill, B.Sc., M.I.E.E., is product manager for spectrum analysers with Marconi Instruments.

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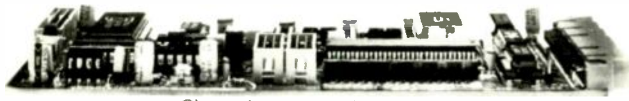
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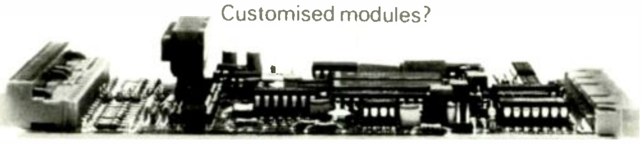
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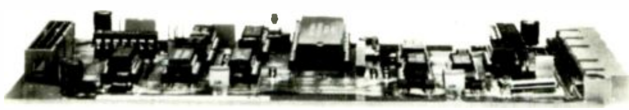
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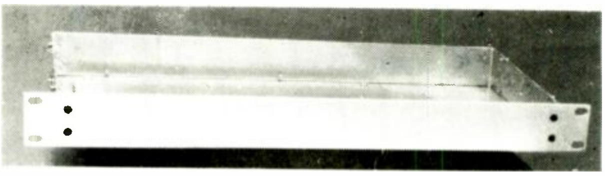

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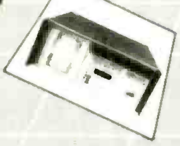

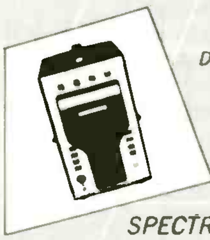

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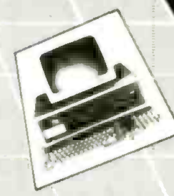

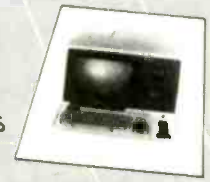

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High-performance colour graphics controller

External hardware is minimal using this new display controller – all the timing and display manipulation is done using programmable registers.

JOHN ADAMS

It is a sign of the times that one computer publication recently justified its use of a less than state-of-the-art computer-produced front cover by explaining that had the latest technology been used, no-one would have recognized the cover as having been computer-generated. The degrees of resolution and hue now possible are quite breath-taking – in cost as well as performance.

Engineers need to strike a balance between cost and performance and in doing so should consider the two other vital parts of the system: the display device and its viewer. Consider the term high-resolution colour graphics. Graphics, of which the display of recognized alphabets is just one form, is the use of patterns to convey information. Colour is a useful adjunct to shape in increasing the information conveyed. High resolution speaks for itself – or does it? High resolution of detailed shape, of colour, or of both.

Our current colour-display medium is the three-gun shadow-mask cathode ray tube where three electron guns are so positioned with respect to a mask that their respective electron beams can only strike certain non-overlapping parts of a screen on the other side of the mask from the guns. This screen is intricately patterned with three different phosphors such that only one type is struck by the beam from one particular gun. One phosphor glows red when struck, one green and one blue. Early tubes had a mosaic pattern consisting of triads of phosphor dots; nowadays it is common for the screen to consist of vertical stripes of phosphor.

Imagine a display of a series of finely spaced red and black vertical lines on such a tube. Provided that the line pitch exceeds that of the red phosphor stripes the display will, from a certain distance, look quite acceptable. When the pitch starts to approach that of the stripes certain lines will vanish as their screen positions will not coincide with a red phosphor stripe. When the pitches are equal you may see all of the lines – or you may see none. It is this phenomenon which limits detail resolution to no less that the pitch of the phosphor stripes.

In practice, it is unlikely that the sense of vertical in terms of image creation will line up exactly with the stripes, reducing resolution even further. This said, it is amazing how much interpolation the brain can carry out, particularly with a text display. With the proviso that it is interpolation and not certainty which is augmenting the image, resolutions down to the stripe pitch are worth experimenting with.

Standard, medium and high-resolution tubes have stripe pitches of 0.6, 0.4 and 0.3mm respectively, although the terms standard, medium and high-resolution are often abused in literature describing colour monitors. For a standard 14in tube with a 10% border around the display area, this corresponds to approximately 420 horizontal phosphor elements. High resolution tubes will naturally give better resolution but at a cost, not just in the tube itself, but in the entire display device from deflection linearity and focussing to shielding from external magnetic fields.

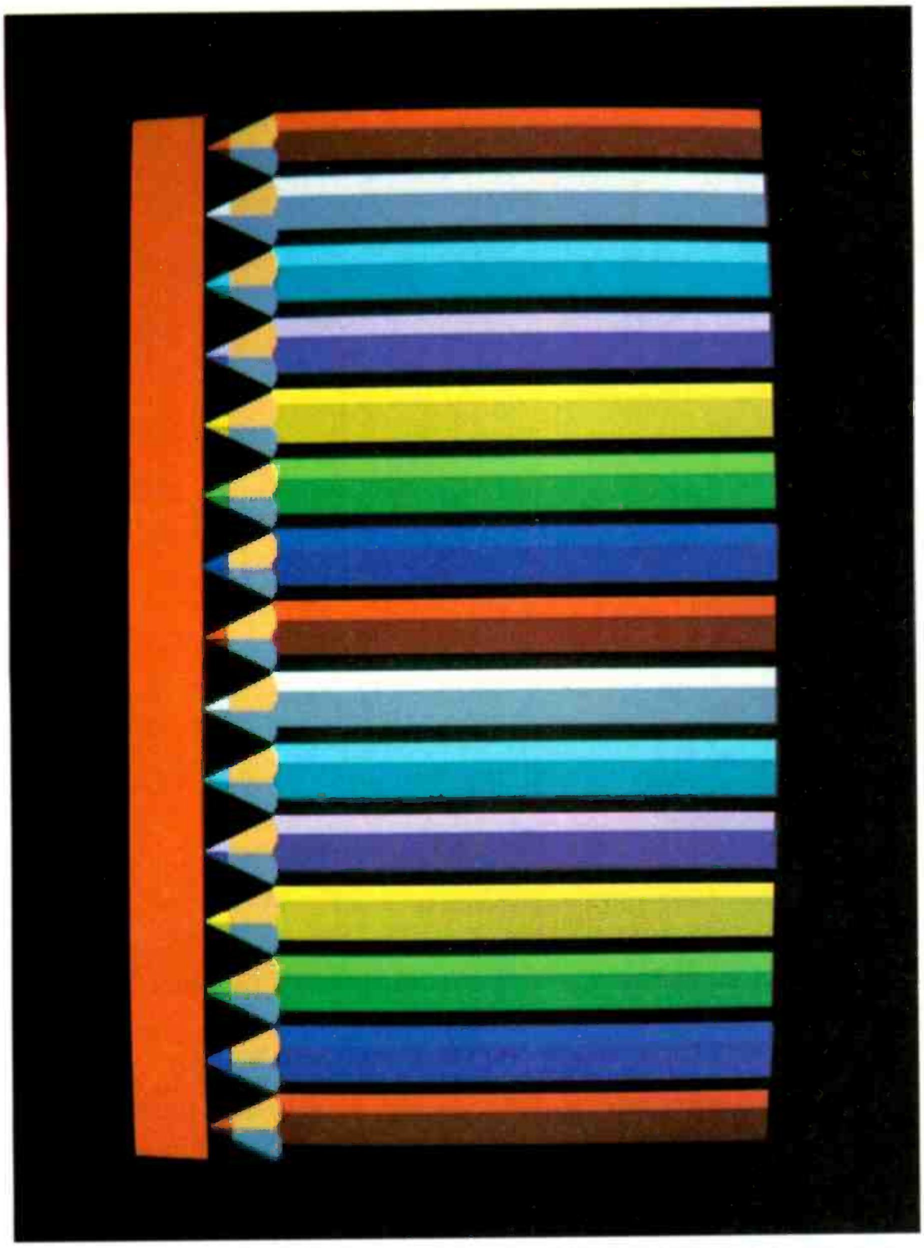
Monochrome monitors consist of a single electron gun capable of striking any part of a screen coated with a single phosphor. Detail resolution is primarily limited by the focussing ability of the display but monochrome monitors typically provide resolution as good as that of the high-resolution colour display at an order of magnitude lower cost. Some redress can be made for the loss of colour by the use of varying luminosity.

No mention has yet been made of bandwidth. Whichever system is chosen, it must have a video bandwidth which is at least equal to the pel clock rate.

There is then, a decision to be made between resolution, the advantage of colour over shading, and cost. Once these factors are decided a choice of monitor must be made. Since this design generates separate sync. and video, a monitor with these attri-

SPECIFICATIONS

Resolution	Up to 640 (horizontal) by 512 (vertical) dots.
Video memory	512Kbyte d-ram.
Video format	Analogue RGBI (Insert) with 16 levels per channel, adjustable step size. – 4-bit digital data representing 2 or 4-bit pel data. – 8-bit multiplexed data representing 8-bit pel data. – 4-bit data representing one of the colour levels generated by pel data, the specific colour selected being software programmable.
Sync. format	Programmable video display window. Combined or separate syncs. Programmable period, pulse width and interlace. Can be programmed as master or slave for sync. purposes.
Display format	Up to 16 objects simultaneously displayed. Display window for each object can be defined to one pel vertically and to one or two pels horizontally depending on display mode. Objects may be split horizontally and can be scrolled smoothly in either direction. A drawing priority determines which objects are placed in front of others. Objects may have opaque or transparent backgrounds.
Object types	– Bit-mapped objects may have two, four or eight bits of video memory representing each pel depending on the colour range required. Attributes available are flash (programmable rate and duty cycle) and background transparency. – Character objects may access up to four programmable character sets each with character matrices up to 16 dots high and with widths of six, eight or twelve dots, or with dot widths individually programmable in two-dot steps for proportional text spacing. Basic attributes are flash and background transparency (as for bit-mapped), one of two character sets and choice from four colours for foreground and background. Additionally, in full-attribute mode, character-set bank, foreground and background transparency, double width, double height, conceal/reveal, colour invert, flash, underline and full colour definition of both foreground and background are programmable on a character basis.
Colour/grey scale	4 from 4096, 16 from 4096 or 256 from 256 colours or grey levels, the third mode requiring external colour-generating hardware.
Pixel rate	Up to 25MHz, depending on chip version.



These pencils are a simple image created using 4bit/pel in bit-mapped mode and a combined system and video clock of 10MHz.

butes is preferable. For colour this means a monitor with RGB and separate sync. inputs. For monochrome displays it is relatively easy to combine the signals into composite video but the display is usually better with separate signals. Next, the right type of input response should be chosen.

There are three types of response: non-linear (often called t.t.l.) inputs, non-linear with an intensity control (RGBI) and analogue. Non-linear systems are designed to be driven digitally and thus only work at one level of intensity for each of the three primary colours. They are simple and are common in low-cost systems. The RGBI type is an advance in that it has a fourth digital input which steps display luminance to give two intensities for each primary colour. This maintains the on-off nature of the colour inputs but it provides 16 rather than 8 colours. IBM colour systems use RGBI. The design to be described can produce 4096 distinct colours by the use of analogue signals, and so an analogue monitor should be chosen.

Finally the line-scan frequency has to be chosen. Normally line-scan frequency is 15.625kHz but this low frequency has the disadvantage that at a 50Hz frame rate, only about 290 displayable scan lines are drawn in the frame period, limiting the vertical resolution. To counter this, monitors with line-scan frequencies as high as 60kHz can now be obtained, giving a vertical resolution of 1000 elements. The disadvantage of these higher performance displays is that the shorter line period leaves less time for pel construction and thus demands a higher performance from the driving circuits.

This design can produce a display of up to 512 lines, for which a line-scan frequency of 31kHz would be suitable for a 50Hz-refresh display. At this line-scan frequency, each line lasts approximately 33μs. A scan line comprising a maximum of 640 horizontal picture elements, or pels, can be produced by this system in 25.6μs, which is well within the line-scan period.

Note that it is dangerous to attempt to operate a display at a line-scan frequency different from that for which it was designed. In order to minimize the drive power required most scanning systems are resonant and any significant shift away from that resonant point increases the load on the driving elements, resulting in their premature failure.

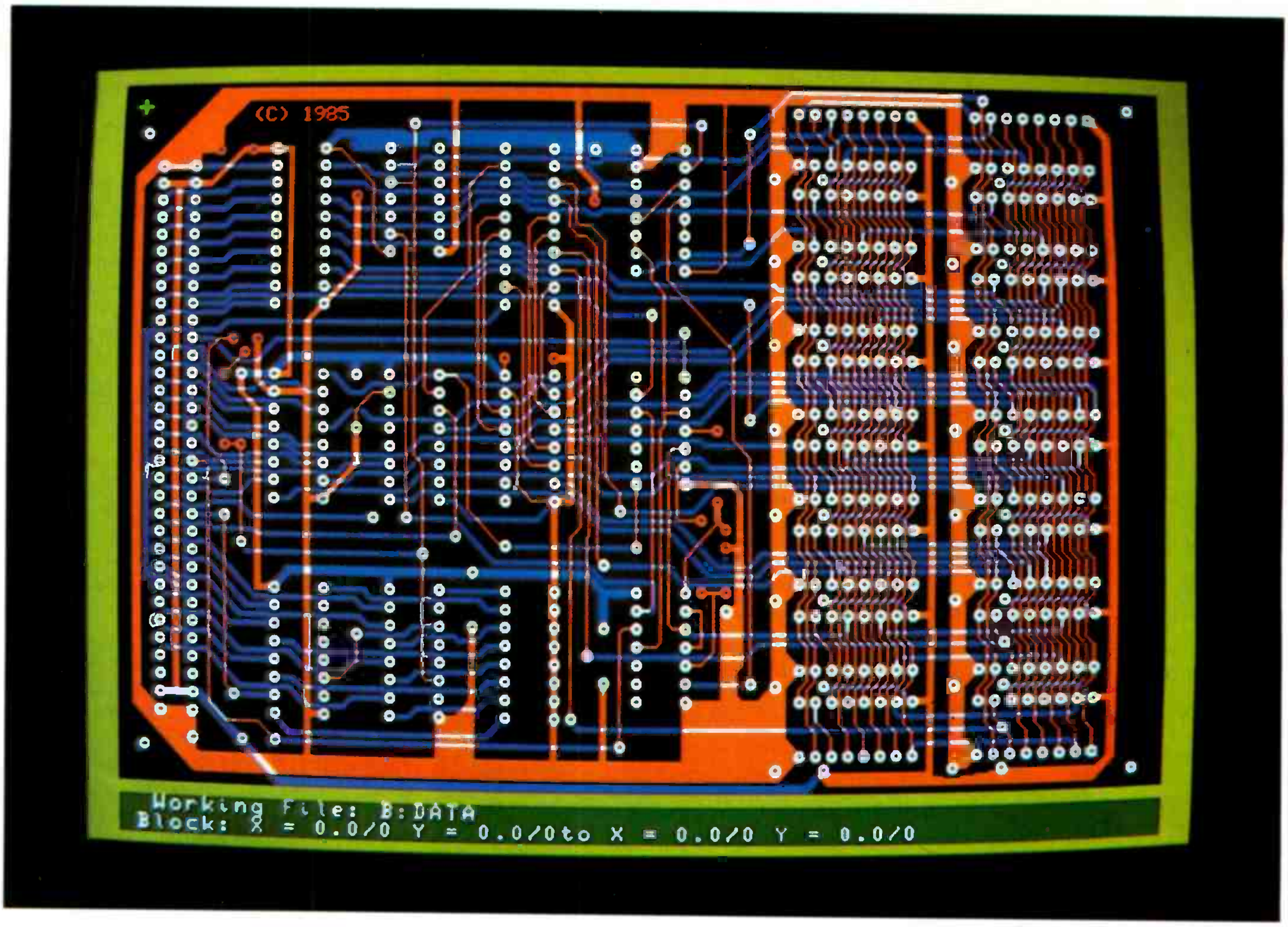
Some systems offer extra vertical resolution by using interlaced sync. and video techniques. There is a minimum frame rate, about 40Hz, below which persistence of vision fails to fill the gap between one viewed frame and the next. To avoid the appearance of flicker and yet permit a slower frame rate and thus more vertical scan lines, interlacing makes use of an optical illusion to make a real screen update frequency appear to be twice what it actually is. It does this by drawing all of the odd lines of the display, then the even ones alternately – and it works, provided that the odd and even images are similar.

Similar odd and even images occur in television but not in computer displays, particularly of text. To get the greater detail in a computer display odd and even parts of a bigger video memory are accessed when constructing the interlaced images and so there is no guarantee that the odd part will bear any relation to the even one. Such displays flicker which is very wearing, but worse, the flicker varies according to how different the odd and even parts are; characters E, F and s flicker far more than l, ! and /.

An ideal colour display is a monitor capable of operating with a range of line frequencies such as the NEC JC-1401P3A used for the photographs in these artiles. This monitor's screen is based upon triads of dots rather than stripes and its dot pitch is 0.31mm. Signal inputs can be t.t.l. RGB, t.t.l. RGBI or analogue and scanning and synchronizing to any line-scan frequency in the range 15.5-35kHz is automatic. This permits non-flickering displays of up to 800 by 560 picture elements.

Having chosen a satisfactory display format the criteria for the display controller must be established. The number of components should be minimal and the circuits used should be off-the-shelf, yet provide the flexibility normally associated with custom-design chips. A new integrated circuit with these facilities is the Matra video display and storage device (VSDD), the 82716. In its simplest configuration this is the nearest thing yet to a one-chip colour-graphics system needing only the addition of a block of dynamic memory to form a complete unit with a microprocessor bus interface at one end and a sync. and analogue or digital RGBI interface at the other. Add to this the virtually complete software programmability of the device and the ideal is approached.

Display controllers have a block of memory storing bit patterns corresponding to the patterns to be displayed. Early controllers were little more than address generators, scanning sequentially through the memory and producing synchronizing pulses for every display row and screen of memory locations scanned. These pulses would synchronize the display with accessing of data in memory. Separate circuitry, if necessary, would convert the bytes of data from the memory into a bit stream for turning the c.r.t. beam on and off.



A typical example of the application of the VSDD is my p.c.b. design software using a display of 384 by 288 pels. There are four objects in use here. The main object is a two bit-per-pel graphics object of 40Kbytes in size representing the two layout sides. As horizontal definition is to more than 320 pels the high-resolution mode is in use, meaning that the minimum horizontal scroll is two pels (see Object descriptor, Word 1).

So that the drawing cursor can be placed over any pel in the layout window, two cursor windows are defined. Both have the attribute of blink and of background transparency (so that their window outlines do not obscure layout detail). bit the actual cross in the window is displaced one pel horizontally in one of the windows.

Software selects which cursor is used depending upon whether the horizontal cursor coordinate is odd or even, so even though the layout scrolls in jumps of two pels, the cursor may be made to move in steps of one. The fourth window has simple-character attributes, is six pels-per-character wide and uses a character generator with a six-by-nine dot aspect. It reports program status to the user. Scrolling is instantaneous as it only involves rewriting a table parameter, not a complete window. Likewise, switching active layout side is immediate. With a processor running at full speed this image occupies about 25% of the available construction time.

A very popular device of this sort is the 6845. This device is fully programmable in terms of memory size scanned, display elements per displayed line and displayed lines per screen. As well as simple scanning of memory the 6845 can be made to subdivide its address bus into three sections so that the codes being fetched from memory can be translated into one of several possible bit patterns depending upon the value held in the middle addressing section. By this means the memory codes may be interpreted as characters, one character code generating a sequence of complex but predefined bit patterns stored in a character generator.

When predefined patterns such as the Ascii character set are being used as described above, memory requirement is quite modest; a 2Kbyte ram and 2Kbyte character-generator rom are adequate. When random graphic plotting is required then there must be at least a one-for-one relationship between bits in memory and picture elements displayed. If one bit represents a pel then that pel is either on or off, precluding the use of colour or shade. Two bits make possibile four colours and shades, four bits provide 16, etc. A display of 432-by-288 pels with four bits per pel requires almost 64Kbyte of memory.

Two schools of thought have developed over how to handle such large amounts of memory. One technique, as exemplified in the NEC7220, is to have a red 'plane' of memory, a 'green' plane, a 'blue' plane and perhaps an attribute 'plane', the latter indicating whether the element is to flash, to be bold, to be colour-inverted etc. With one bit per plane, i.e. four bits per pel, eight colours plus one attribute of 16 colours (if the attribute is bold) can be achieved.

There is a lack of flexibility in this approach as the number of planes will have to match the highest number of bits-per-pel that the system will be called on to provide, wasting memory in other modes. Newer systems tend to use one block of memory as continuous display data, each pel being represented by n sequential bits which are fetched and then translated into one of 2^n colour codes.

Neither technique appears to work well when graphics and characters are mixed since to easily fit characters into a sequentially-organized graphics memory the cell size for the character has to be binarily related. In practice, this means an eight-by-eight-dot matrix, resulting in the squat characters seen in most lower-cost colour systems. Interspersing a character generator rom is also a technical problem. Most systems solve this by not storing the character code but expanding it into its graphic equivalent before sending it to video memory. This takes a lot of time, although not as long as is taken to work out which character is actually at a screen location!

The VSDD solves this, and several other problems, by having just one block of memory and letting the host computer instruct the VSDD as to which areas are to be used for graphic display, which for character display and which for character generator storage. The device is highly programmable; almost all of its own registers are stored in this memory array. These processor-like regis-

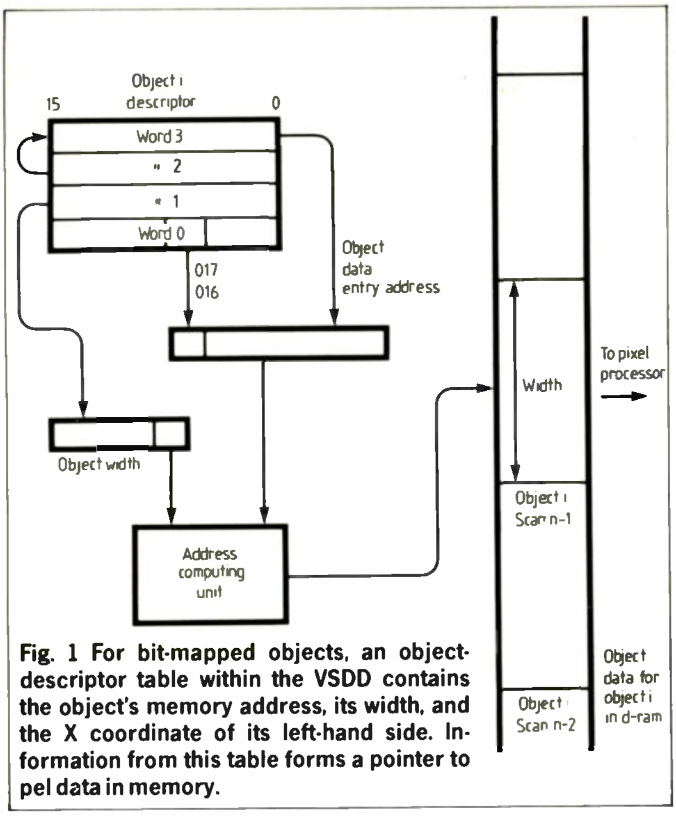


Fig. 1 For bit-mapped objects, an object-descriptor table within the VSDD contains the object's memory address, its width, and the X coordinate of its left-hand side. Information from this table forms a pointer to pel data in memory.

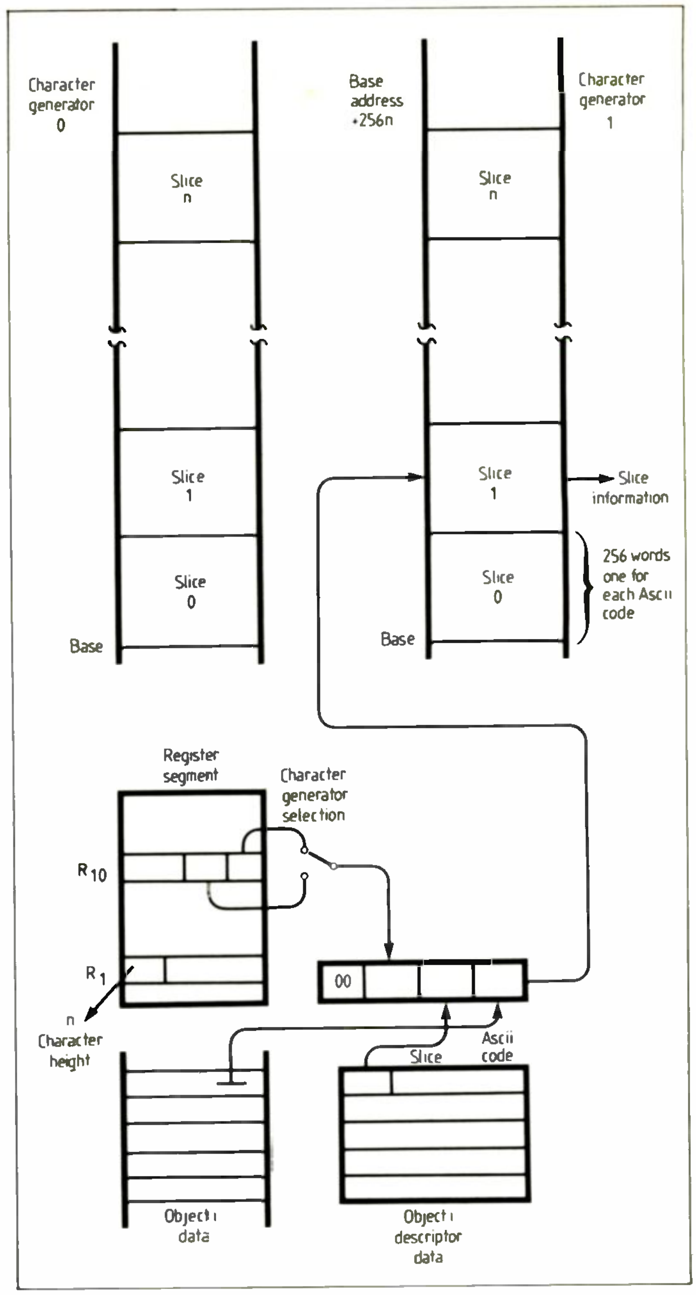
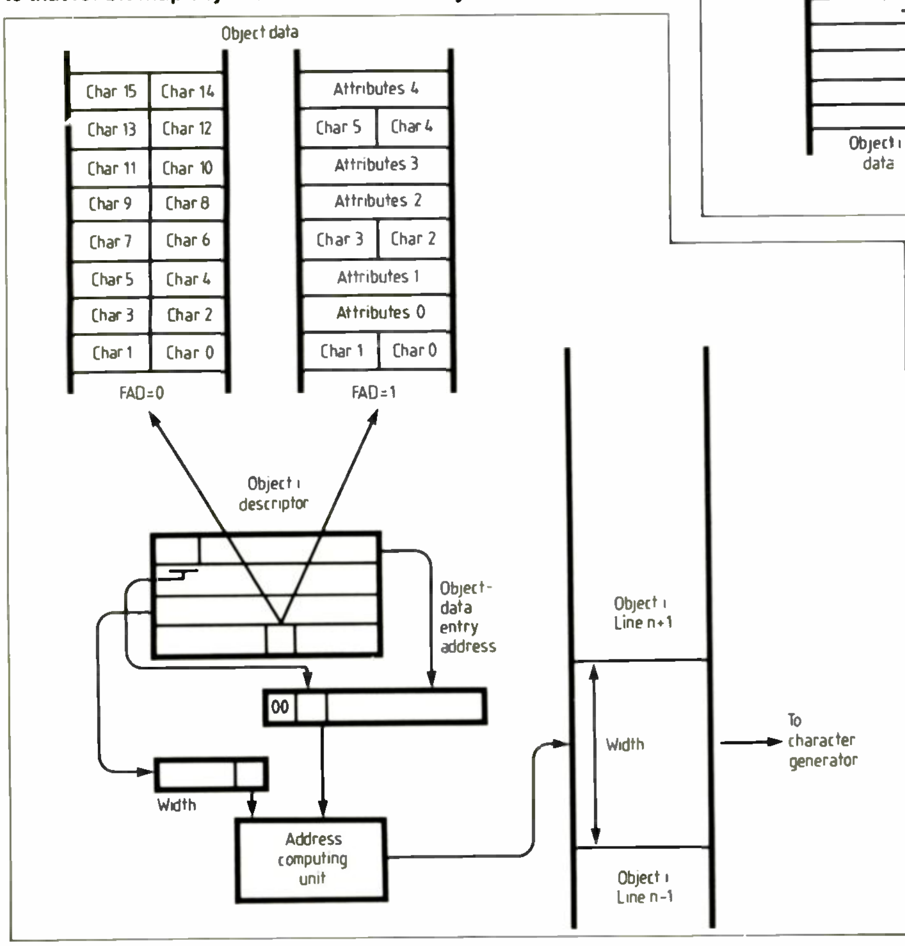


Fig.3 With bit-map objects, information from the object descriptor table is fed directly into a buffer whereas with character-type objects, Ascil data from video memory is combined with the slice number and selected character-generator base address. This combined information is used to extract and pass pel data from the character generator to the video buffer.

Fig.2 Information on character-type objects is held in a similar way to that for bit-map objects but used differently.



ters indicate the memory positions of up to 16 'objects' and up to four character generators each containing up to 256 characters. Timing parameters, object descriptor tables, a colour look-up table and an access table are also contained in these registers.

An object descriptor contains the 'O' address of the object in the video memory, the object width and the X coordinate of the left-hand side of the object. When describing a bit-mapped object, it also includes the number of bits per pel (2, 4 or 8), the quarter of the colour look-up table to be used when using two bits-per-pel and the object blink and transparency attributes. When describing a character object, it also includes the starting slice of character dot row (to permit smooth scrolling), the character width (6, 8, 12, 16 dots or proportional spacing), character generator to be used, colour and mode.

In full attribute mode, where three bytes instead of one are used to store information about each character, extra attributes are foreground and background colours, character height, character width, underlining blinking, colour inversion, conceal/reveal (as in Teletext), alternate character set and transparency.

Figure 1 shows how parameters from the object descriptor table are used to form a pointer to the pel data in video memory. Character objects use a similar process as shown in Fig. 2. In the former case, information accessed is fed directly into a video buffer. For character objects the Ascii value drawn from the video memory is combined with the slice number and selected character-generator base address; pel data is then extracted and passed from the character generator to the video buffer, Fig. 3.

The access table is a general map of the screen consisting of as many words as there are to be displayed lines. Within each word, each of the 16 bits can be programmed to turn the display of an object on or off; a set bit results in toggling of the current display status for that object.

A pointer to the currently-displayed line is used to get the word into the VSDD. From there the word can be combined with the base address of the object descriptor table to form a pointer to the specific object's descriptors, Fig. 4. By modifying the access table and the object's X coordinate, objects may be shifted around the screen or displayed in sections down the screen as required – in tune with the window concept.

The objects have a drawing hierarchy so objects with a high priority overwrite those with a low priority when they are both mapped to appear on the same part of the display screen. This priority can be easily changed to bring objects to the foreground. It is also possible to define one of an object's colours as 'transparent' so that a background object can still be seen in the background.

Once programmed, the VSDD takes full responsibility for the construction of display of up to 640-by-512 pels as well as arbitrating requests for video-memory access from the host system. There is a limit to how complex an image can be formed which is a function of processor clock speed, display-line period, number of objects, object type (character or graphic) and number of host requests. The VSDD can be programmed to only allow a certain number of host high-priority access per line-scan and has a 'construction-time overflow' output which can be used to signal to the host system that the VSDD is getting into difficulties.

For highly complex systems it is possible to literally piggyback one VSDD and its memory onto another and program them to construct each alternate line, improving potential performance several-fold. Using one VSDD, maximum processor speed, two bits per pel, eight objects and a 432-by-288-line display, approximately 2200 pels can be constructed on a line. This could be five full-size objects and three 8-pel ones (cursors for example).

Complexity depends on the image type since the VSDD is designed to make use of d-ram page mode. Using page mode, a number of adjacent memory loctions – 512 for a 256Kbit device – can be accessed more quickly than using normal d-ram accesses; 512 adjacent locations represent 4096 sequential pels. This mode can be used with bit-mapped images since the pel data is indeed sequential in memory but it does not work with character displays since the d-ram is constantly switching between character and character-generator accesses. In practice, this limits the construction capability to scan lines containing no more than about 110 plain or 96 full-attribute characters.

To the host the VSDD looks like two memory windows, the VSDD acting as the access arbitrator. The register window is to a 32-byte segment of the video memory which the VSDD uses to store 16 control words. These control words define the type and size of memory being used for display storage, the locations of the various tables and character generators in the memory, system

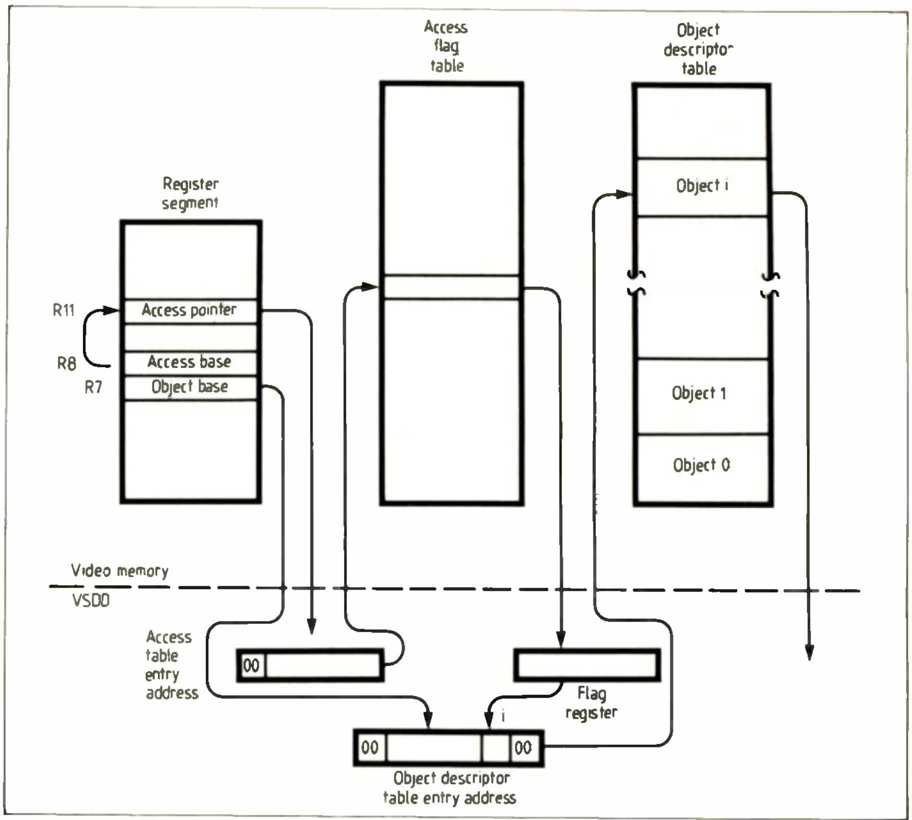
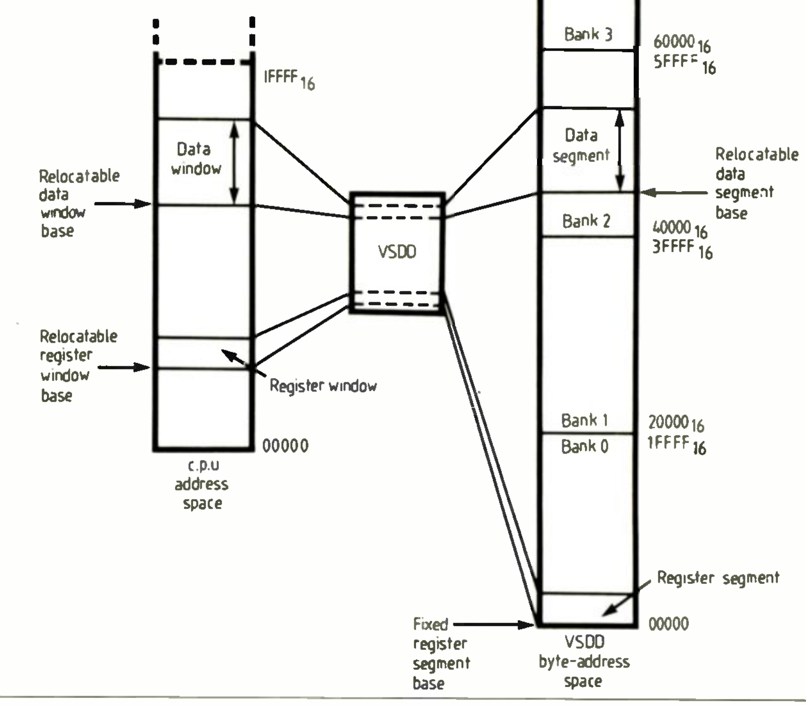


Fig.4 Addressing access and object descriptor tables. By modifying the access table and the object's X coordinate, objects may be shifted around the screen or displayed in sections down the screen.

Fig.5 Memory mapping. To the host, VSDD looks like two memory windows – a fixed one for registers and a variable one for data. Immediately after reset, the register window appears at 400 to 41F in the host memory map.



parameters such as character dot height, interlace, priority access count etc., size and mapping of the video memory window and the mapping of the register segment.

Size of the data window varies. Immediately after a hardware reset the register window appears at addresses 400_{16} to 416_{16} in the host memory map. This is the only unprogrammable feature of the VSDD; where the data window appears in a 17-bit address range of the host memory map, where it appears in the video memory and size of the data window are all programmable. This mapping is process is illustrated in Fig. 5.

As access to the video memory has to be arbitrated the host may not get immediate access to it. Two techniques are provided to cope with this non-random access. An active-high READY, active-low WAIT signal, RDY, is provided for directly driving processors which can extend bus cycles by testing the state of a RDY or WAIT input pin. For those that do not, and must thus execute fixed-length bus transactions, it is possible to program the VSDD to work in pipeline mode. In this mode the current read/write cycle reads or writes to the video memory address used in the previous cycle, the current address being stored and then used during the next cycle.

What actually happens in the cycle before the current one is that, as soon as is possible, the VSDD reads that location and stores the value. If the current cycle is a read then this data is immediately available to the host. If it is a write cycle then the input data is immediately stored by the VSDD and written to video memory as soon as possible. This is followed by a read-and-store of the data at the address used in the current cycle, ready for the next one.

It would, of course, still be possible to overrun the VSDD in this mode. Leaving twenty VSDD video system clock cycles between one pipeline access and the next will make sure that this does not occur. One bonus of not using the RDY signal is that it can be programmed to act as a free-access indicator. This signal is active when the VSDD is idling, i.e. it has finished preparing the next scan line of data, and thus tells the processor that it can have full access to the video memory.

SPECIAL OFFER

A limited number of VSDD display controllers is being made available to EWW readers at a special fully-inclusive price of £39.86 as opposed to the normal one-off price around £64.

Theses 12MHz p.l.c.c. devices, with the full part number S82716.3, can be obtained by sending a cheque made payable to Thame Components to Jacqueline Cole, Thame Components Ltd, Thame Park Road, Thame, Oxon OX9 3XD. The G82716.3 in a pin-grid array package is also available at £45.80 fully inclusive. This offer is limited to one device per reader.

Programming and hardware implementation of the VSDD graphics controller are subjects of the next article. A complete circuit interfacing to 64180 (Z80-like) signals at one end and an RGB monitor at the other will be given, as will p.c.b. details.

Increased resolution from an a-to-d converter

'Dither' and an averaging process provide interpolation between steps

R. A. BECK

Eight-bit A to D converters are common and very convenient to use with eight-bit data buses. However, there are times when it is either beneficial or necessary to achieve a higher resolution than can be given directly from the converter. The methods described below, in some circumstances, enable a higher bit resolution to be achieved than is directly readable from the converter.

METHOD

To understand how the method works, it is first necessary to appreciate what is meant by a converter with a particular number of bits, and what are the implications.

An analogue-to-digital converter, as the name implies, converts an analogue signal (which therefore has an infinite number of discrete levels) to a digital number within a particular range: it has a quantizing effect. The number of different levels which can be recognized by the a-to-d converter depends on the type of the device, but for the sake of example, assume that it is an eight-bit a-to-d converter. There are therefore, 2^8 discrete levels, which is 256. If the a-to-d converter digitizes voltages in the range 0 to 2.56 volts, each quantized step is 2.56/256 = 10mV. This means that in digitizing a direct voltage, a different number is produced from the converter for every 10mV change in level.

One can imagine the converter as being a 256-rung step-ladder lying down on the ground: each rung of the ladder represents a quantization level change. The voltage that the 'ladder' is trying to quantize can be imagined as stick being placed between the rungs of the ladder. If the stick is exactly on a rung, the number given from the converter at successive conversions will rapidly change back and forth between the two levels. If this happens one knows exactly where the stick is and therefore exactly what the voltage is. If the stick now moves between a pair of rungs, a single, constant number will be given out from the a-to-d converter representing between which pair rungs the stick lies. The voltage, at an instant, cannot be read more accurately than the width of the rungs, and in this case, it is 10mV.

If one assumes that the rungs are equally spaced, one can read where the stick is within a pair of rungs provided one is able to condition the stick movement. The method

Actual temperature	Measured (no added wave)	Measured (added wave)	Error	Time delay
0.000	0.118	-0.004	-0.004	0.486
0.100	0.118	0.104	0.004	0.043
0.200	0.118	0.199	-0.001	0.121
0.300	0.118	0.306	0.006	0.374
0.400	0.549	0.401	0.001	0.358
0.500	0.549	0.502	0.002	0.530
0.600	0.549	0.603	0.003	0.168
0.700	0.549	0.697	-0.003	0.304
0.800	0.980	0.792	-0.008	0.495
0.900	0.980	0.900	-0.000	0.358
1.000	0.980	1.007	0.007	0.166
1.100	0.980	1.095	-0.005	0.322
1.200	1.412	1.203	0.003	0.199
1.300	1.412	1.297	-0.003	0.094
1.400	1.412	1.405	0.005	0.487
1.500	1.412	1.499	-0.001	0.540
1.600	1.412	1.594	-0.006	0.203
1.700	1.843	1.702	0.002	0.310
1.800	1.843	1.796	-0.004	0.177
1.900	1.843	1.897	-0.003	0.234
2.000	1.843	2.005	0.005	0.045

Actual temperature	Measured (no noise)	Measured (noise)	Error
0.000	0.118	0.003	0.003
0.100	0.118	0.118	0.018
0.200	0.118	0.205	0.005
0.300	0.118	0.310	0.010
0.400	0.549	0.411	0.011
0.500	0.549	0.498	-0.002
0.600	0.549	0.576	-0.024
0.700	0.549	0.731	0.031
0.800	0.980	0.809	0.009
0.900	0.980	0.913	0.013
1.000	0.980	0.984	-0.016
1.100	0.980	1.085	-0.015
1.200	1.412	1.206	0.006
1.300	1.412	1.334	0.034
1.400	1.412	1.412	0.012
1.500	1.412	1.483	-0.017
1.600	1.412	1.577	-0.023
1.700	1.843	1.698	-0.002
1.800	1.843	1.823	0.023
1.900	1.843	1.880	-0.020
2.000	1.843	1.978	-0.022

is to move the stick randomly over a number of rungs, making sure not to permanently pull the stick off to one side while one is doing so. Then, a number of instantaneous readings are taken of the stick's position and all the readings are averaged. This reduces the effect of the quantization. The effect is similar to averaging the numbers 5 and 6, 5+6/2=5.5. Both the numbers are integers, but the averaged result is between the two.

Provided the stick moves over at least two rungs, and a sufficient number of samples are averaged, quite an accurate result can be achieved. In electrical terms, noise is added to the signal to be measured and number of readings are taken to suit the accuracy of the result required. Noise is, of course, noisy, so more readings must be averaged to achieve an accurate result than one immediately thinks; averaging about 100 samples is usually adequate. This method can also work for a.c. signals. The proviso is that the trigger must be taken from the 'clean' source. The amount of noise which must be added has to be controlled quite closely: if the amplitude is not sufficiently great, the method will not work, and if it is too large, one can get worse readings than not bothering with this method at all.

ALTERNATIVE METHOD

Adding noise to the signal prevents aliasing caused by the sampling frequency of the a-to-d converter and the a.c. component of the input signal. Excellent results can be obtained with fewer samples by using an alternative method, provided the relationship between the two frequencies can be assured.

Noise, by its very nature, is difficult to generate in a controlled manner. Waveforms, on the other hand, are easy to generate and control, but cause aliasing when they are added to a direct voltage which the converter tries to measure. The same result of reducing the quantization effect can be achieved by adding a controlled waveform to a direct voltage, rather than adding noise, provided the relationship between the sampling frequency of the a-to-d converter and the frequency of the superimposed waveform in controlled.

Part of computer simulation of effect on reading of noise added to d.c. (a) and of triangular wave (b), when a-to-d converter used in temperature measurement. Column 5 in (b) is the difference between the start of conversion and the start of the randomly asynchronous triangular wave.

The solution is to run the superimposed waveform, which most conveniently could be a triangular wave, at a frequency which enables a high enough number of samples over one period of the added waveform so that aliasing does not occur, and for the samples to be averaged over an integral number of superimposed waveform periods.

An example of a configuration which worked very well and which was implemented in a temperature measuring circuit, was to measure temperature to an accuracy better than 0.1 degrees over a temperature range of −40 to +70 degrees Centigrade, using an eight-bit a-to-d converter. The resolution obtained by using the converter to give a single number from which the temperature would be calculated would be (70+40)/256=0.43 degrees.

To gain greater resolution, a triangular wave was added to the direct voltage representing the temperature. The period was set to 1/64 of the a-to-d converter period, so that for each complete wavelength of the triangular waveform, 64 samples were taken and averaged. Where on the triangular waveform the a-to-d converter started to take readings was of no consequence due to the readings being averaged over one complete waveform, and the waveform and sampling frequencies were not required to be phase locked.

Part of a computer simulation is shown for the temperature range 0 to 10 degrees Centigrade, in 0.1 degree steps. The tabulated results show the greatest error to be 0.013 degrees, a theoretical accuracy of seven times better than that required of the circuit.

The peak to peak amplitude of the waveform used here was the equivalent of 10 degrees or 23 quantization levels, but is by no means critical. It should be greater than five quantization levels and less than 20. The a-to-d converter was set to sample at a period of 10 ms, and the triangular waveform a period of 640 ms. These frequencies were chosen as they were convenient to generate from the frequencies available on the board.

ACCURACIES

The above discussion assumes that each quantization level is precisely equal to every other, and this is clearly not going to be the case. In general, the accuracy to which the quantization levels are manufactured reflect the bit accuracy of the a-to-d converter; i.e. the range of accuracies usually available is in the range 1/4 to 1 bit or quantization level. However, one should bear in mind that the larger the amplitude of the superimposed waveform, the smaller the absolute error is likely to be, as the averaging occurs over a greater number of quantization levels.

In the example, the requirement was not so much for absolute accuracy, as an accurate reading of temperature was not required, but for the detection of relatively small temperature changes, which might be in the range 0.1 to 20 degrees. This technique provided a satisfactory solution to what was initially thought an insoluble problem. Since the a-to-d converter hardware had already been designed and it was not then possible to change the type of converter.

PENALTIES

The major penalty for this method is likely to be time. To achieve the required accuracy in the example, 64 samples must be taken for averaging. The whole cycle time for each successive reading increases from 10 ms to 640 ms (the time taken to average the readings can be carried out in a very short time relative to the cycle time). However, as the temperature changes minutely within each 640 ms cycle time, the time penalty is of no consequence.

Equally, in other instances where a number of conversions can be averaged without impairment to the operation of the system, the method can achieve very satisfactory results.

A little extra hardware is required, along with greater program length and complexity, but as usual, one cannot get something for nothing!

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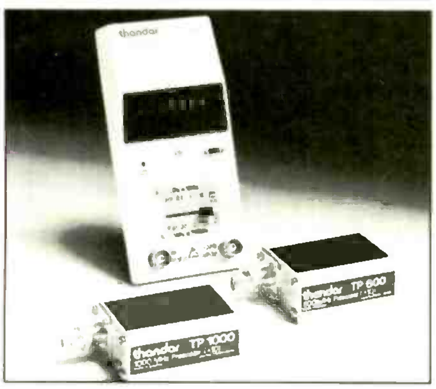

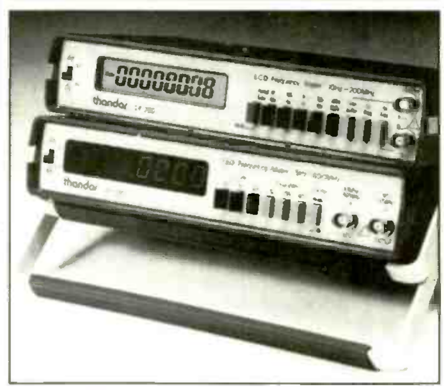

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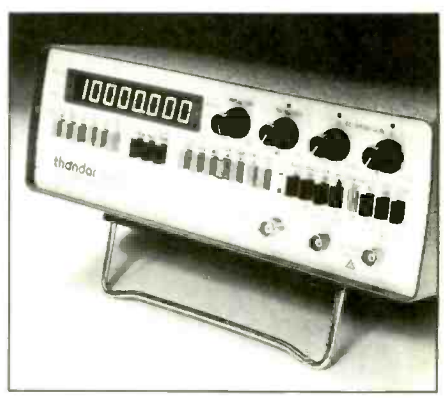

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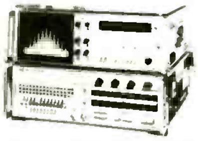

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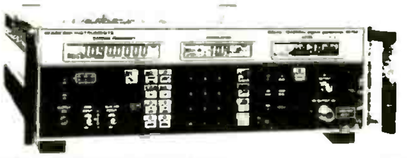

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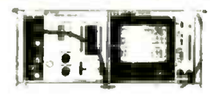

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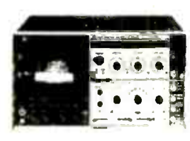

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Franco-German d.b.s.

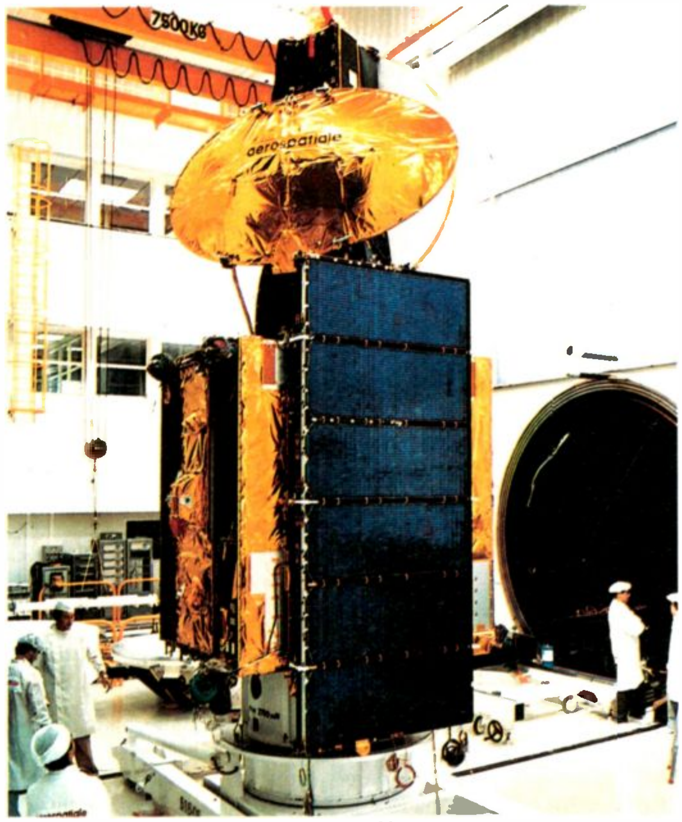
If Arianespace manages to keep to its announced programme of launches, both France and Germany will have direct broadcasting satellites in orbit by the end of this year. Germany's TV-Sat 1 and France's TDF-1 are due to be launched on Ariane 2 rockets and propelled to a slot in the geostationary orbit at 19°W.

These two d.b.s. spacecraft are very similar, having been built more or less simultaneously by a Franco-German manufacturing consortium. Called Eurosatellite, it was formed by Aerospatiale and Alcatel-Thomson Espace of France together with MBB-ERNO, AEG-Telefunken and ANT of W. Germany. Belgian and Swedish firms are also involved. Overall management is by a joint committee representing the French Space Agency (CNES), Telediffusion de France (TDF), the German aerospace R&D institute (DFVLR) and the German Bundespost. The manufacturing programme is also providing a common, spare satellite.

The photo shows TDF-1 being prepared for tests in an Aerospatiale clean room at Cannes, France. The central body measures 2.4m × 1.6m × 2.3m while the total height is 6.5m. Overall weight is 2075 kg. When the folded solar panels are fully extended the spacecraft is 19m wide from tip to tip. Power supplied by these solar panels is 3.2kW (at the end of the satellite's 7-year lifetime).

Like other satellites with this type of structure, the TDF-1 and TV-Sat 1 are stabilized in three axes. An antenna position control system cancels the effect of small angular perturbations in the spacecraft's orientation, so that the 12-GHz transmitting antenna dish is always kept correctly pointed (to an accuracy of 0.1°). Two other antennas are mounted on the structure: a dish for receiving the uplink signals on 17.8 GHz and a telemetry and command antenna.

Each satellite provides four d.b.s. channels. In each channel the r.f. output power from the transponder travelling-wave tube is 230W. When the two satellites are in operation they are expected to broadcast with an e.i.r.p. of 63.5 dBW. Their coverage areas, or 'footprints', are of course slightly different for the two countries but at the outer edge of these footprints (including the UK) the power flux density available to receivers will be about -111 dBW/m^2. More centrally the value will be about -103 dBW/m^2. For readers who prefer to think in terms of microvolts-per-metre field strength contours the last-mentioned figure corresponds to a field strength of 140 μV/m. Domestic receiving dishes of about 70cm diameter are expected to be adequate. With this coverage the potential audience for the d.b.s. services is estimated to be 260 million Europeans.



TDF-1 satellite for d.b.s. at Aerospatiale's factory, Cannes.

A common satnav receiver?

A small satellite navigation receiver about the size of a cigarette packet, costing less than £700 and capable of giving position-fixes in three dimensions to an accuracy of a few centimetres is a practical possibility. Such a receiver could be produced in large quantities to a world standardized design for use with both the American and the Russian satellite navigation systems now moving towards completion.

This is the opinion of Dr P. Daly of Leeds University. He offered it to an IEE audience in London in the course of delivering the 22nd Appleton Lecture on "Satellite navigation systems developed by the super-powers." Dr Daly's opinion is obviously a very well-informed one, as he and his colleagues and students in the Electrical and Electronic Engineering Department have been studying the American and Russian systems intensively for many years and developing their own receivers to work with them.

His lecture was a survey of two pairs of satnav systems. The first pair was the USA's Transit and the USSR's Cicada systems, which are very similar and both fully operational. The second pair was the USA's Navstar (also called Global Positioning System) and the USSR's GLONASS (Global Navigation Satellites System), which again are very similar to each other but in this case are both in a pre-operational state. Their similarities can be seen as part of the technological rivalry between the super-powers.

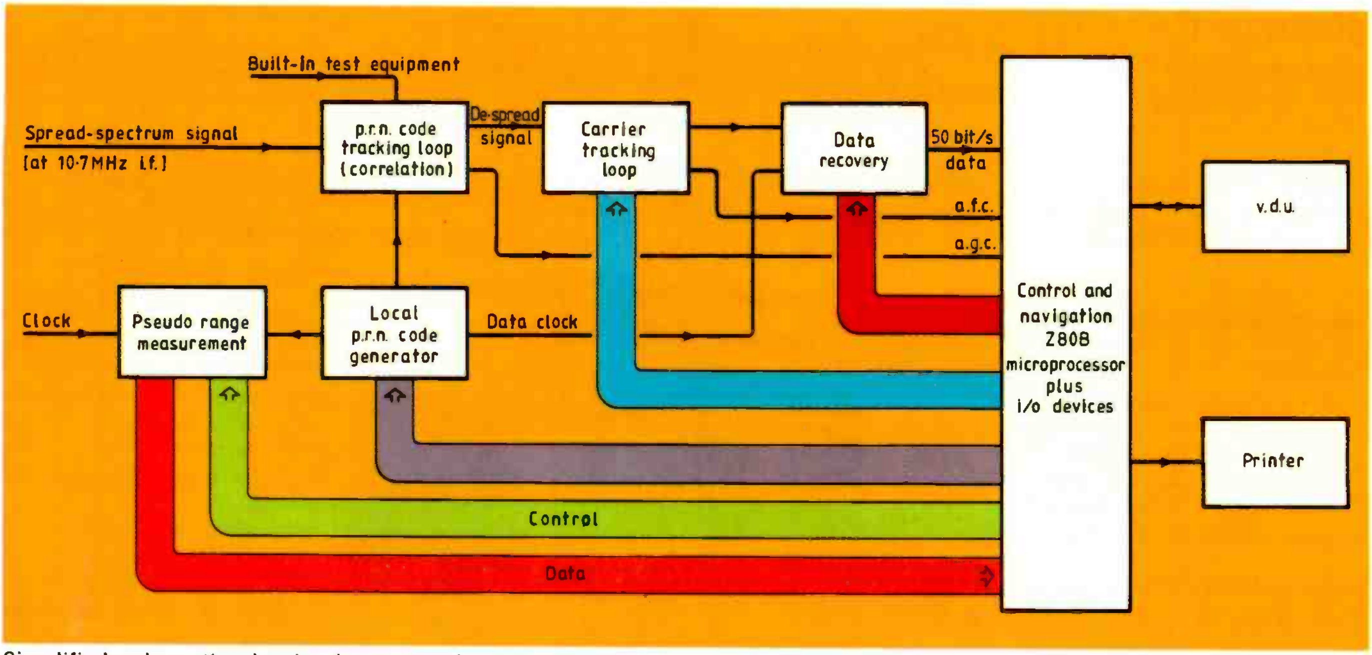
Transit and Cicada, described in this journal some years ago, rely on integrated Doppler and work on v.h.f. at 150 MHz. It was because of their operational performance limitations that Navstar and GLONASS were developed, using the different basic principle of measuring signal transit times to calculate range and working on u.h.f. at about 1.2 and 1.5 GHz (L band). These new systems are better because they are world-wide, all-weather and continuous. As an illustration of relative performance, Dr Daly mentioned that with Navstar the Leeds researchers had been able to make 125 position fixes in less than an hour, whereas the same number of fixes using Transit would take about a week or more. Furthermore, with Transit the velocity of the travelling receiver – say on a ship – must be accurately known.

Whereas Transit and Cicada use satellites in low polar orbits (at about 1000km altitude) with roughly 1¾-hour periods, the newer American and Russian systems have satellites about half-way out to the geostationary orbit with approximately 12-hour periods. The GLONASS orbits are about 1000km below those of Navstar. Both of these systems will be using three orbital planes separated by 120°, though at present only two of these planes are occupied by satellites. Navstar was intended to have a total of 18 satellites in full operation by the end of 1988. But the Challenger shuttle disaster has put back this programme and at present there are six or seven operational spacecraft. GLONASS is in a similar pre-operational phase with eight satellites launched – which is done three at a time, incidentally.

Dr Daly pointed out that 17 complete orbits of GLONASS spacecraft take exactly the same time as 16 orbits of a Navstar spacecraft. So after 17 GLONASS orbits the two systems come back into precisely the same relative positions as they had at the beginning. He felt that this synchronization, along with the many other similarities, was a useful characteristic that would help in providing a common receiver design for civil applications throughout the world.

The block diagram shows the key sections of a Navstar GPS

SATELLITE SYSTEMS



Simplified schematic showing key parts of Leeds University's automatic GPS satellite navigation receiver.

automatic receiver developed at Leeds. It receives the 1575.42-MHz transmissions intended for civil users and is suitable for navigation in slow-moving vehicles. To understand how it works some readers may need a brief outline of the Navstar system. The basic principle is that the user can fix his position in a set of X, Y, Z co-ordinates centred on the Earth. To provide this fix, his receiver measures distances from itself to transmitters in satellites of known (though changing) positions. The distances are computed from the times taken by pulses to travel (at velocity c) from transmitter to receiver. These transit times are measured by means of a standard time reference for the whole system – 'GPS time' – established by caesium and rubidium atomic clocks carried in the satellites themselves. The receiver – say on board a ship – doesn't need to carry its own atomic clock because it obtains the system time reference from the satellite transmissions. Similarly the receiver also obtains the positions of the satellites in the form of orbital data sent by these transmissions.

Thus Navstar/GLONASS is broadly similar in principle to a terrestrial hyperbolic navigation system like Decca or Omega. A constant given difference between the transit times of signals from two transmitters at known positions means that the receiver lies on a particular hyperbola. A third transmitter of known position will establish another hyperbola in the same manner. Where the two hyperbolas intersect is the position of the receiver.

In the satnav system the receiver can work either sequentially (single-channel) or simultaneously (multi-channel) from the satellites. The Leeds receiver shown here is a single-channel type. If the height of the receiver (z) is known, signals from three satellites are sufficient for a position fix; if not, four satellites must be used. The r.f. signals transmit digital data carrying all the necessary timing, synchronization, positional, orbital and correction information, including an 'almanac' giving satellite positions for months ahead to help the user. This 50-bit/s data is transmitted by spread-spectrum technique to counter jamming, the received signal being buried at least 20dB down in the noise. One pseudo-random noise (p.r.n.) code is transmitted for civil use, another for military use.

Thus the receiver's job is to acquire the p.r.n. code signals, decode them and process the resulting data to calculate position fixes. It involves a mixture of conventional r.f. engineering, signal processing and digital computation. The central part of the computation is to solve a set of four simultaneous equations, corresponding to four satellite inputs, to obtain distances in the co-ordinate system.

In the single-channel Leeds receiver (see diagram) the civil satnav signal at 1575.42 MHz with a power of about 10^{-16}W is picked up by a small microstrip antenna and fed to a front end. Then two stages of frequency down-conversion produce an i.f. of 10.7 MHz. This is still a spread-spectrum signal with no tunable carrier in the conventional sense. To recover the transmitted p.r.n. code, the signal is correlated with a locally generated p.r.n. code obtained through the action of a code tracking loop.

When correlation is achieved by the loop the spread-spectrum signal is de-spread. The comparatively wide p.r.n. signal bandwidth of about 2 MHz is collapsed to that of the data – a few hundred hertz. The signal then passes to a carrier tracking loop, and conventional coherent demodulation technique is used to regenerate a carrier and recover the 50-bit/s p.s.k. encoded data.

The block marked 'pseudo-range measurement' is for measuring the time of arrival of certain precise data signals called epochs by reference to a 10-MHz master clock in the receiver. These measurements, along with the data recovered by correlation etc., provide the basic information required for the position-fixing computations. All system control and computation is performed digitally by a Z80B microprocessor, using an STD bus and the C programming language. Navigational and other data are transferred via i/o devices to a v.d.u. and printer.

Normally the position-fixing accuracy of a 'straight' Navstar receiver is within 20m or perhaps even 10m. But Dr Daly explained that this could be greatly improved by the use of additional receiver techniques. For example, integrated Doppler would increase the precision to about 1 metre. Then measurements of code phase could be used, and also measurements of carrier phase, where the period is much shorter. At the L-band frequency used, for example, the wavelength was about 19cm. He said it was not difficult to make phase measurements to a tenth or twentieth of a period.

Dr Daly mentioned that current research at Leeds included a refinement called 'differential capability.' This has two Navstar receivers working together. If receiver A already 'knows' where it is, it can compute any systematic errors. It then transmits this error information over a communication link to receiver B, in a format like that of a satellite code transmission. Receiver B can then receive, decode and utilize this sytematic error information to correct its own position-fixing data to the level of accuracy possessed by A.

Satellite systems was written by Tom Ivall.

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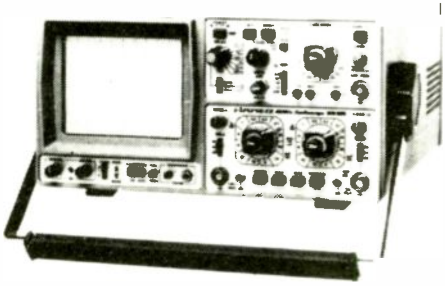

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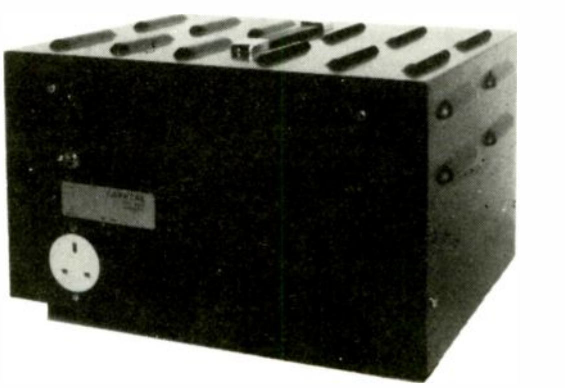

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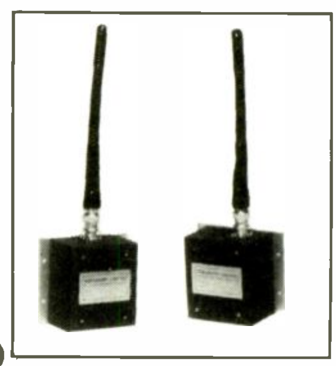

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Pioneers

4. Charles Wheatstone (1802-1875) – Master of telegraphy

W.A. ATHERTON

Sir Charles Wheatstone and his family: this stereoscopic daguerreotype is in the National Portrait Gallery, London.

It is an irony indeed when a prolific inventor is mostly remembered for an invention that was not his.

Charles Wheatstone did not invent the Wheatstone Bridge. He did however invent the concertina, one of the first electrical relays, the rheostat, a solar clock, improvements to the mouth organ, a typewriter, a binocular 3-D viewer similar to the modern toys, a stethoscope which he called a microphone, and some of the best 19th century telegraph systems – amongst other things.

Born in Gloucester on the 6th February, 1802, Wheatstone was the son of a music seller. He was educated at a private school but had no formal scientific education.

At 21 he was living in London where he and his brother had entered the business of making and selling musical instruments. Those instruments, and the related science of acoustics, were to figure large in his life.

Although as yet an outsider to established scientific circles, he received a visit from Oersted in 1823. His first scientific paper was read to the French Académie des Sciences that year by Arago and published in London, all at the age of 21.

As part of his study of musical instruments, in 1821, Wheatstone had demonstrated an 'enchanted lyre'. This was an entertaining application of the transmission of sound through a solid rod. A sounding board, in the shape of a classical lyre and apparently hanging from the ceiling, appeared to play music! It was in fact amplifying sound vibrations conducted to it by a rod from a piano in an upper room.

This early fascination with the passage of sound waves through a solid rod helped to turn Wheatstone's thoughts to telegraphy, the art of sending messages over a distance. He described the enchanted lyre to the Royal Institution of London in 1831 and reported that sound travelled through a solid rod about 16 times faster than through air. It would, he said, travel the distance of 200 miles in less than a minute – if a suitable conducting substance could be found. His thought, even then, was to transmit messages. Speech, he had already found, could be transmitted over short distances "perfectly, though feeble."

The "almost hopeless difficulty" of a breakthrough for long distances, he wrote, "might induce us to despair of further success." The answer, he speculated, lay with a mechanical speech synthesizer! Bell's telephone was to be invented shortly after Wheatstone's death.

In 1833, however, his attention turned to electricity, and in particular the question of its speed of transmission. It was known to be extremely fast, so fast that no-one had been able to measure it. Wheatstone provided the breakthrough.

His genius lay in devising a method of measuring the tiny intervals of time between three sparks located at the beginning, middle and end of half a mile of wire. This measurement of minute amounts of time had defied everyone else. His solution, using a revolving mirror, was simple and effective. It became a laboratory classic. He even attached a siren to the hand-cranked mirror so that the tone it generated helped him to govern the speed of rotation.

Wheatstone's measurement of the speed of electricity was much too high, but it was of the right order and the first to be achieved. Later with four miles of wire he revised the figure to 192 000 miles per second, much closer to the present-day value of 186 000. Partly as a result of this huge success he was appointed Professor of Experimental Philosophy at King's College, London, a position he retained for life.

But standing before an audience filled him with terror and he gave few lectures. At the Royal Institution his scientific papers were read for him by Michael Faraday who was an enthralling speaker. It is said that on one occasion, when due to speak himself, Wheatstone fled leaving Faraday to pick up the pieces.

THE TELEGRAPH

'Who invented the electric telegraph?' is, as politicians say, a very good question.

To the modern mind Morse's name comes most readily; but while he was one of the most successful telegraph inventors, he was not the first. Wheatstone could justifiably claim to have invented the first telegraph system to be put into daily commercial operation. In partnership with W.F. Cooke he installed a telegraph able to send and receive messages between London (Paddington) and West Drayton along the Great Western Railway from July 1839 and it operated on a daily basis for 10 years, even being extended as far as Slough. It was from this that the British telegraph system sprang.

Even so, it was not the first electric telegraph. Once the magnetic effects of a current were known (1820) several telegraphs using magnetic needle detectors were invented as the same idea came to different people in different places.

Probably the first to produce an experimental electromagnetic-needle telegraph was a Russian baron, P.L. Schilling, perhaps as early as 1825. Although he died in 1837, samples of his equipment had been sent to friends abroad and one of them was seen in Germany by William Fothergill Cooke. Fired with enthusiasm, Cooke returned to England with burning ambitions to build telegraphs – especially for the railway companies, his first potential customers. His partnership with Wheatstone led to commercial telegraphy.

Amongst several remembered for their experiments with electric telegraphy around this time are the Gauss and Weber partnership in Germany, Edward Davy and William Alexander in Britain, and of course Morse in America.

On his return to England Cooke sought help to solve the problem of how to get his telegraph to work over long distances. Over a mile his results were poor. He turned to Wheatstone in February 1837 only to discover that the scientist already had his own ideas for a telegraph, and a knowledge of electricity, and success with four miles of wire. Whilst Wheatstone provided the technical expertise and scientific knowledge, Cooke supplied the drive and vision necessary for commercial telegraphy to become a reality.

In April that year Wheatstone received a visit from the great American scientist Joseph Henry, and learned of Henry's outstanding work on electromagnets and their operation through long lengths of wire. A missing scientific link slotted neatly into place.

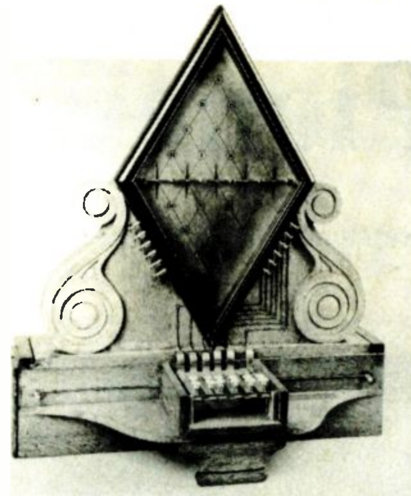


Fig.1. Cooke and Wheatstone five-needle telegraph, 1837 (Science Museum).

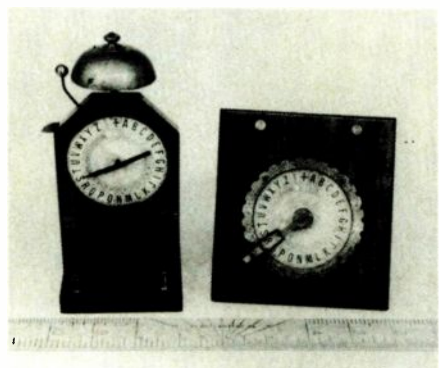


Fig.2. A simple ABC telegraph from about 1890-1900, bought with other 'junk' in an auction. It still works and is now in the hands of a collector. The transmitter is on the right.

A partnership was formed, at times very acrimonious and in need of arbitration to settle disputes. Patents were acquired, and after trials and tribulations, success came with the Paddington to West Drayton telegraph.

This was the famous five-needle telegraph now in the London Science Museum. Five wires were needed, one to each needle, any two of which could be made to complete a battery circuit. The current flowed out by one wire and back by the other. The choice of wires and direction of flow was dictated by a permutating keyboard and a letter was indicated on the diamond-shaped dial by the simultaneous deflection of two needles (Fig.1). The instruments were well designed and made, a characteristic of Wheatstone probably born during his apprenticeship as a musical instrument maker.

This telegraph was a huge technical success. In 1843 the line was extended to Slough by Cooke, a total distance of 19 miles, using only two needles with codes. Two years later it achieved fame when police in Slough telegraphed to Paddington the description of a man who had just murdered his mistress in Slough. His escape by train to London took him into the arms of the constables.

By the end of 1845 the telegraph had arrived and the number of lines was increasing. The next year the Electric Telegraph Company was formed and Wheatstone received the healthy sum of £30,000 for his share of the patents. By 1870 the telegraphs had been nationalized at a cost of some £8 million.

Wheatstone had meanwhile turned to the design of ABC or 'letter showing' telegraphs. These had a dial with letters printed around the edge, only one of which would be visible. (or indicated) at any time. The first were essentially synchronized stop clocks with a remotely-operated electromagnet which could be used for stopping and re-starting the mechanism. The user simply noted down the letter shown each time the clock stopped.

Later, however, Wheatstone made the transmitter send multiple pulses down the line, each of which stepped the receiving dial on by one letter. Some of these devices were little bigger than a pocket watch and exquisitely made.

Although slow, ABC telegraphs were used in a sizeable network in London from 1860. Wheatstone's were not the only versions; they were made in several countries and some remained in use up to World War I.

Much faster than the ABCs was the Wheatstone automatic telegraph of 1859. Its successors were in use for over half a century. As with computers a hundred years later, paper tape was used to speed transmission, the message being coded by hand as punched holes which then drove a transmitter at high speed. Wheatstone's interest in coding developing into an interest in cryptography and he even deciphered some documents for the British Museum.

Charles Wheatstone made so many inventions they could fill a book. Just one suffices to illustrate his breadth of interests; a solar clock which used the polarization of sunlight to indicate time even when the sun itself was obscured. It was used on Arctic expeditions.

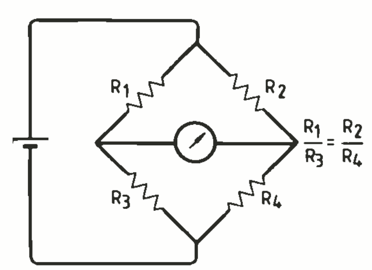
When Wheatstone died in Paris on 19th October 1875, a renowned scientist and inventor, he had received many and varied honours. The medals alone are said to fill a box of a cubic foot capacity. He sat on many important committees, was a Fellow of the Royal Society, and a foreign member of the French Académie des Sciences. Both Oxford and Cambridge Universities honoured him and he was knighted in 1868. He refused the Albert Medal of the Royal Society of Arts because they offered the same award to Cooke, his former partner. It was a bitter legacy of the tensions and disputes between them.

There was one unusual honour, though, of which Wheatstone may not even have been aware. In 1841, with Isambard Kingdom Brunel and others, he was aboard a locomotive when Brunel set out to discover how fast it could go. At about 90 miles per hour Wheatstone and his companions probably held the world land speed record!

Samuel Finley Breese Morse, the American artist and engineer, will be next in this series of pioneers of electrical communication.

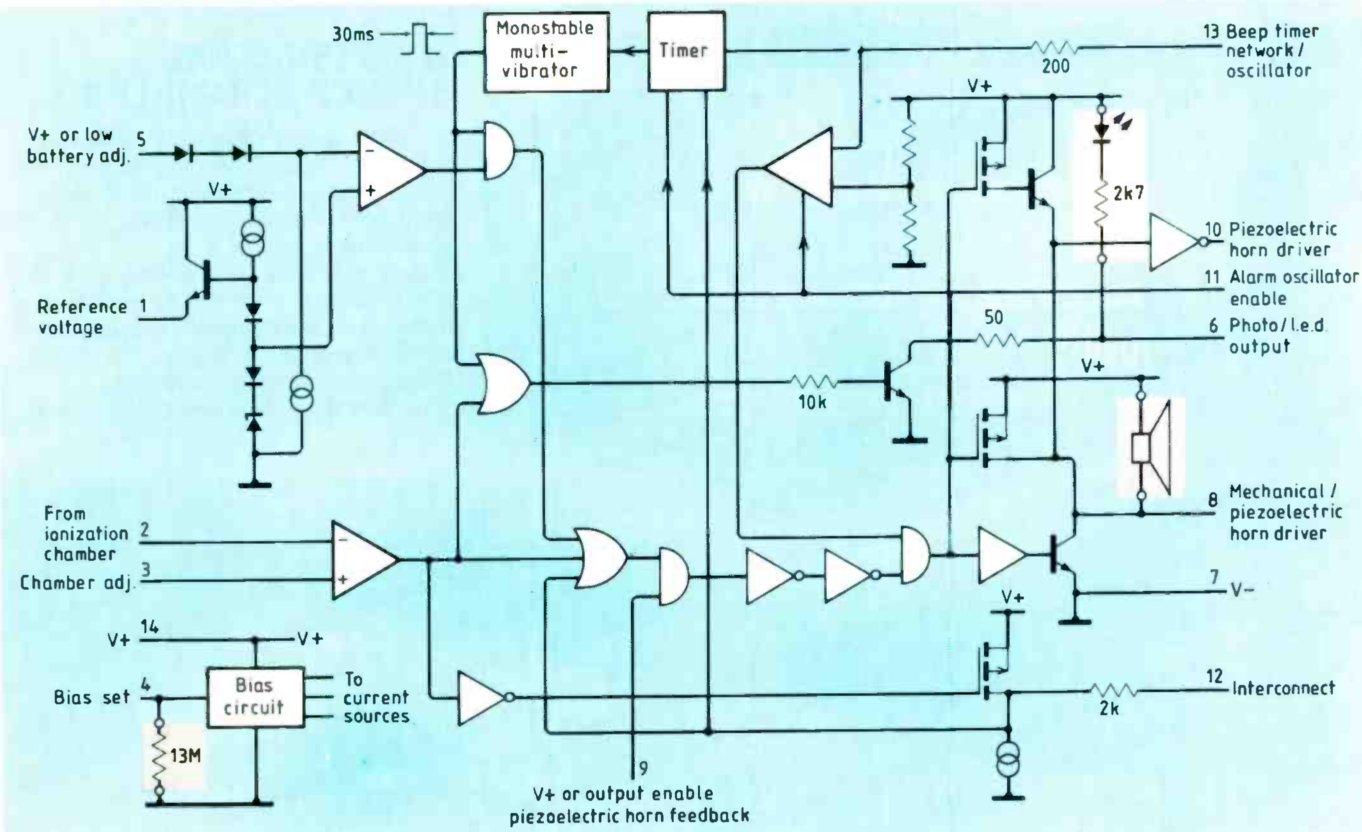
The invention Wheatstone did *not* create

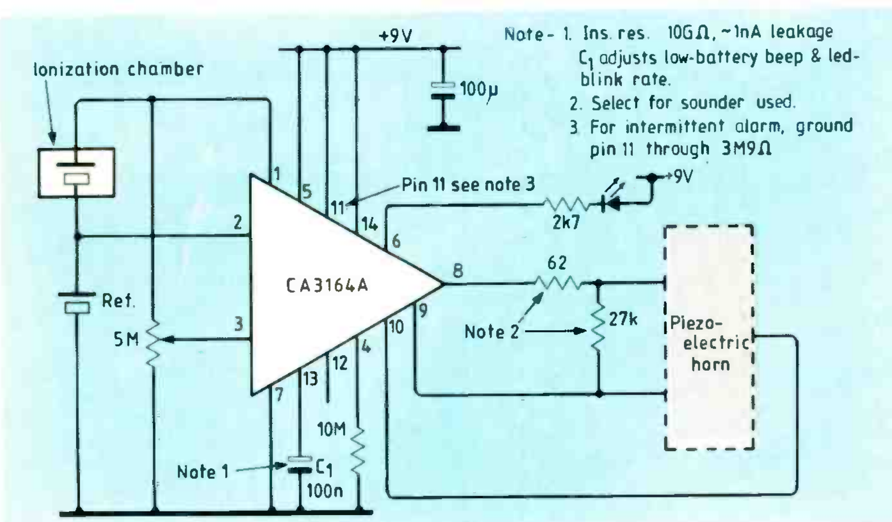
THE WHEATSTONE BRIDGE



In the early 1840s Wheatstone set out to obtain a firm basis for electrical measurements: voltage, current, and resistance. This was at a time when Ohm's law was still not widely known in Britain. Using Ohm's work, Wheatstone devised his own units and built a standard resistance. During this work he used the bridge principle described by Samuel Hunter Christie in 1833. Despite his giving Christie due credit for inventing the bridge it was Wheatstone's name which stuck.

APPLICATIONS SUMMARY



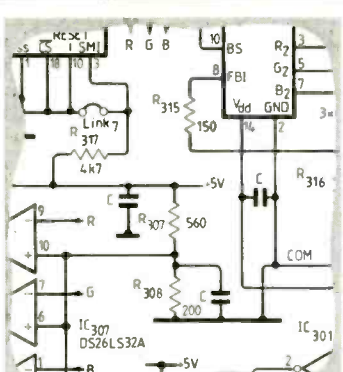


ONE-CHIP SMOKE DETECTOR/ALARM

In the 3164 detector/alarm i.c. mos circuits form an ionization chamber amplifier while bipolar transistors drive alarm devices. Detector input current is sub-picoamp and alarm-output sink current is up to 300 mA.

The 3164 is designed primarily for use with ionization-chamber smoke detectors, but it can be used with photoelectric chambers by adding a few components. Besides triggering on detection of decreasing voltage at the smoke detector input, the device monitors battery voltage and produces a beep once every 50s when battery voltage falls below a presettable limit.

Booklet 1139 from RCA describing the CA3164A includes circuits for a photoelectric detector/alarm and photographic flash trigger.



In Fig. 28 (page 302, March) the value of R_{217} was omitted and the connections of R_{308} and its associated capacitor were wrongly drawn. This amended diagram shows them as they should be. The author has also pointed out an error in the text: in the penultimate line on page 302, the word advantage should read disadvantage.

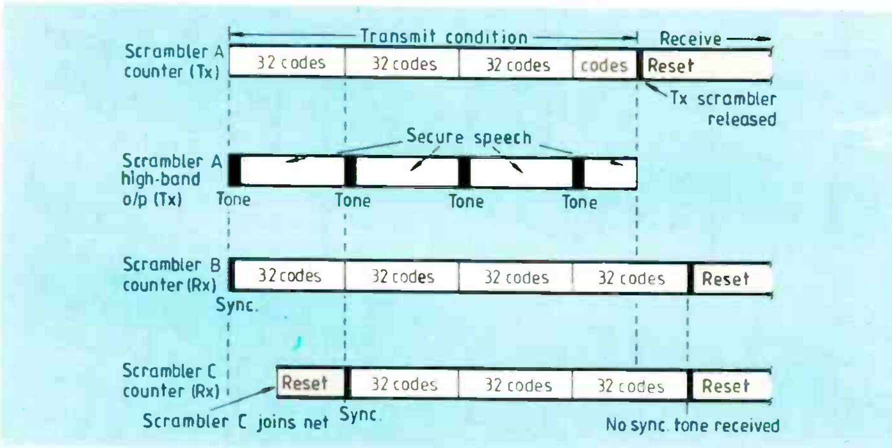
ADDRESSES:

Consumer Microcircuits Ltd
Wheaton Road, Industrial Estate East, Witham, Essex CM8 3TD, tel: 376 513833.

Motorola Ltd
STC Electronics Services, Edinburgh Way, Harlow, Essex CM20 2DF, tel: 0279 26777.

RCA Limited/Solid State Division
Lincoln Way, Windmill Road, Sunbury-on-Thames, Middlesex TW16 7HW, tel: 09327 85511.

APPLICATIONS SUMMARY

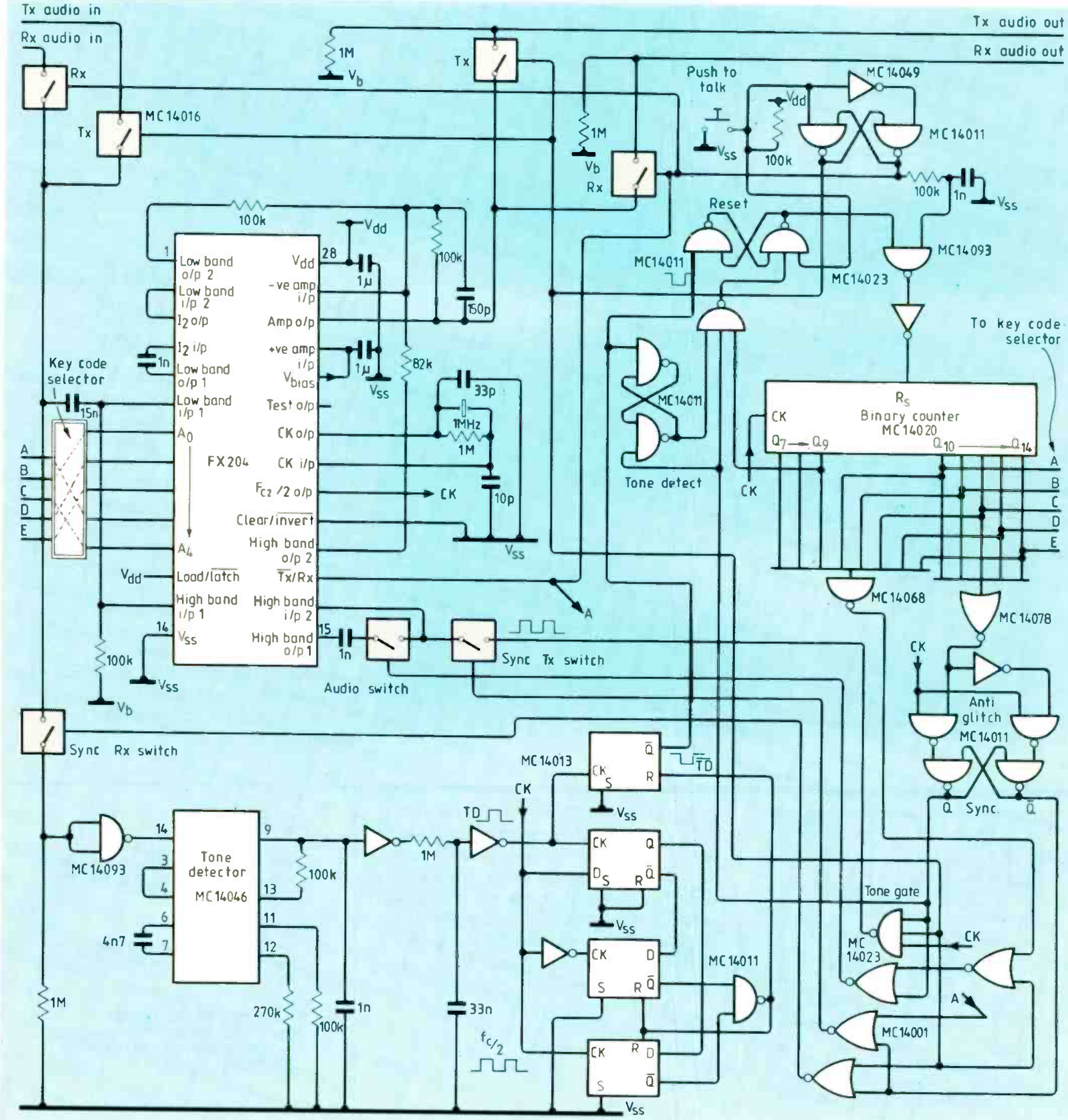


ROLLING-CODE SPEECH SCRAMBLER

In simple speech scrambling applications, the FX204 from Consumer Microcircuits splits the voice spectrum into high and low frequency bands and then inverts each band about its own centre.

Frequency of the split point is programmable in 32 steps from 300 to 3000Hz. For more secure operation, the split point can be continually varied, as it is in this rolling-code speech scrambler/descrambler.

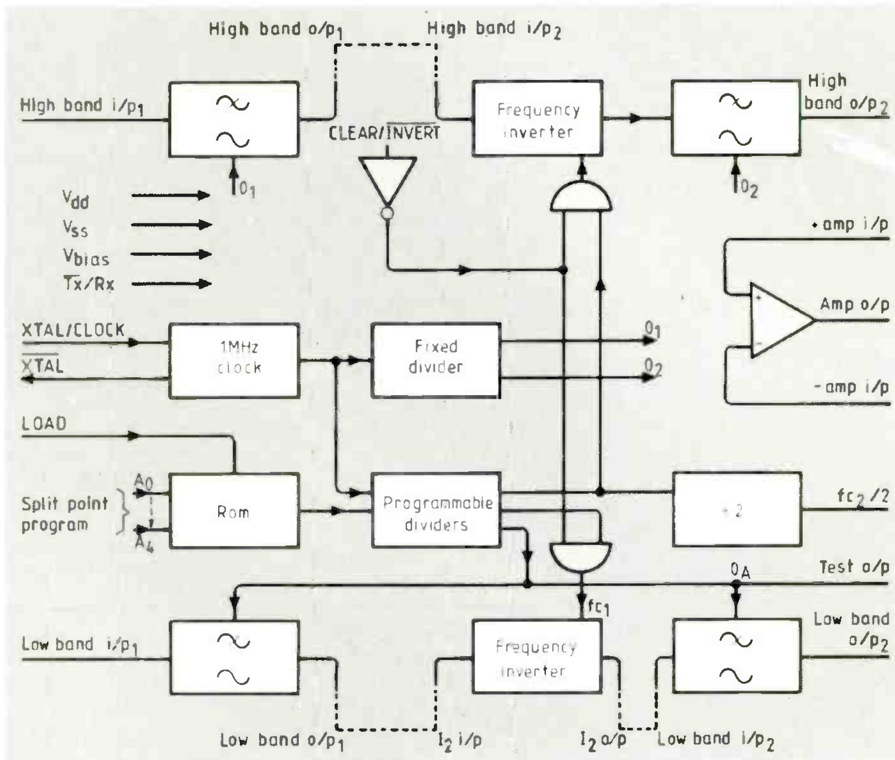
Because the code is continually varying,



APPLICATIONS SUMMARY

the receiver needs some means of synchronizing itself with the transmitter. For this purpose, an f.s.k. data burst can be sent at the start of each transmission. Alternatively a continuous tone above or below the voice band may be sent and this tone could have phase reversals. In the circuit shown, a p.l.l. detects tones higher than 2400Hz.

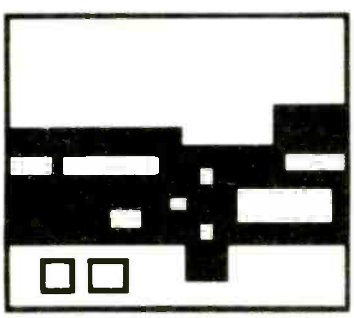
Besides this and other applications, the FX204 data sheet covers specifications and operation of the device.



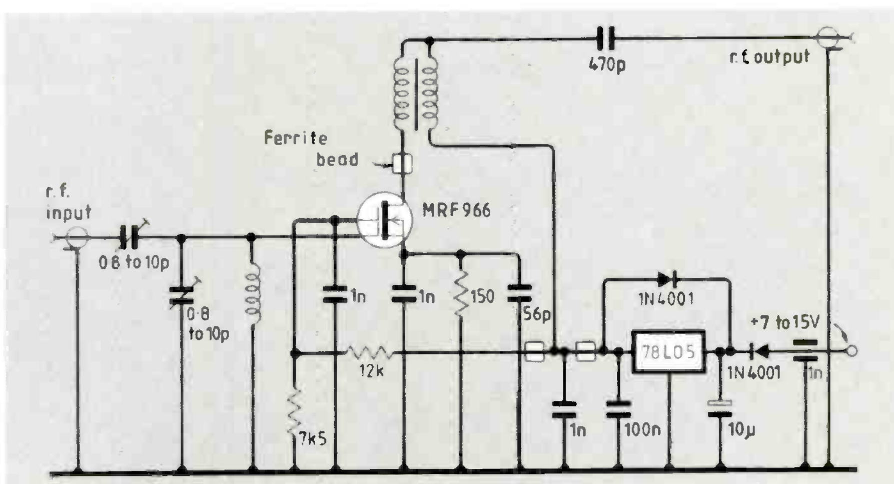
400-512MHz PREAMPLIFIER

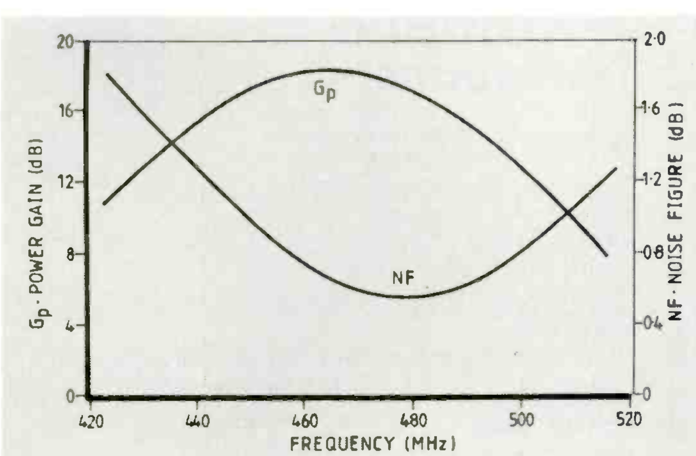
Electrical, mechanical and performance details for a GaAs fet 400-512MHz preamplifier are given in Motorola note AN925. The MRF966 GaAs fet used is a low-cost dual-gate device designed for u.h.f. applications.

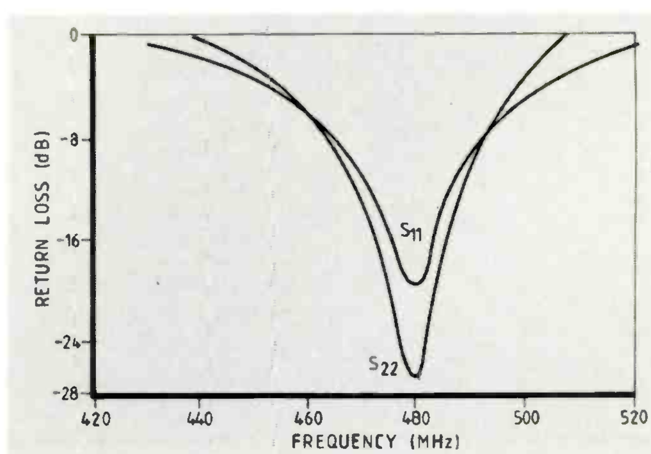
In the three-page note, Smith charts show input/output matching networks and two graphs show gain at noise figure and optimum noise figure versus frequency with the preamplifier tuned to 430 and 480MHz. Two further graphs give input and output return loss versus frequency; the ones shown here are for 480MHz. Circuit board, coil winding and housing details are also given.



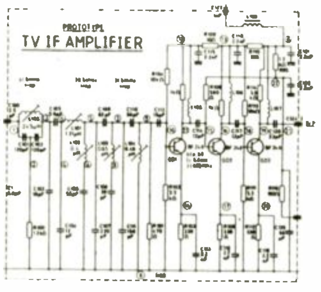
Top of PCB

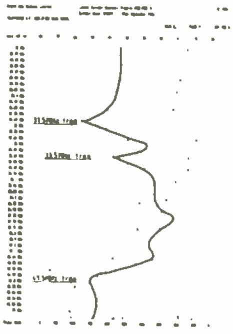


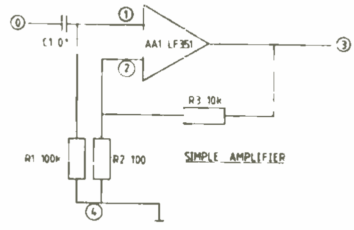




LOW COST ELECTRONICS C.A.D.







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Frequency range	20Hz 20kHz	20Hz 20kHz	30Hz 20kHz	20Hz-20kHz	20Hz 20kHz	300Hz 3k4Hz	20Hz-20kHz
Performance	· 0 1dB over above range	0 25dB over above range	· 0 5dB over above range	· 0 3dB 40Hz-15kHz · 0 5dB 20Hz 20kHz	0 5dB over above range	0 5dB over above range	· 0 2dB over above range
Maximum Level	7 75V r m s on secondary	7 75V r m s on 600Ω	on 5kΩ load 3 4V r m s at 30Hz	26dBm at 30Hz	2 3V r m s at 30Hz	0 6V p p on Primary	2 0Vr m s on Py at 30Hz
Maximum Distortion	With 10V r m s at 40Hz only 0 12%	On 600Ω low source Z 0 1%	Less than 0 1% at 1kHz	0 1% at 30Hz at 26dBm	negligible 0 1% at 1kHz	negligible	0 1% at 20Hz
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European moves from AT&T

The American giant telecommunications company, AT&T, are opening new sales and design centres in Bracknell, Berkshire, and in Stockholm, Sweden. These will add to the AT&T offices in Madrid and Munich and further facilities are planned for France and Italy.

The British branch at Bracknell will offer basic design facilities as well as a sales office for AT&T products. These products result from research at their Bell Laboratories and claim to have many unrivalled attributes: their 32-bit, floating-point, digital signal processor, for example, which can operate at 24MHz. AT&T have also produced a 32-bit microprocessor which is designed specifically to work with the Unix-V operating system (another Bell Labs product). Their i.c. manufacturing offers 1.75 and 1.25μm geometries with 0.9μm available soon.

The company specializes in communications equipment and can offer a wide range of communication circuits and fibre-optic components.

Philips to sell Pye TVT?

Philips Electronics has announced that it is holding discussions concerning the sale of its broadcast transmission subsidiary, Pye TVT Ltd, with a potential American purchaser, Varian Associates.

Pye TVT of Cambridge employs about 220 staff in the design and manufacture of broadcasting equipment, especially for tv transmission. Varian supplies communications, medicali, analytical and semi-conductor equipment with a reported turnover of $900 million in 1966. The purchase of Pye TVT would be part of Varian's programme to strengthen its role in the communications field. It had already acquired in 1985 the Texas-based Continental Electronics Company and has considerable strength in high-power broadcast and satellite ground-station transmitters, which would be complemented by the Pye TVT range. Varian has indicated its intention of continuing the Cambridge operations.

In brief

For those interested in preserving the history of the telephone, there has been founded the Telecommunications Heritage Group. The group will publish a quarterly newsletter, appropriately called 'Exchanges' which will include articles, and notices for the sale of, and requests for equipment and information. Although the group is independent of BT, the Telecom Technology Showcase, 135 Queen Victoria Street, London EC4V 4AT, has agreed to act as a coordinating and postage centre. This year's subscription is £3. Further information from the group through the Showcase.

A firm of London solicitors has claimed a world first by offering legal advice via electronic mail. Pennefather and Co. is the company that has decided to break fresh ground by opting for this form of communication to answer queries from clients. The service is being provided on Microlink, a national electronic-mail network. Clients of the solicitors can transmit their messages and receive replies using their home or business computer.

As an introduction to this on-line service, all subscribers to Microlink are being given the chance of a free consultation. They can receive one free reply on any legal query they wish to raise with the firm.

Philips have opened a new integrated research and development centre at its headquarters in Eindhoven, Holland. Its principal object will be development of sub-micron technology (silicon structures with less than 1μm width and spacing) in a research cooperation between Philips and Siemens of Germany.

Dr Marc Faktor, who spent more than two decades researching the optical and electrical properties of materials, was presented with BT's Martlesham Medal. His "pioneering work has helped to put Britain in the world forefront of optoelectronic technology."

Much of his work with British Telecom concerned the growing of crystals from vapour; building up layers of semiconductor material no more than a millionth of an inch thick – on which the fabrication of today's optical devices are based. The techniques which he pioneered, such as metallo-organic vapour phase epitaxy are now sufficiently well defined as to be capable of commercial exploitation. A joint venture company set up in 1986 between British Telecom and du Pont is to develop, manufacture and market optoelectronic components and devices which stem directly from Dr Faktor's work.

During the early 1970s he headed a team which used organic materials to build reliable 'directly modulatable' semiconductor lasers. He also devised the electrochemical technique at the heart of the British Telecom profile plotter, which produces an accurate profile of the electric-current carriers in semiconductors. This is now manufactured under licence and sold worldwide. Dr Faktor left British Telecom in 1982 and is a now a visiting professor at Queen Mary College, London University.

The construction of two military communications satellites for Nato has been awarded to British Aerospace. The Nato tv satellite will be virtually identical to Skynet 4, currently under construction for the British forces. Marconi are the principal subcontractors for the communications payloads to be launched in 1990.

A report by Dataquest, of California, on the worldwide semiconductor market for 1986, says that the three top chip suppliers, measured in US dollars, are Japanese companies.

NEC retained its number one position, achieved in 1985. Second and third places for 1986 went, respectively, to Hitachi and Toshiba. Motorola and TI were relegated to fourth and fifth places respectively. The places are quite difficult to work out because of the fluctuations in currencies: the Japanese attained a world growth of 40%, expressed in dollars, but only 0.2% when accounted in Yen. Japanese exports actually fell by 8%, but this is offset by a 2.6% increase in the share of their home market.

IEE and IEEIE lectures and meetings

All meetings held at the IEE, Savoy Place, London WC2; information from the Institution, Tel: 01 240 7753, Ext. 296 or 283, unless otherwise indicated.

24 March
Electronic filters: IEE colloquium

24 to 26 March
Computer aids for electrical and electronic engineers. Conference at the Metropole Hotel Brighton in conjunction with the CADCAM 87 Exhibition. Details from EMAP, Tel: 01-606 1161.

25 March
Multi-octave components and antennae: IEE colloquium.

26 March
The code-breaking computers of 1944: IEE discussion meeting at 1415h.
Colossus and the German cyphers in WW2: IEE lecture by Sir Harry Hinsley. 1800h.

27 March
Evaluation of interactive systems design: IEE colloquium.

30 March to 2 April
Antennae and propagation (ICAP 87): IEE Fifth international conference at the University of York.

1 April
Digitally implemented radios: IEE colloquium.

1 to 3 April
Command, control, communications and managment information systems. Second International conference in Bournemouth.

2 April
V.l.s.i. for image processing: IEE colloquium.
Fibre optics in communications. IEEIE lecture by R.R. Willet of Mercury. University of Cambridge Engineering Laboratories. 1900h. Details from IEEIE 01 836 3357 ext. 212.

6 April
Component tv measurements: colloquium.

7 April
Software engineering – the importance of documentation: colloquium.

Round Australia by microwave

The commissioning of the last link in Telecom Australia's $1billion round-Australia broadband microwave network has meant a significant improvement in the security of national communications in Australia. Telecom Australia is the national common carrier, owned by the Federal Government and charged with the development of a modern telecommunications system in Australia.

When the link across the West Australian/Northern Territory border was switched on recently, it immediately became possible to direct Perth calls to the east coast of Australia, via the north. For the first time any failure in the main trunk route across the Nullarbor desert no longer meant Western Australia's communications could be cut off from the rest of Australia. Just as importantly for people who live in the remote Kimberleys in the north west of Western Australia, the 455km link that now joins Kununurra to Katherine in the Northern Territory has given them additional security in the event of a cyclone disaster.

Although the towers holding the network's parabolic dishes are designed to withstand winds up to 225km/h, it is still possible for a cyclone to put a dish out of action. It happened with Cyclone Joan in 1984, when high winds twisted an angle-iron, and a dish on a tower was edged 5° off line. On a 40km line-of-sight between dishes the 5° was sufficient to break the link and bring the network down for two hours before the dish could be re-aligned. The completion of the final link means that such a fault would no longer disable the network; communications traffic could be simply redirected around Australia in the opposite direction, away from the fault.

Communications Highway One, as it is called, began in 1959 with a link between Melbourne and Bendigo. At this time, some areas were only connected by telegraph lines and these were being replaced by h.f. radio links; allowing phone calls for the first time to the Kimberleys, for example.

The completed network carries telephone traffic, computer data, telex, facsimile, tv and stereo sound broadcasts. It stretches 11,916km in a giant continental loop. To provide line-of-sight communications, the 303 masts are placed at 40km intervals in a zig-zag pattern to prevent overshooting into the next section. Repeater equipment is housed at the base of each mast. In the northern regions where the temperature can rise to 50°C, the repeaters are buried in underground shelters to keep the temperature stable, to within 5°C of the required ambient. Remote repeaters are solar powered.

– William Scholes, Sydney.

Russians cease jamming

Skywave jamming of the BBC's Russian-language service all but ceased on January 20th, and, judging from reception in Moscow, so too did local groundwave jamming – much beloved of the Soviet Union.

The jamming began in 1949, since when jammers have been turned on whenever the political climate has cooled. 1963 marked a temporary lull, but jamming reappeared after the invasion of Czechoslovakia in 1968. Another respite occurred in the 1970s.

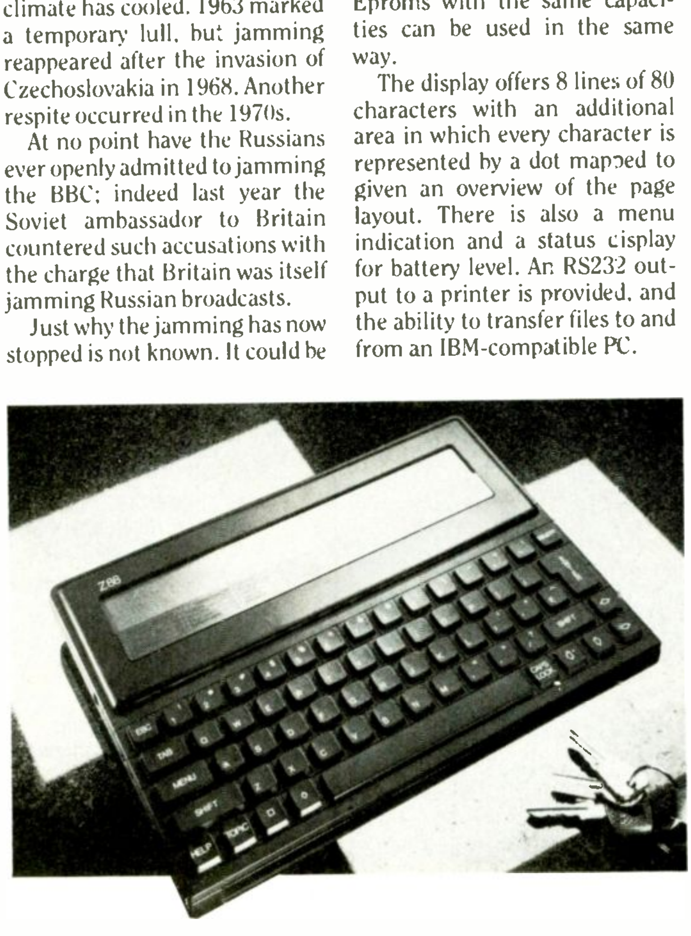
At no point have the Russians ever openly admitted to jamming the BBC; indeed last year the Soviet ambassador to Britain countered such accusations with the charge that Britain was itself jamming Russian broadcasts.

Just why the jamming has now stopped is not known. It could be a desire for better relations with Britain following the visit to Moscow of the Foreign Office Minister, Timothy Renton. This is given more weight by the fact that (at the time of writing) other western broadcasters are still being jammed. The approaching 1987 World Administration Radio Conference may also have some bearing, allowing the Soviets to present a cleaner image in terms of spectral pollution. Or it may turn out to be another step in Mr Gorbachov's liberalization policy, already demonstrated through limited western access to the country's print media. – JW.

Sinclair's Z88

Having sold the Sinclair brand to Amstrad, Sir Clive Sinclair has started a new company, Cambridge Computers. Its first product is the Z88 computer; a battery-powered lap-top which comes with a built-in word-processor, BBC Basic, spreadsheet, database, calculator and diary/calendar. 32K of ram is provided but it is possible to plug in up to three ram extension cartridges, of 32K, 128K and (available later) 1Mbytes. Eproms with the same capacities can be used in the same way.

The display offers 8 lines of 80 characters with an additional area in which every character is represented by a dot mapped to given an overview of the page layout. There is also a menu indication and a status display for battery level. An RS232 output to a printer is provided, and the ability to transfer files to and from an IBM-compatible PC.



EXHIBITIONS AND CONFERENCES

24-26 March 1987
Cadcam 87 exhibition and conference. NEC Birmingham. EMAP Int. Exhibitions, Tel: 01-608 1161
Internepcon Production Show and conference – 'from CAD to testing' NEC Birmingham. Cahners Exhibitions. Tel: 01-891 5051

25-26 March 1987
Instrumentation Bristol 87 Exhibition. Bristol Crest Hotel. Trident Int. Exhibitions, Tel: 0822 4671

31 March-2 April
Scottish Computer Show and conference. Scottish Exhibition Centre, Glasgow. Cahners Exhibitions. Tel: 01-891 5051

6-8 April 1987
Offshore computers conference and exhibition. Heathrow Penta Hotel, London. Offshore Conferences, Tel: 01-549 5831

13-16 April 1987
Acoustics '87 conference at the Management Centre, Portsmouth Polytechnic. Institute of Acoustics, Edinburgh, Tel: 031-225 2143

28-29 April 1987
Cellular and mobile communications conference, Barbican Centre, London
Value-added network services (VANS) conference. Barbican Centre, London

12-15 May 1987
Automan: 4th European Automated Manufacturing systems exhibition and conference. NEC, Birmingham. Cahners Exhibitions. Tel: 01-891 5051

17-20 May 1987
CES – Consumer Electronics and Technology Show. Earls Court, London. Organized by Montbuild Ltd, Tel: 01-486 1951

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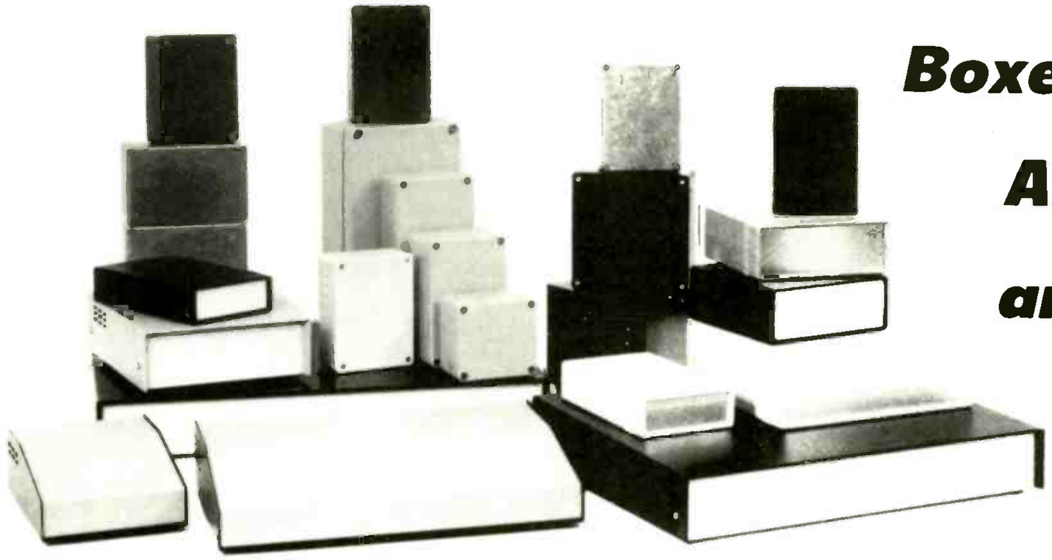

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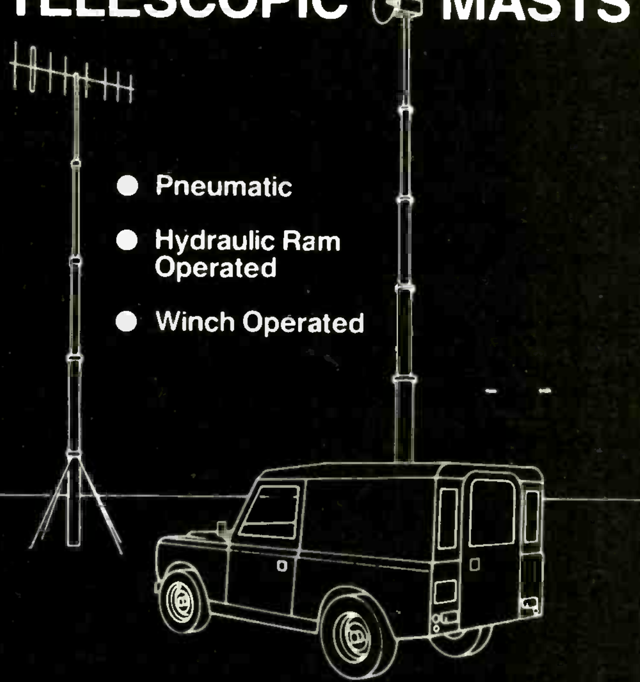

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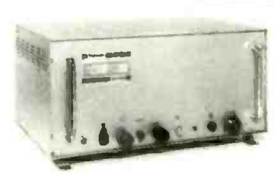

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Forth processor hardware

Using the Novix processor relatively few devices are needed to make a complete Forth computer capable of at least 4 mips.

WILLIAM WATSON

My first article on the Novix NC4000 in the February issue outlined Novix architecture and design philosophy. This article illustrates how to design Novix based hardware, looking at the criteria that determine its design, and describes a working system. This design is the basis of the NX4 board, a low cost Novix evaluation system.

A number of factors determine which components are used in a microprocessor system – timing diagrams, memory map, amount of rom and ram needed, choice of technology, and so on. But before exploring these in detail, we need to put together a brief specification for the system. The aim is to produce an evaluation system that will give engineers an idea of the NC4000's capabilities. The main key requirements in no particular order are

- Low cost
- Use of readily available parts
- Highest possible performance
- Minimum component count
- Serial i/o (RS232) for interactive programming

Some of these criteria are mutually incompatible (e.g. low cost versus speed) but I will explain how to get the best performance from the NC4000 for any particular combination of devices, whether they be ram, eprom or i/o.

The board can be used as a complete Forth development system by connecting its RS232 port to a computer (an IBM PC or compatible) which is then used as a terminal and pseudo disc drive, Fig. 1. Software, including the serial-link handler, Forth compiler and keyboard interpreter for the NC4000, will be in eprom on the board, and will be explained in the next article on software. However, there are one or two unavoidable forward references to the next article made necessary by software characteristics that have an impact on the hardware such as reset address, interrupt vectors and program space.

TECHNOLOGY CHOICE

As the NC4000 is an HCMOS device, it will drive bipolar devices (standard, S, LS and F series t.t.l.), NMOS and, of course, other CMOS devices. Problems are only likely to occur if a bipolar output has to be read by an NC4000 input since HCMOS inputs switch at below 1.5V and above 3.5V whereas t.t.l. input thresholds are 0.8V and 2V respectively. To

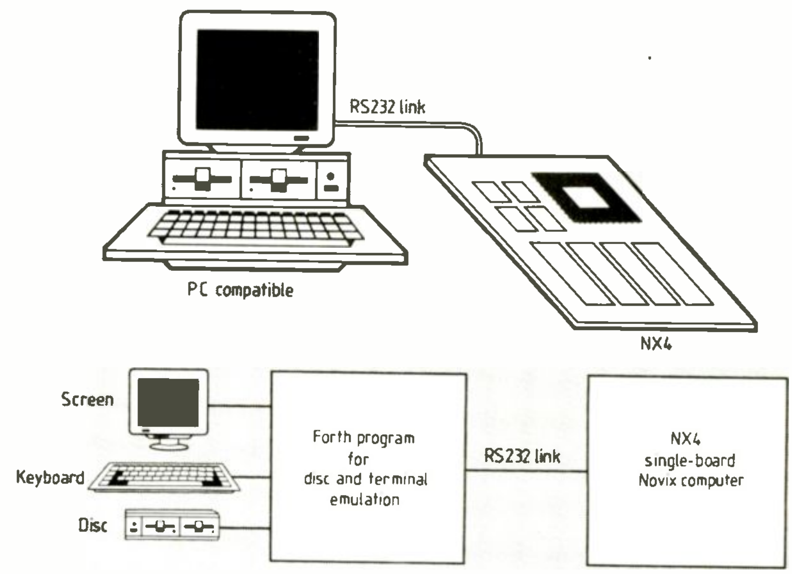
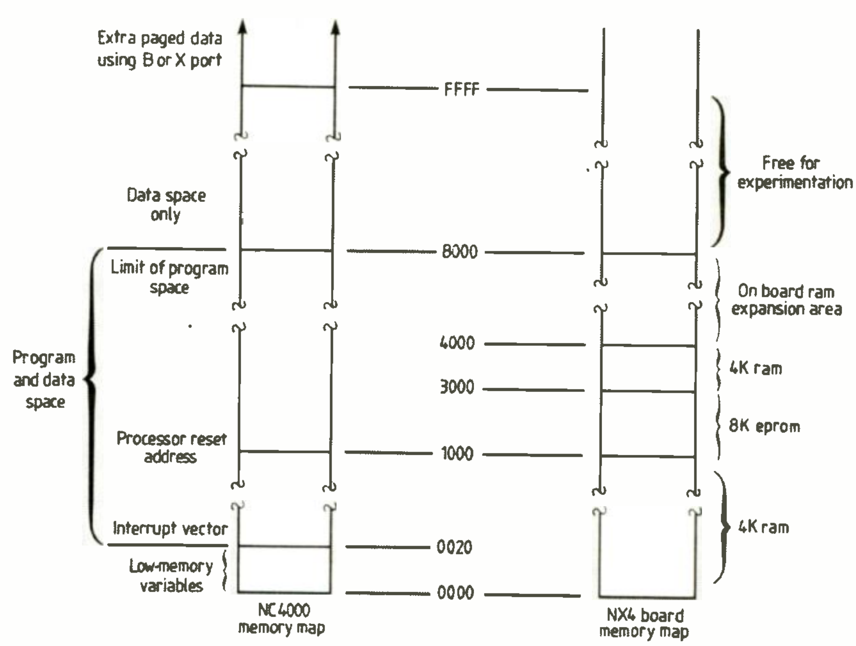


Fig.1. Low-cost NC4000 development. The NX4 board is ideal for stand-alone real-time applications, but also allows interactive development of those applications. Forth PC software configures the host computer to act as a terminal and disc drive, all down the one serial line, for the NX4 Board.

Fig.2. The memory map determines some of the eprom and ram mapping. In this design, the eprom is mapped into the middle of the ram, which can be expanded up to 24K words by replacing the 8Kbyte with 32Kbyte devices.



Main address and data bus	
T_{as}	65
T_{ah}	35
T_{dm}	40
T_{ds}	75
T_{wede}	60
T_{wedh}	45

I/O ports	
T_x	95
T_y	100
T_{webl}	50
T_{webh}	35

Data stack bus	
T_{ks}	75
T_{kh}	35
T_{ss}	45
T_{sh}	25
T_{wese}	50
T_{wesh}	40

Return-stack bus	
T_{js}	55
T_{jh}	30
T_{rs}	35
T_{rh}	30
T_{werl}	35
T_{wehl}	40

solve this problem, it is only necessary to interpose an HCT buffer to perform level conversion. Usually NMOS and CMOS memory devices have their outputs specified as being t.t.l. compatible, but they are also implicitly HCMOS compatible.

Output lines on the NC4000 come from HCMOS bus drivers on-chip so extra bus buffering is only required in exceptional circumstances. It is possible to load the address lines of a 4MHz NC4000 system with <500Ω and >300pF. Resulting output drive voltages will be within t.t.l. and HCMOS voltage levels, and the system will still function satisfactorily. The combination of the NC4000's relatively low clock speed (compared with some new processors), its HCMOS technology and its bus drive capability all help to reduce noise.

For the application described here, standard components are used wherever possible. However, memory decoding is done in 'fast' t.t.l. to leave as much time as possible for memory access.

CIRCUIT OVERVIEW

The NC4000 is a true 16bit processor so byte-wide memory devices are used in pairs. All addressing is in 16bit words, whether for program rom, ram or the two hardware stacks. As you can see from Figs 4, 5 this means a minimum of eight memory devices.

Two eproms, $IC_{9,10}$, contain a Forth operating system/development environment with plenty of room for expansion as over half of it is unused. Main memory ram is provided by $IC_{7,8}$. As shown, the board has 8K words (16Kbyte) of ram but, by rearranging some jumpers in the decoding and changing the 8Kbyte for 32Kbyte rams, all the memory space not already occupied by eprom can be populated by ram.

The parameter stack uses the bottom 256 locations of two 2Kbyte rams $IC_{13,14}$ as does the Return Stack, $IC_{11,12}$. Including the

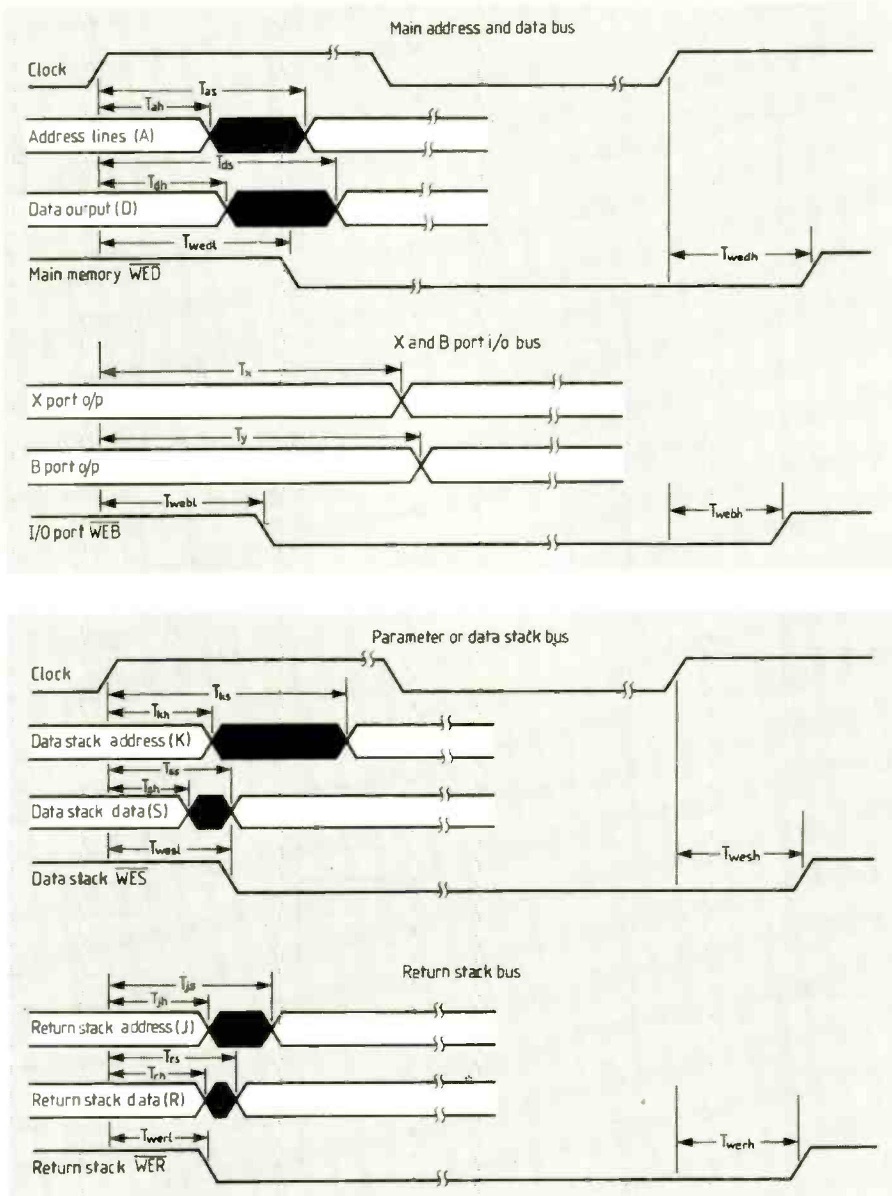


Fig.3. These timings in nanoseconds are average values based on devices with a T_{as} of 65ns. Shaded waveforms represent an indeterminate transitional period. Two important figures are T_{as} and T_{ks}. Time T_{as} needs to be ready early to give as much time as possible for memory decoding. Time T_{ks} has to be subtracted from overall cycle time to give the access time required for parameter (data) and return stack rams.

NX4 board specification

CPU	NC4000P
Memory	8K words (16K bytes) eprom 8K words (16K bytes) static ram Separate parameter and return stack rams
Speed	Average 4MHz (>4, and can be uprated to >5 mips)
I/O	One serial port (RS232), Novix 16bit B-port and 5bit X-port
Expansion	On-board memory expansion to 24K words (48Kbyte). Access to all Novix bus signals (except for stacks) provided on 64-way DIN 41612 connector pads.
Size	Single-width Eurocard
Power	0.5A with on-board 5V regulator
Software	cmFORTH in Eprom on the board, 5¼ in floppy disc for IBM PC/MS-DOS type host such as Amstrad PC-1512 with – Full source code for cmFORTH, utilities and demonstration, – Compiler to produce rom-based applications, – Forth Editor to run on PC host, – Terminal and disc emulation (for board) to run on host, – Documentation

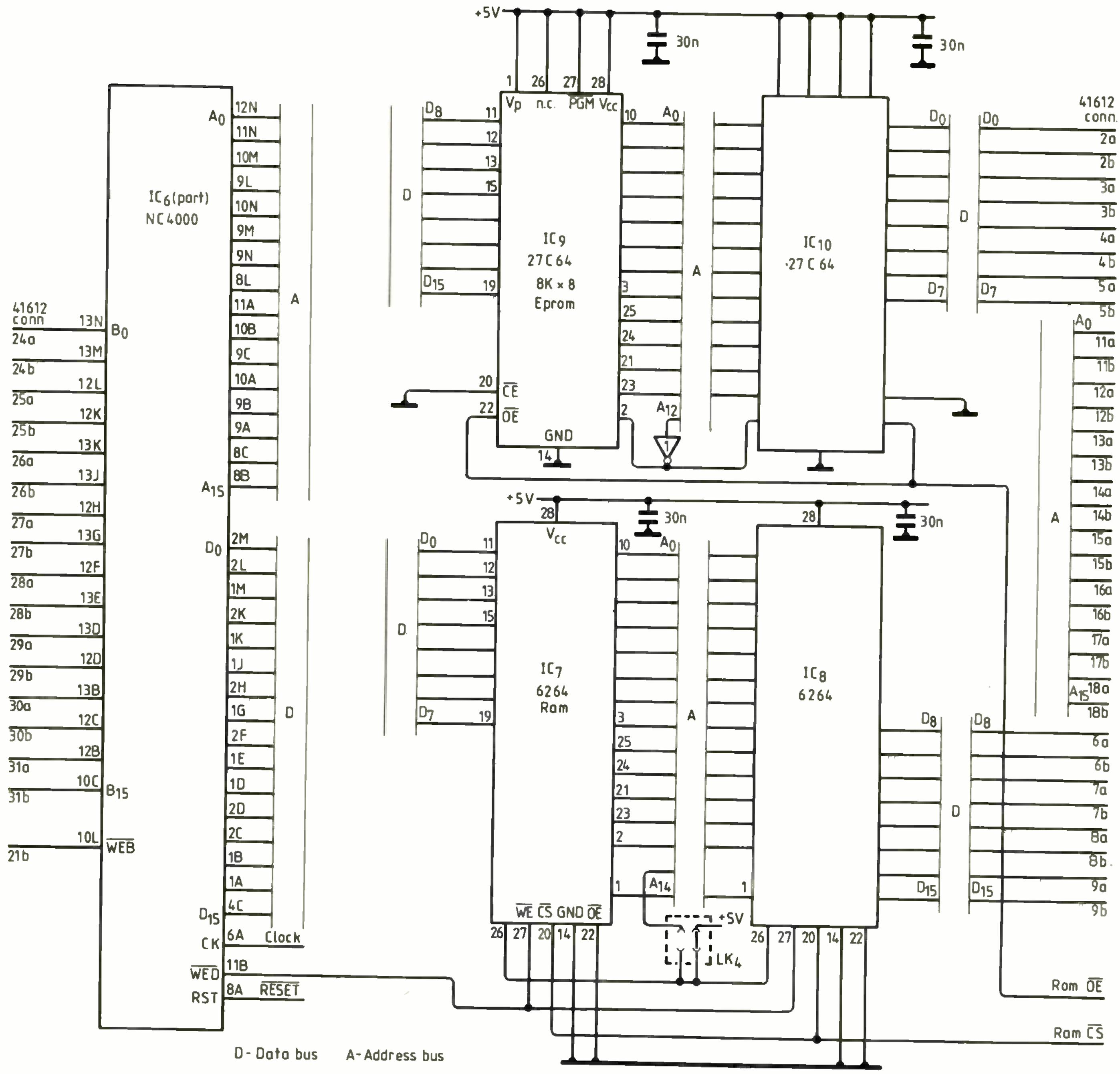


Fig.4. NC4000 processor main memory eprom and ram.

NC4000, this already accounts for nine of the 17 i.cs used. The remaining eight are for generating clock signals, decoding and RS232 buffering.

All major Novix signals, except for the data and address buses for the two stacks, are brought to a 64-way DIN connector, PL_1, so that additional hardware can be easily added. The speed of the 4000 makes it suitable for a number of applications including audio processing, vector graphics, robotics and computer vision. For maximum i/o throughput you will want to use the two on-chip i/o ports (B and Xport) but the main memory data, address and write-enable lines also allow you to add extra memory or memory mapped i/o devices.

Referring to Fig.6, the 74F138 decoder selects memory in 4K pages, and the subsequent And gates then give the optimum mapping of eprom and ram. It also uses the low part of the clock cycle to enable the chip-select outputs (Q_{0-7}) as a means of synchronizing the memory access part of the NC4000 instruction cycle with the actual memory devices. This section of the circuit also shows the switched-frequency clock generator which can be made to adapt to different memory access times, of which more later.

Power, reset and RS232 drivers are shown in Fig.7, and do not need comment, except perhaps to note the use of a spare Or gate to give an external reset line on connector PL_1.

NC4000 MEMORY MAP

On Figure 2, the memory map of the NC4000, there are five key points to note. Our first article described how the NC4000 uses bit 15 to denote a 'jump-to-subroutine' instruction with the remaining bits giving the destination address. The compiler effectively includes a value (the address) as part of the machine code instruction.

In the same way, the compiler can recognize short literals and addresses below 20_{16} and compile them with other Forth actions. As a result there is a scratch area from 0 to 1F that can be written to or read from in one machine instruction taking, in this case, two clock cycles.

Variable reading or writing normally takes two instructions and four clock cycles, so these low-memory variables are very useful for time-critical code. One way to regard them is as 32 off-chip scratch registers. This part of low memory clearly needs to be ram. More of these time-saving software details are discussed in the next article.

The next landmark is 20_{16}, the location to which the processor jumps when it receives an interrupt. As interrupt code can be held in ram or rom, it has no impact on the hardware design – it will almost certainly be a continuation of the ram used for low-memory variables.

Prototype versions of the 4000 series, designated 4000P, have a fault in that they

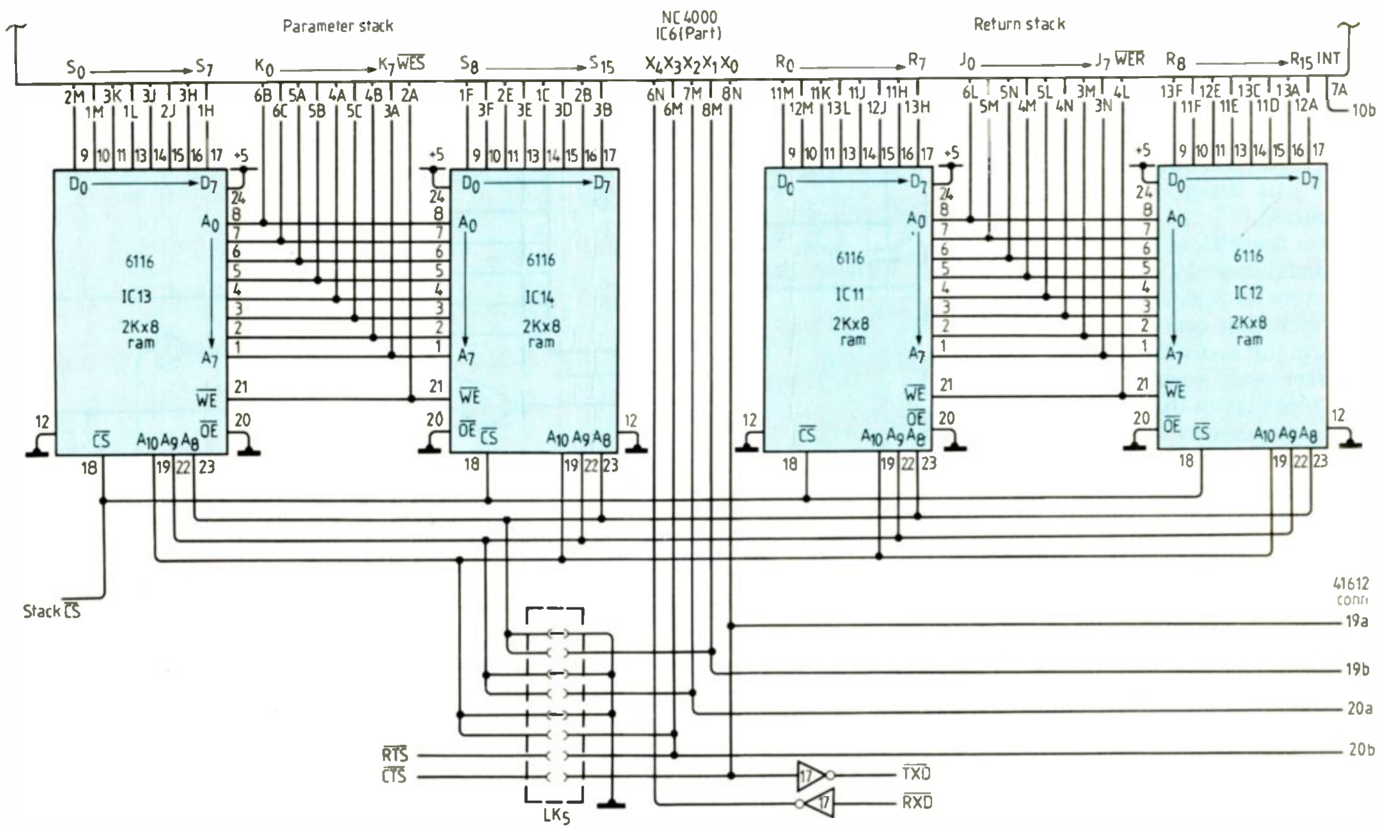


Fig.5. Stack ram and Xport hardware for the NC4000 processor.

will not correctly interrupt multi-cycle instructions. Use can still be made of the interrupt structure but a software routine is required to support its operation.

The address to which the processor jumps at reset comes next at 1000_{16} and will almost always be the start of rom or eprom. The reset address is on a 4K boundary which is inconvenient given the ready availability of 8Kbyte ram/eprom devices. Using 6264 rams and 2764 eproms, the solution is to map the lower 4K ram from 0 to FFF, eprom from 1000 to 2FFF and the remaining 4K ram from 2000 to 2FFF.

This is quite easily done by adding some And gates to the decoded outputs of IC_5. Referring to Fig.6, $Q_{1,2}$ feed the And gate which generates the eprom $\overline{OE}$ signal. However A_{12} is inverted at 1000_{16} (Q_1 active on IC_5) so an inverter has to be inserted on line A_{12} between the NC4000 and the eprom, Fig. 4. This provides linear addressing between 1000 and 2FFF.

Because the jump-subroutine address range is limited to 15 bits, program space has to be below 32K and it makes sense to keep that area full of ram and rom. To make full use of this part of memory, the circuit has an expansion capability of up to 24K words of ram.

Links LK_2 of Fig.6 allow you to select addressing for 6264 or 62256 type devices. Circuit IC_{16} maps the relevant Q outputs from IC_5 to give a $\overline{CS}$ for the 62256 option. processor can still read and write above 8000_{16} and this area is useful for data, tables, i/o devices and so on. If a full 64K words (128Kbyte) is insufficient, data storage can be vastly extended by using the X or B ports to page in further 32K pages.

TIMING

A necessary area of study for any new processor is its timing diagram. The NC4000's appears to be complicated by the fact that there are four of them, one for each bus. However, each bus is easy to understand once you realize that everything is timed from the rising edge of the clock input.

Figure 3 shows how all the signals relate to the external clock applied to the processor. As the clock goes high, the NC4000 latches any input data or program instruction, so outputs from ram, rom or i/o need to be held stable at this time (about 5ns). Propagation delay through memory decoding and deselect delay from standard rom and ram devices is enough to cover this. In fact, the address buses are all stable for a further 30ns.

The chip then carries out internal actions at maximum speed. Any output lines, for example main memory address and data lines, become available on the chip's pins the moment they have been generated; internal latching would produce delays and impair the chip's performance. There is a period of transition from the previous to the new values and these are shown as unspecified on the timing diagram. The most crucial time on the diagram is T_{as} since decoding for the next instruction can begin as soon as it is stable. Having the data ready 10ns after the address is fine as a memory device needs to be decoded and addressed before data can be applied to it.

Upon receiving the falling edge of the clock the NC4000 carries out no further actions. Instead, the designer must use this part of the clock signal to synchronize decoding, chip selects and so on, since the lower part of the clock cycle is for memory access only. You can see from the circuit that this synchronization is done by one of the SE inputs to IC_5.

The clock must be generated externally, and arranged so that the upper part of its cycle is at least T_{as} (65ns) long, equivalent to 7.5MHz. Running the clock with a 1:1 mark-to-space ratio at this frequency leaves only 65ns for the decode and memory access part of the cycle – realistically only 50ns after 10-15ns has been subtracted for decoding. While this frequency could give a computational performance in excess of eight mips, 45ns ram and rom are not yet widely available and are certainly not cheap. A low cost design forces use of lower frequencies.

If you now look at the lower part of the cycle and choose, say, 250ns as a practicable access time for readily available eproms, the clock cycle time goes up to 2×(250+15)= 530ns, or just under 2MHz, giving 2.4 mips. This represents a performance of around three times better than a 68000 programmed using assembly language and running at 8MHz, but it is still slow by Novix standards.

Somewhere between lies the ideal; by arranging a suitable mark/space ratio to the clock, the processor and memory can each be made to work at near-optimum efficiency. This clock waveform could be produced by Anding the clock signal with a delayed version of itself. An alternative is to use a high clock frequency and then divide it with a 74HC4017 counter, IC_4.

By connecting one of the counter outputs to the master-reset line, it is possible to set up a suitable mark/space ratio. A 15MHz clock gives a convenient clock pulse of 67ns, and a division of five puts the lower part of the cycle at 266ns.

Further optimization is still possible. Using a few extra components it is possible to reset IC_4 using a cs line to give a mark/space ratio which adapts to the speed of the device being accessed. A standard crystal oscillator feeds the clock input of the counter, IC_4.

Addition of an Or gate and two And gates allows the decoder to select the appropriate output to reset the counter and give the correct mark/space ratio for rom or ram. The Or gate has a spare input which is tied low. This can be used in conjunction with externally generated chip selects and the i/o clock signal to give a suitable access time for slower i/o devices.

Effective memory access time is, of course, reduced by any decoding delays there may be. In this design, decoding takes place through $IC_{5,2}$, with a total delay of about 12ns. The counter gives the following net memory access time for its outputs after decoding delays are subtracted.

Output stage	Access time
3	121ns
4	188
5	254
6	321
7	388
8	466
9	533
o/c	600

This scheme allows a free choice of ram and rom access times. Outputs three and five provide convenient times for 120ns rams and 250ns eproms, giving 5 and 3MHz clocks respectively. Accessing any device outside the board's memory map without putting a WAIT signal into the Or gate causes a default to the slowest cycle time of 600ns.

The NC4000 is entirely static and its clock may be stopped at any point in its clock cycle. If it is a few nanoseconds after the

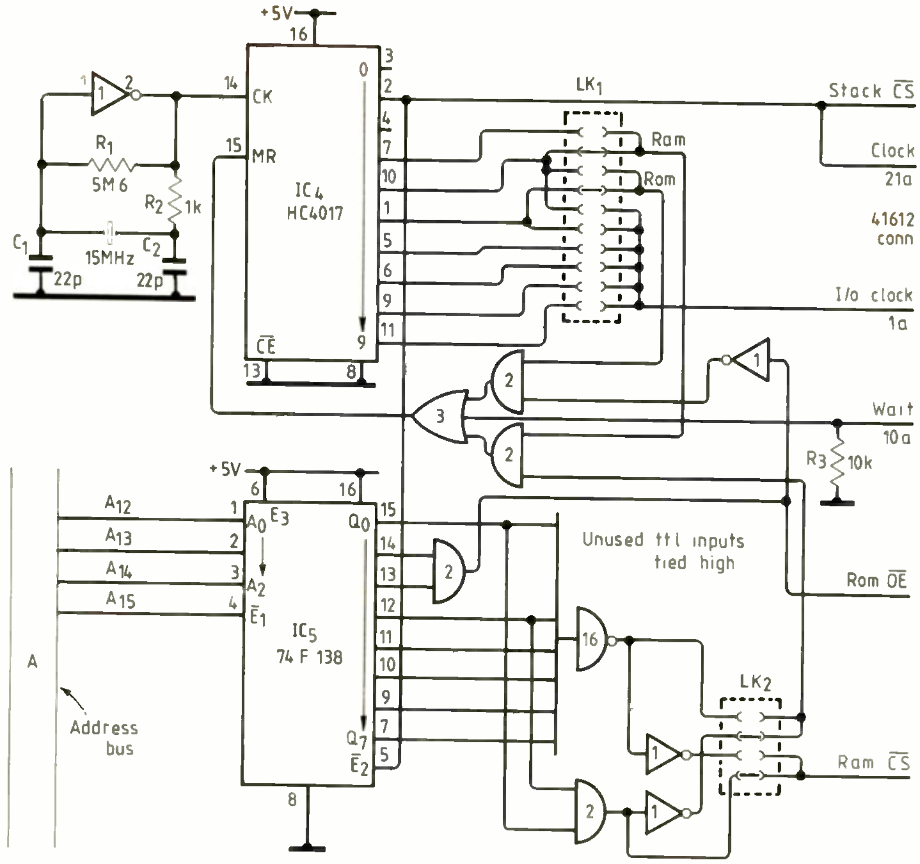


Fig.6. Variable mark/space ratio clock and decoding.

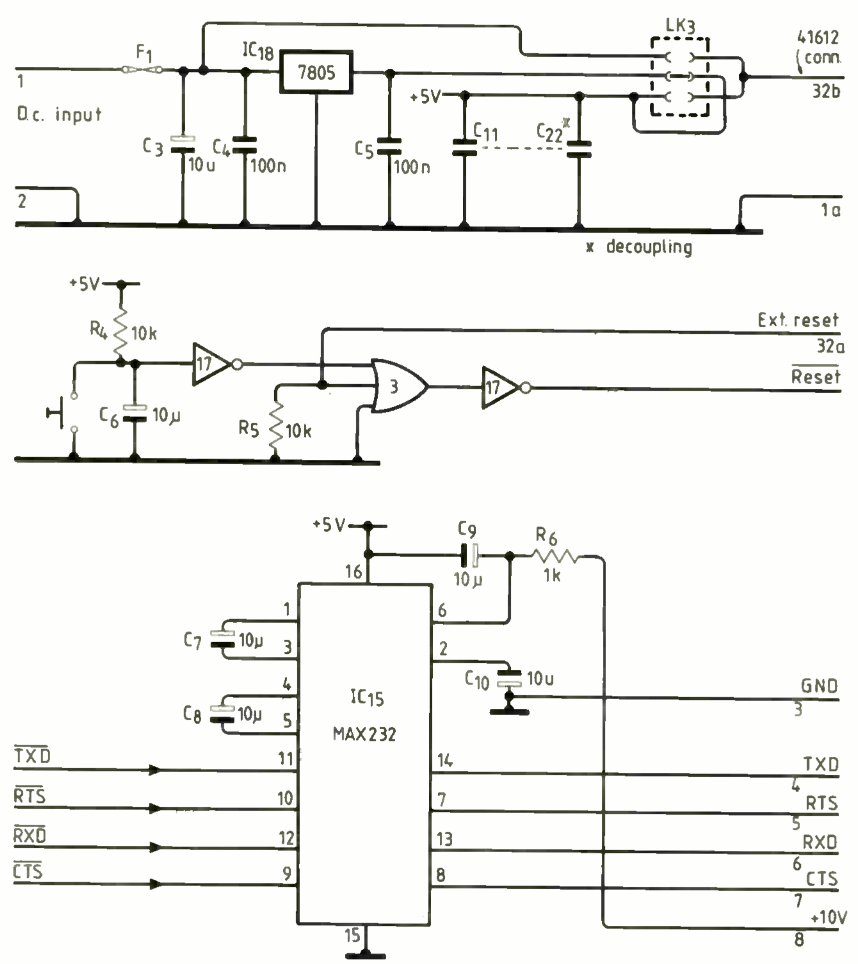


Fig.7. Power supply, reset and RS232 port hardware. The Maxim 232 produces RS232 levels from a 5V supply.

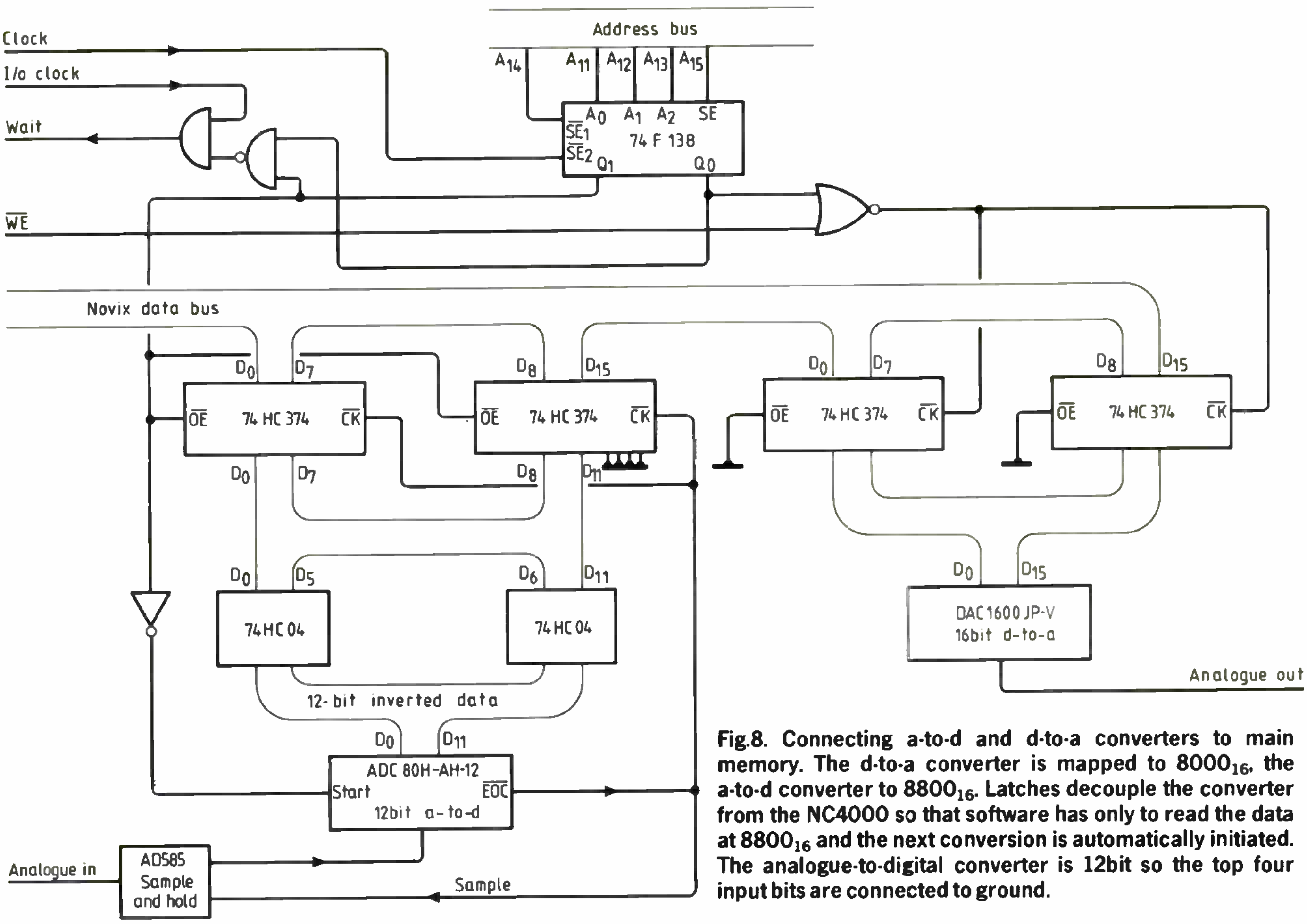


Fig.8. Connecting a-to-d and d-to-a converters to main memory. The d-to-a converter is mapped to 8000_{16}, the a-to-d converter to 8800_{16}. Latches decouple the converter from the NC4000 so that software has only to read the data at 8800_{16} and the next conversion is automatically initiated. The analogue-to-digital converter is 12bit so the top four input bits are connected to ground.

rising clock edge the c.p.u. completes its internal operations and then stops. Halted like this, the processor draws around 50μA.

STACK HARDWARE

Figure 5 shows stack hardware. Data stack, $IC_{13,14}$, and return stack, $IC_{11,12}$, rams do not require any decoding as the stack address lines only access the bottom 256 cells. Their timing depends on the shortest memory cycle time taken elsewhere in the system, e.g. when addressing program ram.

Referring to Fig.2, the longest time taken to output a valid stack address is T_{ks}, or about 75ns. Using a 5MHz clock the lower part of the clock cycle is 133ns, so the clock signal itself can be used to drive the ram select lines using 120ns-access devices. Note that the stack rams are accessed almost every clock cycle; standard nmos devices can be quite warm under these circumstances.

INPUT/OUTPUT

An important feature of the NC4000 is its i/o capability. There are 21 programmable on-chip i/o lines arranged as a 16bit port (Bport) and 5bit port (Xport) with separate mask and data direction registers for each port.

Ports X and B are useful in that they can often be used to replace other hardware, with consequent reduction in component and manufacturing costs. In this design port B is uncommitted and is available for experimentation. You may decide to use it for analogue/digital conversion or to extend the data storage space. The Xport gets used for two separate functions : serial i/o and multitasking hardware support.

There is no uart chip in this design – none is needed. The Forth system supplied in eprom uses one X-port line for serial input and another for output to form a software uart. During development, the serial line is used for communication with a host computer such as an IBM PC, which in turn is used as a terminal and disc drive for the Novix board, Fig.1. Software to handle this is discussed in the next article; it is only necessary to say that for such an arrangement, a software-uart serial link is adequate.

If you refer to Fig.4 you will see that Xport lines 0 and 4 are used for this purpose. Lines RTS and CTS are included even though the software supplied on rom does not use them.

The only restriction to a software uart is that it limits software using the serial line to single-tasking only. So what hardware is required to support multi-tasking? First, for any application that involves serial data, you will have to add a serial device to the hardware so that data can be transmitted and received independently from the c.p.u. Next, the NC4000 needs to have separate parameter and return stack areas for each task. Now it is perfectly feasible to run more than one task in 256 words of parameter and return stack, but the software for each task may have to be restricted.

A better scheme is to give each task its own protected parameter and return stacks by selecting a different area of ram. Three Xport i/o lines are available to do this, giving eight separate hardware task areas, neatly fitting into the 2Kbyte ram chips. As shown, the circuit is set up for just one task area (as is the software supplied in eprom), but the patch area LK_5 between the Xport bus and the Stack rams allows this to be done if required.

Adding extra hardware to the main memory bus is straightforward. Figure 8 shows how to add standard a-to-d and d-to-a converters to the memory map, which are useful for processing such as audio frequency analogue signals.

CONCLUSION

The NX4 board illustrates how to design Novix-based hardware. A number of improvements could be made, such as adding a proper uart and reducing component count by using pals or e.p.l.ds to replace decoding and clock hardware. Further component reductions will be possible as 16bit-wide memory devices become more readily available. Even with current components a minimal system need only consist of ten devices: two roms, six rams, a clock and an NC4000.

A description of supporting software (a small, but complete Forth development environment including a compiler for producing rom-compatible code) will be given in a subsequent article.

William Watson is with Computer Solutions of Byfleet, Surrey.

DHSS orders Plessey ISDX

The Department of Health and Social Security (DHSS) has placed an order, worth around £3.3m, with Plessey Communication Systems (PCS) for ISDX, digital private telephone exchanges. This, the largest individual ISDX order that Plessey has received, is for 57 systems for DHSS offices all over the country. The systems range in size from 48 to between 300 and 400 line capacities. Included in the price was a ten-year maintenance contract.

The DHSS is currently undertaking a three-year modernization programme. Its new network marks a change in telecommunications policy – purchasing instead of renting. One of the requirements for the new network is to be able to switch 64Kbit/s voice and data. This order, according to Plessey, includes some 6,700 extensions and accounts for around 14% of the new exchanges required. Where there are digital trunks, DPNSS (digital private network signalling system) is used to link exchanges and a newly introduced facility known as RAS II (remote access system) will aid maintenance.

RAS enables an ISDX to dial automatically a special telephone number in the event of a problem and connect with the PCS National Computer Aided Service Centre at Nottingham. Once the telephone exchange is in contact with the computer, the two machines can analyse the problem, and very often cure it, without human intervention. Should the problem require the attention of an engineer, staff at the computer centre can determine whether the problem can be resolved remotely or whether an engineer must be despatched.

NATO's new satellites from BAe

British Aerospace (BAe) has won the contract, worth in excess of £100million, to supply two communications satellites for NATO. They will provide secure military and diplomatic communications and be virtually identical to the UK's armed forces Skynet 4 series currently under construction by BAe and for which Marconi supplies the payloads. Skynet 4 services are voice, data and telex to and from naval vessels and fixed and mobile land terminals.

Designated NATO IV, the first of the new satellites is to be launched in the early 1990s. The previous NATO satellites were built by US company, Ford Aerospace.

Telecomms and IT converge at Northern Telecom

Northern Telecom has merged its Communications Systems and Data Systems divisions in the UK, the aim being to enable the company to provide a better response to market demands for converging voice-and-data networks.

Norwich Union gets distributed digital dealing

As part of its new £800,000 telecommunications upgrade, major insurance company Norwich Union will be one of the first geographically remote financial dealing rooms to be connected to BT's City of London Dealer Interlink exchange. Users of this exchange system can have their digital private wires patched through a central exchange at Moorgate in the City so that circuits can be added or reallocated rapidly to match changing business patterns.

The network is based on a Thorn-Ericsson MD110 digital PABX and handles 2976 extensions plus 267 trunk lines and private wires. It consists of a main exchange unit at its headquarters building in Norwich together with two remote sites in Norwich and one in London to handle dealer traffic. The private circuits are connected to Norwich Union's own London PABX and then routed through the new corporate network to the Norwich dealing room.

Dealers are equipped with 36-key Thorn Ericsson Courier digital programmable telephones. These have built-in displays to show each dealer the origin and destination of any Dealer Interlink call.

Philips adopts Siemen's ISDN standard

Philips Electronic Components and Materials Division has adopted the Siemens-developed ISDN-orientated Modular Architecture (IOM) and its associated interface as the standard for a new range of ISDN c-mos integrated circuits. The modularity of the IOM architecture is claimed to make for easy implementation of the ISDN customer basic access.

This interface is a standard 4-wire, local point-to-point duplex interface which interconnects ISDN layer 1 and 2 i.cs, or layer 1 circuits together. By conforming to the IOM interface standard, the new i.cs are suitable for use according to the CCITT I-series recommendations in ISDN terminals as well as in network terminations, line repeaters and line cards.

Besides the 2B + D channels required for basic subscriber access, a 64Kbit/s M-channel and a 48Kbit/s S channel are also available. They respectively transfer status information for local circuit control and ISDN basic access referred service information (such as signals for activation, de-activation and maintenance purposes).

Booming datacom test market

According to a report from international market research company, Frost & Sullivan, there will be major growth in datacom test and management markets over the next five years. The report "Data Communications Test, Measurement and Network Management Markets in Western Europe" (No.E887) projects an average annual growth of 26.5% from a base of $154 million in 1985 to a forecast $632 million (constant 1985 dollars) in 1991.

The study notes that the market will be driven both by user intolerance of system down-time and by the increasing complexity and diversity of communications systems. F & S expect the most explosive growth to be in programmable multi-function instruments, which embrace analogue, digital and protocol measuring and analysing functions. Here, from a small European base of $4m in 1985, they forecast the market to reach $104m in 1991.

Analogue instruments will be the least dynamic product class, increasing more slowly as a greater number of digital transmission systems are implemented and modems phased out. The network management and control segment will, according to F&S, increase from $64m to $268million by 1991.

Private network owners such as banks, insurance companies, airlines and oil companies will be the biggest consumers of all the groups covered in the study, with the exception of optical time-domain reflectometers which are used more by PTTs.

In 1985, the UK accounted for 28% of Western Europe's consumption of data communications test and measurement instruments and network management systems. At that date West Germany absorbed 13%, while Italy and France took 12% each. By 1991, the UK's share is forecast to drop to 25% with Scandinavia and the Benelux countries claiming 14% each.

Besides analysing and forecasting product and country markets, the report reviews relevant technology and the country-by-country data communications environment in Europe. Individual product lines are compared and major suppliers profiled.

More information on the report, which is priced at $2,500, from Frost & Sullivan on 01-730 3438

Cellular by the day

A deal between Avis car hire and Cellrent, a new company offering Vodafone cellular telephones for short-term hire, enables car rental clients at London's Heathrow Airport to have the option to hire a hand-portable Vodafone. Cellrent has identified as a prime target the international business traveller who wants instant worldwide communications while visiting the UK. Leading hotel chains and travel groups will also act as outlets.

Basic rental is £4.95 per day with billing being based on the Meterfone facility. This feature, unique to the Vodafone network, allows the call charge units to be read from the handset display. It automatically adjusts to the different charge rates.

Virgin hot air sponsored by Cellnet

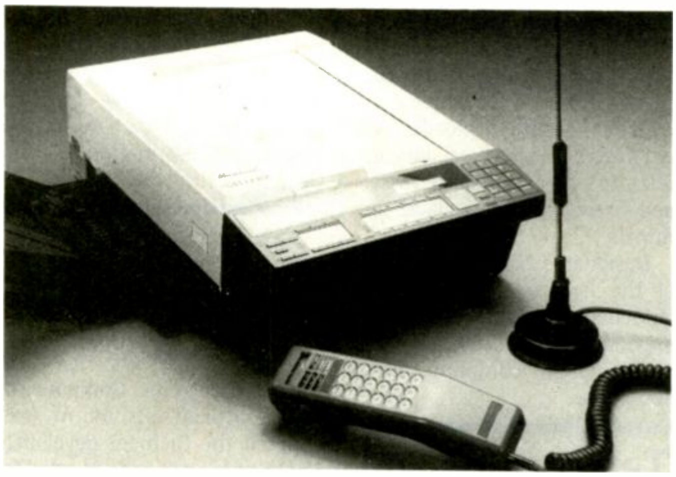
The Virgin Atlantic Balloon Challenge, the first attempt to make an Atlantic crossing by hot air balloon, is being supported by Cellnet, one of the two cellular networks. It will be providing a number of cellphones to the organizers of the challenge together with Celldata equipment to enable them to transmit and receive technical information.

The Cellnet International Servicelink programme will enable the Virgin team to use cellular phones in New York as well, where there is a different cellular system. This scheme allows Cellnet's customers to use cellphones whilst in the USA and Hong Kong more easily and cheaply than they might otherwise be able to do.

Muirhead moves to high street

Muirhead, the UK's first manufacturer of facsimile machines and well known for the machines used to transmit newspaper photographs, has launched a new range of Group 3 office facsimile machines. The three machines, each with an increasing range of features, all have the ability to scan A3-wide documents and have an RS232C interface port for linking to an encryption device or computer.

With the objective of expanding its customer base, the company will sell through a dealer network in addition to its established approach of selling direct. This, in the past, has been aimed mainly at the Blue-Chip companies, corporations, government and other public bodies – often those needing real systems experience.



Cellfax facsimile system from Muirhead, which transmits an A4 sheet in 11 seconds.

At a time when growth is running at 100% per annum and the UK population now exceeds 70,000 machines, the market is getting increasingly competitive. Muirhead does not intend to just become a "hot-box merchant" and aims to employ its technical expertise to solve customers' communications problems. For example, it is offering Cellfax, an adaptation of a standard machine. This is connected to cellphones via an interface unit fitted with a standard BT plug and socket arrangement, eliminating the use of acoustic couplers which are often unsatisfactory. Equally important, the system provides full error correction facilities to ensure uncorrupted transmission regardless of line quality.

Telecom Gold improves telex facility

Telecom Gold, British Telecom's electronic mail service, has installed CASE Beeline equipment to provide increased capacity for message delivery to the telex network. While users of the enhanced telex service will see few outward changes, they will benefit from an increased number of telex lines and an even spread of telex traffic. An additional feature is the optional online assistance, available before each prompt, to guide new users.

The Beeline equipment at Telecom Gold combines CASE's DCX communications exchange and a specialized applications processor into a single electronic telex switching system. This is integrated with TG's operational network via an X.25 packet switching gateway. Messages intended to be sent by telex are entered at users' terminals, word processors or personal computers and are passed through the network into Beeline's message store. Here the Beeline system takes over the message, transferring it onwards to the telex network.

Nynex acquires BIS

Business Intelligence Services Ltd (BIS Group) has been acquired by Nynex Corporation (New England Telephone and New York Telephone) in an exchange of shares valued at £75 million.

BIS Group, a major London-based information technology and marketing services organization operating worldwide, will continue to operate under its present management. It provides management of major organisation with a range of strategic information and communications.

Nynex is the third largest telecommunications company in the USA in terms of sales which were $10 billion (£6.7 billion) in 1985 and also has overseas offices in Geneva and Hong Kong. As well as providing telecommunications services in the north-east region of the USA, its companies also: offer international marketing and consulting services; market cellular mobile telephone services; and sell information systems and products; etc.

Variable block length protocol

Microcom has enhanced its error-correcting Microcom Networking Protocol (MNP) with further classes which increase the effective line throughput beyond that provided by MNP Class 3 which has, for example, been implemented by Dowty in its Quattro dial-up modem. MNP conforms to the ISO Open Systems Interconnection (OSI) network reference model and supports interactive and file transfer applications.

The protocol efficiency of the new MNP Class 4 implementation is about 120% so that a device employing it with a 2400bit/s modem will provide a throughput of approximately 2900 bit/s. It uses an adaptive packet assembly so that when line conditions are poor and retransmissions are high, packet size decreases thus minimizing the amount of data that needs to be retransmitted. Conversely, when line conditions are good, and retransmissions are few, packet size increases, and so maximizing data throughput. Class 5 adds a real-time adaptive algorithm for data compression with a resultant protocol efficiency of 200% while Class 6 provides a universal modem system which will operate at a full range of speeds between 300 and 9,600bit/s and dynamically adopt the highest speed that can be successfully handled.

Microcom has just received BABT Approval for its own AX/2400 and AX/2400c modems which conform to MNP Class 4 and 5 protocols respectively. It hopes to obtain approval for its Class 6 modem by the middle of the year.

Telecomms Topics was written by Adrian Morant.

CIRCUIT IDEAS

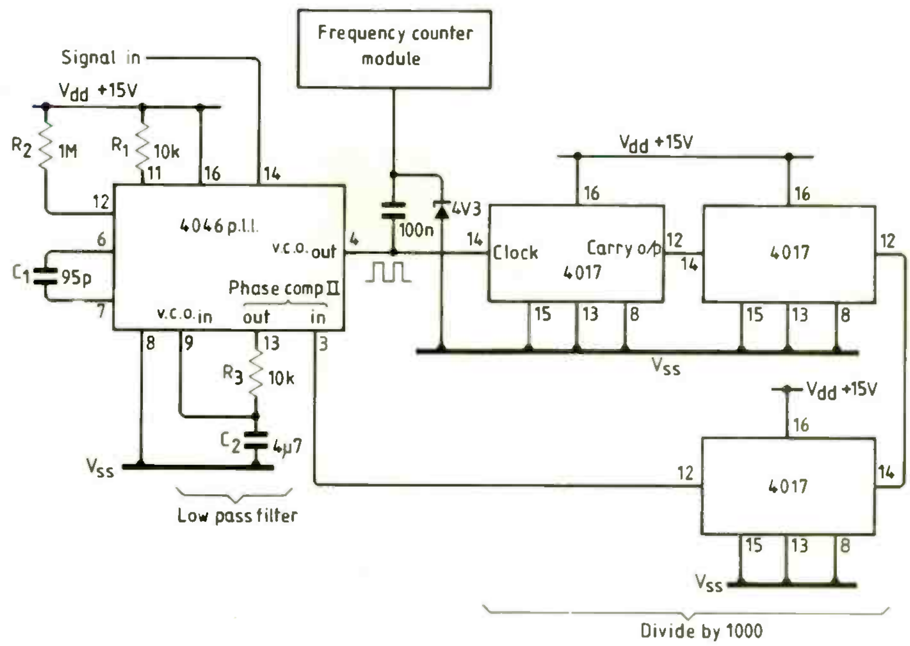
FREQUENCY MULTIPLIER

I needed a cheap but accurate way of displaying frequencies from 350 to 800Hz with a resolution of better than 0.5Hz. This design multiplies by 1000 over a 100Hz to 1kHz range and locks onto input changes very quickly – a standard counter would require a gate time of about 10s to give the same resolution.

Output of the 4046 phase-locked-loop v.c.o., which is used to drive the frequency meter, is 1000 times the input frequency. This output frequency is divided by three decade dividers to provide a signal for the phase-comparator input. Phase of the divided v.c.o. output is compared with phase of the input signal and the difference output drives the v.c.o.

Changing the number of dividers changes the multiplication factor, but bear in mind that the v.c.o. only works up to just over 1MHz. Response time is controlled by the low-pass filter.

Damon Hoggett
Carlisle
Cumbria.



CLOCK CIRCUIT FOR ASYNCHRONOUS DATA TRANSFER

Besides being simpler than a p.l.l, this clock circuit with synchronizing inputs can be used in systems receiving asynchronous data from several sources.

Normally a fixed squarewave clock is produced but if there is a transition on any input, a short output pulse occurs. If output level is high a negative pulse is added and *vice versa* so positive and negative clock edges are produced for each input transition.

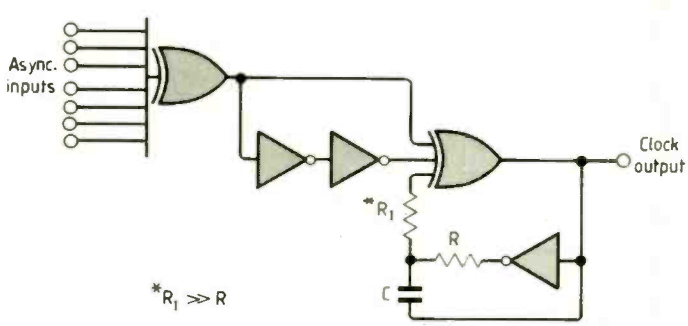
Operation of the oscillator is similar to that of the two-inverter type so its clock period is

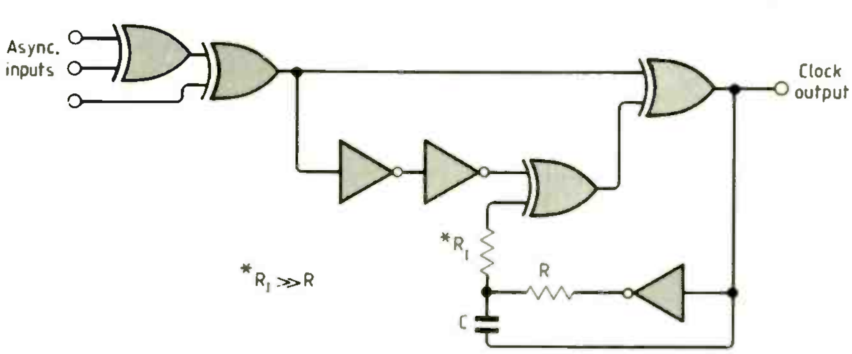
$$\tau \ln\left[\frac{(2-k)(1+k)}{k(1-k)}\right]$$

where τ is RC, V_{th} is threshold voltage for a logic-level transition, V_{DD} is supply voltage and k is V_{th}/V_{DD}.

Both a simplified circuit and a c-mos version for three asynchronous inputs are shown. With no input, clock frequency is at its lowest so the design is useful for battery-powered equipment.

Hernán Tacca
Buenos Aires
Argentina





Further reading

CMOS Linear Applications, G. Taajes, National Semiconductor application note 88, 1978 (two-inverter oscillator).
Nuevo circuito de reloj para máquinas secuenciales sincrónicas, H. Tacca, *Revista Telegráfica Electrónica* No 831, July 1982.
Nuevo método de proyecto en circuitos secuenciales, E. Capdevile, A. Barragán, N. Vergani and R. Ahumda, *Revista Telegrafica Electrónica* No 821, July 1981.

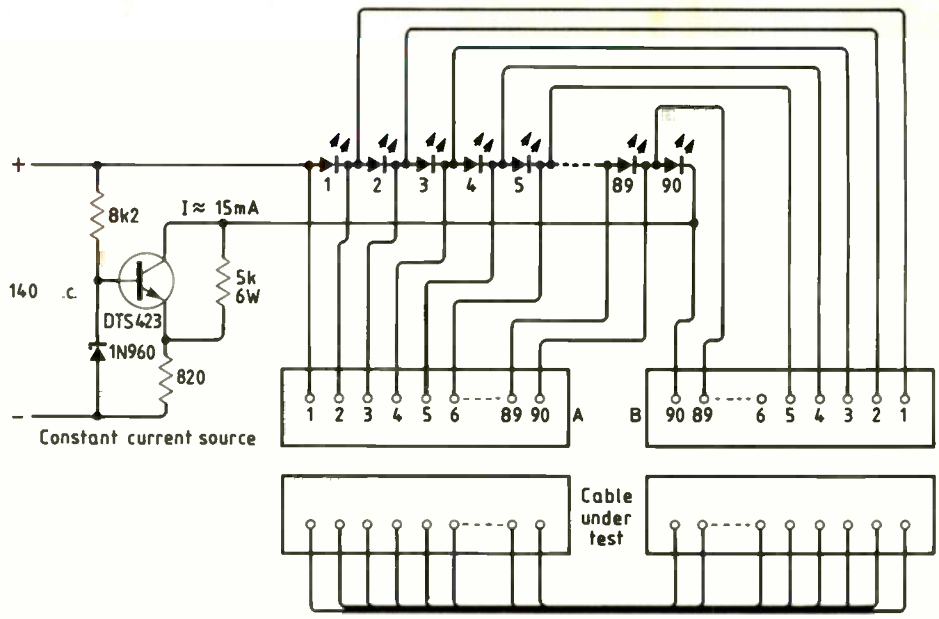
CIRCUIT IDEAS

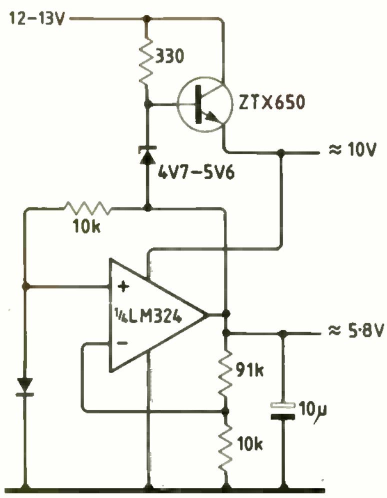
MULTIPLE-CORE CABLE TESTER

A string of leds powered from a constant-current source is used in this simple multi-way cable tester to check for broken or shorted conductors and crossed wires.

To test for short circuits, the cable is plugged into connector A. A short between, say pins 2 and 5 extinguishes diodes 3, 4 and 5. Open conductors are found by connecting the cable to both connector A at one end and connector B at the other. A lit led indicates that its corresponding line is open.

K. Dvorak
Canadian Standards Association
Rexdale
Ontario





DUAL-OUTPUT REGULATOR

One part of a quad single-supply op-amp forms a regulator both for its own supply voltage and other circuits. A secondary lower voltage output with better regulation is available for references, etc.

Despite its simplicity, this circuit is adequate for many applications. Performance is better than circuits using just a higher-voltage zener diode and trimming is possible using the op-amp feedback network. Note that the two voltages very together when the feedback network is altered.

Current output is about 500mA using the 2A ZTX650. If more current is needed, it may be wise to buffer the op-amp with a second transistor.

Robert Baines
Jesmond
Newcastle-upon-Tyne

AMPLIFYING SMALL VOLTAGES

Common practice when amplifying small direct voltages is to use a bandpass amplifier with switches at its inputs and outputs. This proposal is based upon simulation of a resistor by a switched capacitor.

The first op-amp functions as an amplifier and d.c.-to-a.c. converter, so the second op-amp amplifies an a.c. signal. Attenuation is provided by the third op-amp, which also acts as a switch for removing switching effects.

Two inverting and one non-inverting op-amps are used. Resistance R_{eq} is simulated by a capacitor $C_u(10^{-11}$ to $10^{-10}F)$ given by $R_{eq}=1/C_u f$ where f is switching frequency so

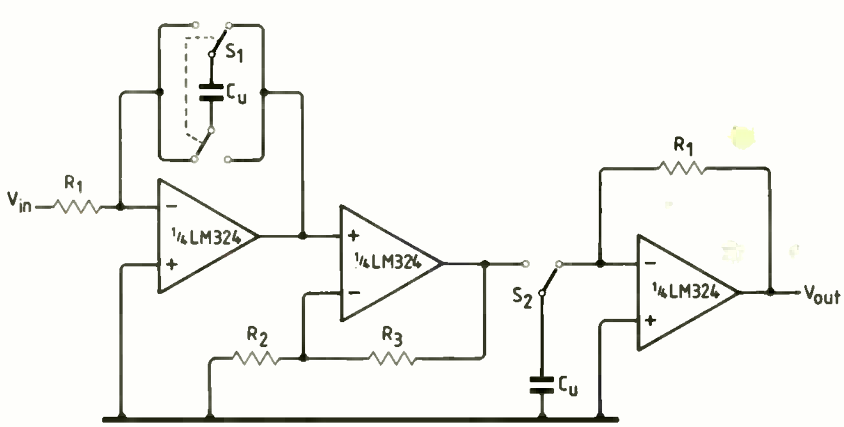
$$V_1=-V_{in}/fR_1C_u,$$
$$V_2=KV_1$$

and

$$V_{out}=-R_1C_ufV_2=KV_{in}$$

where K is $1+R_3/R_2$.

Kamil Kraus
Rokycany
Czechoslovakia



Designing a communications receiver

This new British-made receiver aims to outstrip far-eastern competition in both price and performance. John Thorpe of Lowe Electronics outlines his design approach.

J.R. THORPE

Most modern communications receivers adopt a dual-conversion superheterodyne design (Fig.1.). The multiple-conversion receiver provides several advantages:

- A high first i.f., higher than the highest frequency received, distances the mixer conversion image from the required coverage, and allows its rejection by a low-pass filter at the input. Also the local oscillator tunes through a sub-octave range.
- A low-frequency final i.f. can provide selective filters with good shape factors, and amplifiers for the bulk of the receiver's gain.

Each i.f. section must have a sufficiently narrow bandwidth to remove image responses from the subsequent section. With the availability of monolithic crystal filters for the first i.f., a dual-conversion h.f. receiver will be able to offer more than 80dB of image rejection for its second i.f.

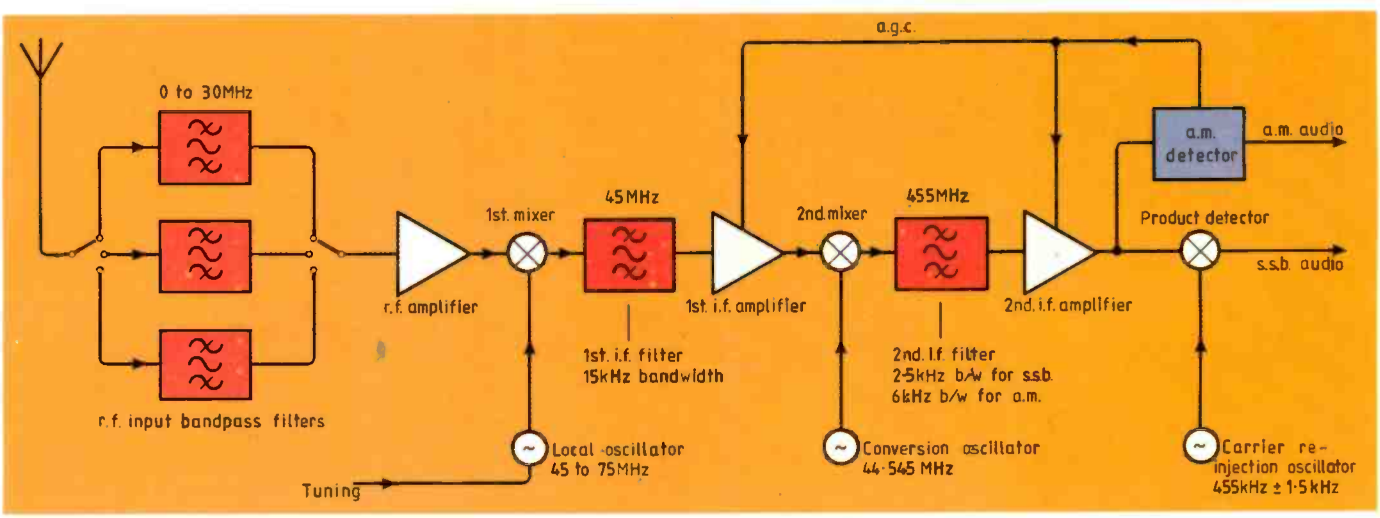
The r.f. filters at the receiver input are usually arranged as a bank of fixed band-pass filters, an appropriate one being selected to match the receiver's tuned frequency. In earlier receivers these filters would have a bandwidth typically less than 100kHz and would be mechanically tuned, either by a ganged tuning device or separately as a preselector. In electronically-tuned receivers this is uncommon: with a few exceptions, there is no tracked r.f. tuning and filters are consequently wider.

If the filter bandwidth is less than one octave the receiver system will be protected from strong signals that can produce even order intermodulation products within the receiver's tuning range. A set of suboctave filters is commonly found for frequencies above 1 or 2MHz, but below this limit fewer and wider filters are used.

A very important function of the input filters is to attenuate frequencies close to the first i.f. of the receiver and in the image tuning range. A separate 30MHz low-pass filter is often included to ensure good attenuation. A second requirement is low insertion loss, since signal losses here directly worsen the receiver's sensitivity.

The need for an r.f. amplifier stage will depend on the type of mixer and on the sensitivity required. With a useful sensitivity, an h.f. receiver would produce an output signal-to-noise ratio of 10dB for an input signal of about 0.2μV (p.d. into 50 ohms) in s.s.b. mode. This corresponds to an input noise figure of around 10dB, a noise level which will be exceeded by antenna noise in most locations using fixed aerial systems. If the receiver is intended for portable use with a whip antenna it should be more sensitive, and noise figures of around 3dB are appropriate.

Fig.1. Dual-conversion superhet for general h.f. coverage. First i.f. is commonly between 40 and 75MHz; second i.f. is often at 455kHz because of the wide range of standard filters available for this frequency.



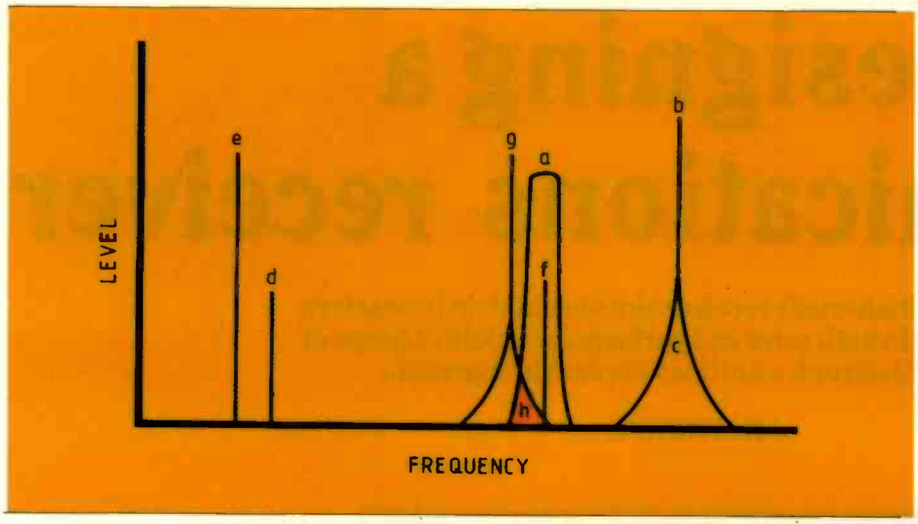


Fig.2. Reciprocal mixing may reduce receiver sensitivity when a strong, unwanted signal is present. Noise at h originating from the local oscillator b is mixed into the receiver's i.f. passband a; this noise may also be modulated by unwanted signal g.

- c noise sidebands due to phase noise in oscillator
- d wanted signal (weak)
- e unwanted signal (strong)
- f wanted signal after mixing, including local oscillator noise.

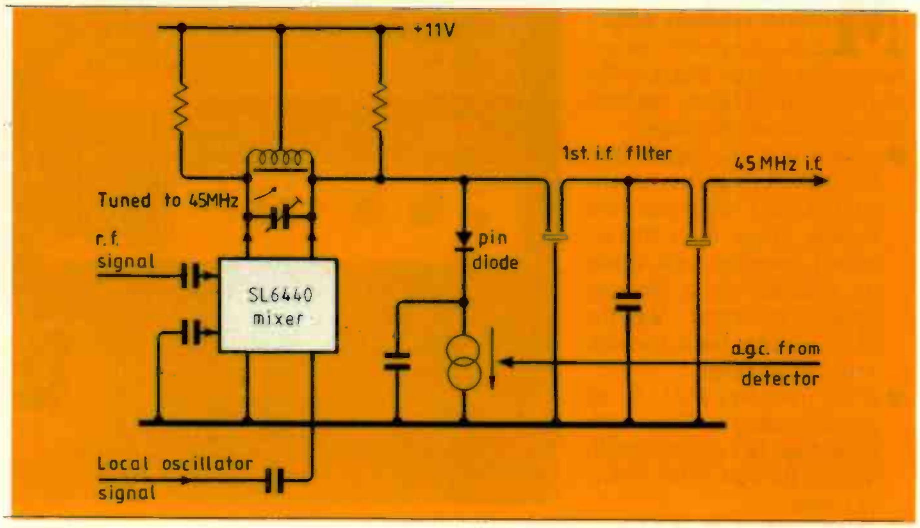
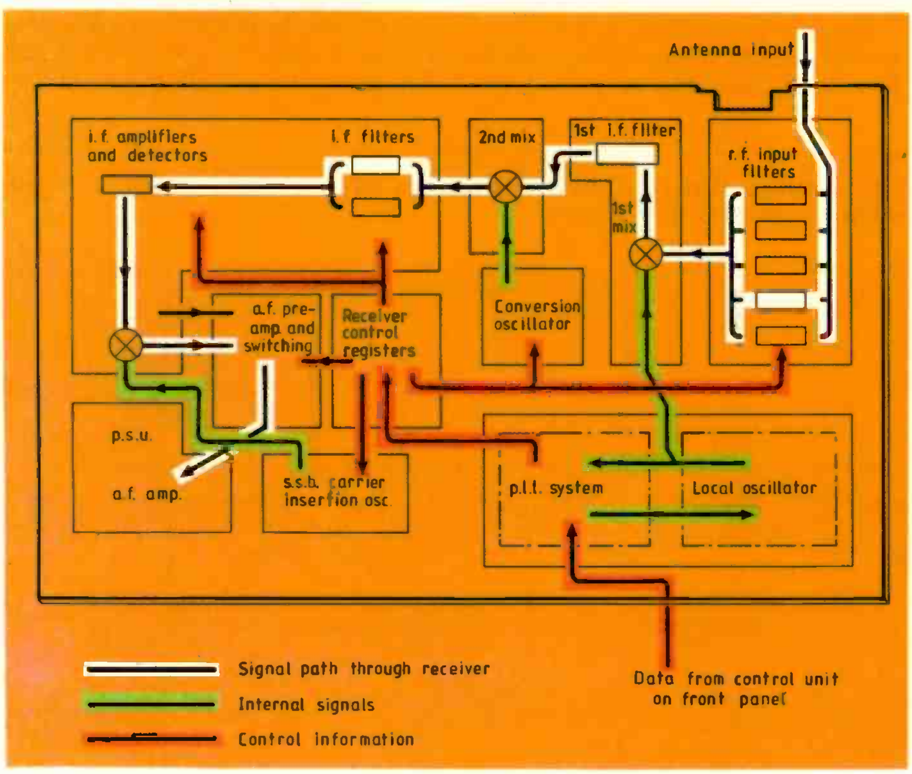


Fig.3 (right). First mixer and i.f. filter. A balanced output from the SL6440 mixer helps achieve maximum gain and dynamic range.

Below: layout of the main p.c.b., showing signal and control paths. Manufacture is greatly simplified by avoiding the need for inter-board wiring, connectors and screening.



FIRST MIXER

The first mixer and first i.f. filter must withstand the effects of potentially many strong signals over quite a wide range of frequencies; the performance of these stages will directly affect the receiver's ability to resist overload.

Double-balanced mixers are finding favour with many designers for several reasons:

- a useful 30 to 40dB of attenuation of the local oscillator signal fed into the i.f. filter is obtained by using a balanced mixer, with consequently less noise fed into the i.f. system.
- good isolation between the local oscillator port and the mixer input port means less signal fed back towards the antenna.
- sensitivity of the receiver to signals at the intermediate frequency is reduced by 30 to 40dB.
- even-order intermodulation performance is usually very good, and consequent savings can be made in the r.f. input filters without sacrificing overall performance.

The first i.f. filter serves two purposes: firstly to attenuate signals at the image frequency of the conversion to the second i.f., and secondly to reduce the number of signals that can reach, and may overload, the second mixer. Filter bandwidths are in the range 12 to 18kHz, but this is more chosen by available filter elements than by receiver requirements, which would call for a narrower filter.

Matching the first mixer to the filter is often a problem. Many mixers require a constant impedance at their output across a wide frequency range if they are to give good intermodulation performance.

SECOND MIXER

The second mixer generally has only to cope with in-band signals: the majority of out-of-band signals are removed by the first i.f. filter. It is often selected as a low-noise device or is preceded by a low-noise amplifier stage. But if there is excessive gain before or in the mixer, the receiver's third-order intermodulation performance usually suffers badly at signal separations of 10 or 5kHz.

Gain up to the selective filter (following the second mixer) should be kept as low as possible whilst preserving adequate receiver sensitivity.

Amplifier and detector stages following the selective filter have much more effect on resolved audio quality than on receiver r.f. performance. The a.m. envelope detector's linearity is critical for good quality, especially since some broadcasters now use modulation levels approaching 100% with heavily compressed signals.

The response of the a.g.c. system can have a marked effect on audio quality. For a.m. reception the average (i.e. carrier) level of the signal is best used, and the a.g.c. response should be slow enough to stop low frequency modulation causing excessive signal distortion via the a.g.c. feedback path. With s.s.b. signals, a.g.c. must be derived from peak signal levels. The attack (gain reduction) time needs to be fast enough to prevent i.f. amplifier clipping, but not so fast that the receiver is deafened by impulse noise spikes. Slow release times improve quality, but can be inconvenient for search tuning and for monitoring two-way traffic when the signals are of different strengths.

OSCILLATOR PROBLEMS

The local oscillator can have a considerable effect on the r.f. performance of a receiver.

Modern designs, with cheaper digital integrated circuits, favour electronically-tuned oscillators and frequency synthesis systems based on quartz crystal references. These can provide excellent frequency stability but suffer from a number of other problems:

- receiver tuning is not continuous as with a mechanically-tuned oscillator, but occurs in discrete tuning steps. For s.s.b. reception the steps must be small enough to resolve signal frequencies correctly; a step size of 10Hz is considered adequate.
- the oscillators and digital dividers produce quite large quantities of signals at a variety of frequencies. These can affect receiver operation in two ways: signals picked up by the sensitive input circuits of the receiver appear as spurious signals which can mask stations being received or produce annoying heterodynes; and signals may alternatively appear as sidebands to the local oscillator output, causing the receiver to have spurious responses at frequencies other than its tuned frequency.

HF-125 SPECIFICATION

Coverage: 30kHz-30MHz (150kHz-26.1MHz for German market)
Modes: a.m., s.s.b. (u.s.b., l.s.b. and c.w.)
Tuning: by spin-wheel, in 15.6Hz steps (step size increases with faster tuning rate); megahertz quick selection by up/down push buttons.
Memories: 30, with lithium battery back-up
I.f. filter bandwidths: 2.5/4/7/10kHz; 400Hz audio filter for c.w.
Sensitivity (typical values for frequencies above 500kHz): (s.s.b.) 0.3μV for 10dB s/n (a.m.): 0.7μV for 10dB s/n at 70% modulation
R.f. attenuator: user-selectable, 20dB
Noise blanker: permanent operation, 0.4ms blank period
Dynamic range: > 90dB at 50kHz from tuned frequency, 80dB at 20kHz (both intermodulation distortion and reciprocal mixing)
Image and spurious responses: >80dB rejection
Audio output: 0.75W into internal loudspeaker 1.25W into external 4Ω loudspeaker
Connections: antenna, 50Ω (SO-239 socket) or 600Ω + earth terminal; jack sockets for headphones, recorder, external loudspeaker, d.c. input (12V at about 250mA)
Options: f.m. and synchronous a.m. modes; internal NiCd pack, charger and active whip aerial; keypad frequency controller.

- Electronically-tuned oscillators used in frequency synthesis tend to have quite low-Q tuned systems and as a result produce an output with significant phase noise. By a process known as reciprocal mixing (Fig.2) this phase noise worsens the selectivity of the receiver. With a low-noise oscillator and a good quality s.s.b. filter, selectivities of −105dB at 20kHz, improving to better than −110dB at 50kHz from the tuned frequency are obtainable, but more typical values are −85dB and −95dB.

THE HF-125

At the design stage, the HF-125 communications receiver was required to have adequate performance to operate well on the short-wave broadcast and communication bands; but an overriding objective was to produce a receiver which could sell on the UK market in the £300 to £400 price bracket. Designing with a fixed price but a flexible specification produced the following initial guidelines:

- Standard parts and components should be used whenever possible; specialized parts should be producible with minimal tooling costs. As a direct result of this, the design does not require large volume production to maintain a low price.
- Assembly should be as simple as possible. A single p.c.b. design was desirable, avoiding wiring and connectors. Mechanical assemblies should be avoided in favour of an all-electronic design.
- As much circuit as possible should require no alignment, and necessary adjustments should be straightforward and independent. Testing and alignment procedures should be provided in the control system.

CHOICE OF MIXER

For the first mixer, a double-balanced device was required to overcome performance deficiencies in the necessarily economical r.f. filters. A choice of three types was available: diode ring, active ring (using fets) and integrated circuit (a transistor tree mixer). The transistor tree mixer, in the form of a Plessey SL6440 integrated circuit appeared to offer significant advantages over the other types:

- It could offer a small amount of gain and so removed the need for an amplifier stage in the first i.f.
- No broadband r.f. transformers were needed at the input and local oscillator ports of the mixer, significantly reducing costs. Also, the local oscillator power requirement was small.
- Mixer performance was relatively unaffected by the impedance seen at its output, allowing direct connection to the following crystal filter.

Operating current of the SL6440 mixer can be externally controlled, allowing a balance between power requirement, intermodulation performance and mixer noise figure. In the HF-125, the mixer is operated with about 10dB of gain; a mixer noise figure of 8dB is achieved with an input third-order intercept point of +10dBm. This performance fits the specification very well.

The gain of the mixer is dependent on its output impedance, and with a gain of 10dB performance is limited by the output stages. The 45MHz first i.f. crystal filters are of the fundamental type, with an input impedance of about 500 ohms matching the mixer's output directly. With no i.f. amplifier, a.g.c. action is provided by a p-i-n diode which reduces the mixer load impedance, decreasing its gain and at the same time raising its intercept point.

INPUT FILTERS

The input impedance of the first mixer is around 600 ohms, and since this is a convenient value for a high impedance input to the receiver, all the input filters were designed to match it. A 50 ohm input, also provided on the receiver, is transformed up to 600 ohms by a broad-band transformer.

Five selectable filters cover frequency ranges 18 to 30MHz, 10 to 18MHz, 4.2 to 10MHz, 1.6 to 4.2MHz and below 1.6MHz. Although there are too few filters to provide sub-octave coverage for much of the h.f. spectrum, an attempt has been made to separate broadcast bands containing strong signals from communications bands. Particular attention has been paid to removing medium wave signals (below 1.6MHz) from the higher frequencies. The appropriate filter is switched into the input circuit by p-i-n diodes; the high filter impedance helps reduce signal currents through these diodes and so prevents intermodulation.

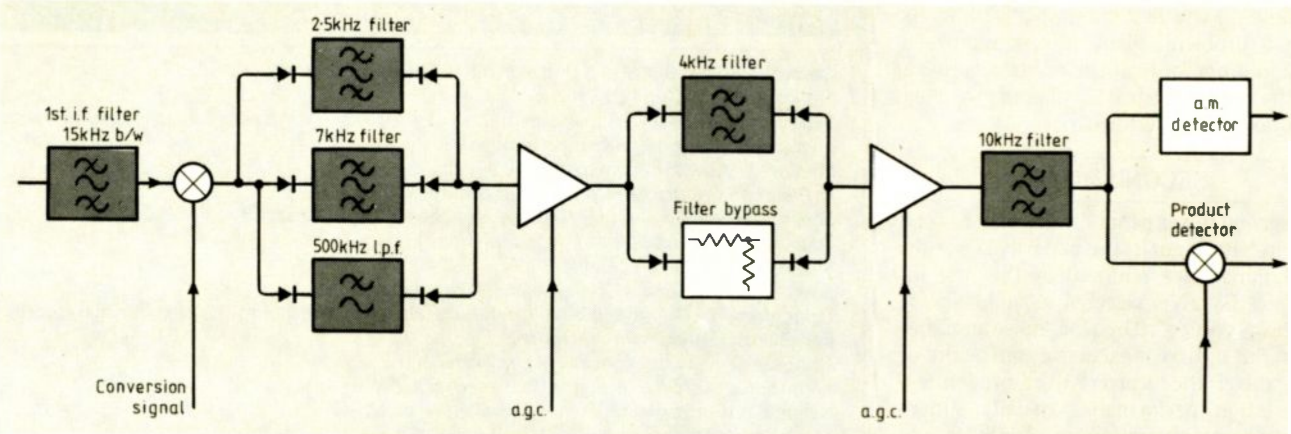


Fig.4. Second i.f. stage includes a cascaded series of amplifiers and filters. Filters are diode-switched for different i.f. bandwidths.

The filters consist of five-pole high-pass and low-pass sections constructed from fixed value inductors and capacitors. There are no adjustments; to cope with component tolerances the filters are designed to be wider than their required bandwidth. Even so there may be a variation of several decibels in receiver sensitivity at the extreme edges of the filter bands. The alternative type of filter using over-coupled tuned circuits was rejected because of the difficulty of production alignment.

SECOND I.F. SYSTEM

The first i.f. filters feed directly into the input of the second mixer. This is also an SL6440, although it operates at a much lower current than the first mixer. Configured to give about 4dB of voltage gain, it still has quite good intermodulation performance; and this, coupled with low gain in the first i.f. (about 8dB allowing for filter losses) ensures that the receiver's overall dynamic range is maintained above 70dB almost to the edges of the selective passband.

Because there is little room for worsening the noise figure from the first mixer, the noise figure of the second mixer is, of necessity, very low. The receiver as a whole achieves a noise figure of about 12dB (0.28 μV sensitivity for 10dB s/n in s.s.b. mode), which is quite adequate for nearly all applications except perhaps for optimum 10 metre amateur band listening.

The remainder of the second i.f. stage is based upon the Plessey SL6700 integrated circuit, intended for a.m. receivers. It contains two a.g.c.-controlled amplifiers, an a.m. and a.g.c. detector, and an i.f. conversion mixer which in this receiver is used as a product detector. Use of this chip means that there are only three active devices in the whole of the r.f. and i.f. sections of the receiver.

Multi-element ceramic filters are used in the 455kHz i.f. for the receiver's main selectivity. Because the small four and six-element filters cost little more than a tuned i.f. transformer, they were used for all coupling between amplifiers and detectors. The result is an i.f. system with good filter shape factors and excellent stop-band attenuation, that requires no alignment in production. In addition four different i.f. bandwidths are available by bypassing selected filters.

The 2.5kHz filter used is an expensive 14-element device; but it gives a 6:60 dB shape factor of better than 1:2, and is especially suitable for reception of a.m. signals in s.s.b. mode where a degree of carrier attenuation is required. Careful filter matching to achieve a flat i.f. passband response, coupled with a linear detector in the SL6700 produces good audio quality in a.m. mode. The 10kHz filter immediately before the detector improves the s/n ratio by removing broadband noise generated in the final i.f. amplifier.

P.L.L. SYSTEM AND TUNING

The easiest way to achieve the required frequency stability is to use a phase-locked loop synthesizer to produce the receiver's local oscillator signal. Several l.s.i. devices – programmable dividers and phase detectors – make the single loop synthesizer a straightforward and economical circuit. Unfortunately it is not generally suitable for receiver use, because the frequency steps (i.e. tuning increments) are equal to the reference frequency; and for the loop to control a wide-range voltage controlled oscillator (v.c.o.) adequately the reference must be greater than the required 10 to 20Hz tuning increment.

Two approaches are commonly used to overcome this problem:

- a controlled phase slip within the p.l.l. system, where a higher frequency reference is used with fractional division implemented by dividing by integers N or N+1 for varying proportions of time. Because the v.c.o. is divided by a number either above or below the required value (although the average value is correct) there is a gradual phase change between the oscillator and the reference, and this has to be made up by some form of controlled phase shift.
- a multiple loop system, using two, three, or even four separate p.l.ls to control the final output frequency. The loops share a common reference, but the output frequency of each loop is divided by a fixed value before being mixed into the next loop.

The cost advantages of a single loop p.l.l. were so great that the system was considered very carefully to see if its problems could be overcome. In a dual conversion receiver tuning is affected by both the local oscillator and the conversion oscillator frequencies; so, provided that the first i.f. is kept within the bandwidth of its filter, the conversion frequency can be tuned. This allows the local oscillator to tune in steps larger than the required tuning increments, and the conversion frequency to fill in with the fine tuning.

Table 1: i.f. filter selection (frequencies in kHz).

i.f. bandwith	1st filter	2nd filter	3rd filter
2.5	2.5	4	10
4	7	4	10
7	7	bypassed	10
10	500(l.p.f.)	bypassed	10

In the HF-125, the conversion frequency is about 44.5MHz, and a crystal oscillator is the obvious choice to generate this. This oscillator can be electronically tuned over a small frequency range of a few kHz by the control system, and although the resultant frequency is not locked to a reference oscillator, the stability is good. In practice the tuning range was restricted to 1kHz because beyond this range the linearity of control suffered unless thermal stability was sacrificed. The control voltage is derived from a d-to-a converter to allow digital tuning control.

By tuning the conversion oscillator the requirements of the local oscillator are eased somewhat: it is now required to tune in 1kHz increments. A synthesizer producing 45 to 75MHz from a 1kHz reference is feasible, but several problems will arise:

- the phase detector and loop filter require very careful design to reduce sidebands on the output (at 1kHz intervals) to an acceptable level.
- tuning response of the loop will be slow.
- the p.l.l. system will not be able to correct frequency fluctuations in the oscillator caused by noise or mechanical vibration to any great extent.

To offset these points, low cost of the system and a low component count produces a compact design; and with a c-mos l.s.i. divider there is virtually no spurious signal radiation and no need for screening.

PHASE DETECTOR

An important part of the p.l.l. system is the phase detector and low pass loop filter. The output from the phase detector will change at the same frequency as the reference signal, in this case at 1kHz. Signal components at this frequency must be removed by the loop filter to ensure purity of the local oscillator signal. Here, a digital phase detector has the advantage that when the oscillator and reference signals are in phase there is virtually no signal output from the detector. Also, the capture range of the p.l.l. is not dependent on the response of the loop filter. The digital phase detector consists of a series of edge-triggered latches.

To achieve the necessary reduction of 1kHz signal in the v.c.o. control voltage, the loop filter has a long time constant. As a consequence the lock time of the loop is considerable – about 600ms for a large frequency change. This is not normally a problem in a manually tuned receiver, but to alleviate unpleasant noises after, say, keypad entry of a new frequency, the receiver output is muted until the system achieves lock.

The p.l.l. is implemented with a single-chip Motorola device containing a programmable divider, a reference frequency divider and a digital phase detector. The necessary division range is from 45 000 to 75 000, and an additional dual-modulus prescaler (divide by 128 or 129) provides a 17-bit counter.

LOCAL OSCILLATOR

A fundamental LC oscillator provides the local oscillator signal over a frequency range of 45 to 75MHz.

The varicap tuning element provides a rather lossy capacitance, and to include it as a major part of the tuning reactance would result in an oscillator with a poor phase noise performance. To overcome this problem receiver designers often use several separate oscillators to each cover part of the required frequency range; three-oscillator systems are common. By this means the required capacitance change from the varicap element is reduced, and its Q can be improved by a small series capacitor combined with a fixed capacitor to provide most of the LC reactance. In the HF-125 a similar effect is produced without the expense of several oscillators: the inductance is switched to give four frequency ranges: 45 to 51MHz, 51 to 57MHz, 57 to 66MHz and 66 to 75MHz.

Performance is quite satisfactory for a low-cost receiver. The 1kHz sidebands on the oscillator output are below −45dBc, below −60dBc at 2kHz, and at or below the noise floor further from the carrier. Peak f.m. deviation is about ±5Hz at the lower end of the tuning range, rising to about ±10Hz at the higher end. The latter is audible when a pure tone is resolved, but is not detectable on s.s.b. voice signals. Oscillator phase noise results in a receiver selectivity of about 85dB at 20kHz, and 95dB at 50kHz, corresponding to oscillator noise levels of −120dBc/Hz and −130dBc/Hz respectively.

CONTROL SYSTEM

The control system provides the interface between the user and the internal workings of the receiver. It needs to be designed at two levels: the electronics required to control the parts of the receiver and the user's operating procedure. The latter forms a very important part of the receiver's specification, and in a domestic market is often dominant over r.f. performance in establishing sales potential.

To minimize costs and to keep the front panel uncluttered, many receiver functions, such as a.g.c. time constant and r.f./i.f. gain, are left to automatic control with no manual over-ride. This approach helps the less experienced user to operate the receiver.

For the control system a microprocessor using prom for program storage was chosen so that mask programming would not be necessary, and devices could be programmed as required for production.

Software holds the microprocessor in a static condition when the receiver's controls are not operated, and with the exception of the clock oscillator all signals in the control system remain at a steady d.c. level. This eliminates nearly all radiation from the control system and allows screening to be eliminated without affecting performance. The microprocessor clock also serves as the p.l.l. reference oscillator, reducing the number of signal sources within the receiver.

The microprocessor is supported by a liquid crystal display driver chip and a c-mos ram chip with lithium battery supply backup for the receiver's memories. These are interfaced through the processor's i/o ports rather than being connected to the c.p.u. data bus for reasons stated above. The receiver is controlled via a three-line synchronous serial data bus, which is well filtered to remove low level signals emanating from the c.p.u. A serial bus was chosen to minimize filtering and simplify connections.

H.F. RECEIVER DESIGN

Recent years have seen a trend towards more expensive and more feature-laden short-wave communications receivers on the domestic market. Unfortunately, many new designs have achieved little or no improvement, or have even worsened, the ability of a receiver – to receive.

This article looks at the design criteria, and necessary compromises, in producing a low-cost communications receiver with good performance.

To quantify that performance, we can consider some of its aspects –

Sensitivity: **the input signal level required for the receiver to produce, say, a 10dB signal-to-noise ratio at the output, under ideal conditions with no other signals present.**

Selectivity: **the ability to extract a wanted signal from a band containing many signals. Selectivity assessment would include measuring filter shape factors and their degradation by reciprocal mixing.**

Dynamic range: **the level of rejection of effects due to strong unwanted signals, including blocking, cross-modulation and intermodulation.**

Stability: **the extent of frequency changes with time and temperature.**

Signal quality: **the quality of resolved signals, distortion, signal-to-noise ratio, frequency response. Also the characteristic of the a.g.c. system.**

Facilities: **for example, reception modes, available filter bandwidths, noise blanker, notch filter, memory channels, external connections etc.**

Ease of use: **methods of tuning, frequency display, selection of modes and filters etc.**

A successful design should balance the different performance requirements so that the receiver is neither lacking in any one respect, nor excessively expensive because of the cost of making one aspect outstandingly good. Features offered will depend very much on the intended market area and the projected price.

ASSEMBLY

All components are mounted on two printed circuit boards. A small board behind the front panel contains the microprocessor and memory circuits, the display and all the front panel controls. It is connected to the main board by two right-angled connectors, a total of 15 connections for power and control lines. The main board is mounted in the bottom of the case, and connections on the rear panel of the receiver mount directly on to this p.c.b. There is no wiring in the receiver with the exception of a cable to the loudspeaker mounted in the top of the case.

The main p.c.b. is double-sided; the component side is mostly covered with a ground plane. This, with a careful component layout, reduces interaction between separate sections of the receiver; no additional screening is required.

The local oscillator and p.l.l. system have a separate ground plane from the rest of the receiver circuit to eliminate circulating currents in the ground system and the metal case. Splitting the ground plane was effective in reducing local oscillator radiation from the antenna input. An aluminium case screens the receiver circuits from external signals.

John Thorpe read engineering and computer science at Cambridge University, with sponsorship from Lowe Electronics. Since graduating in 1983 he has been with Lowe at Matlock where he is head of development. One of his spare-time interests is bell-ringing.

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139	0.40	0.49
151	0.45	0.59
153	0.45	0.59
154	0.85	
157	0.40	0.55
158	0.40	0.55
160	0.55	
161	0.55	0.55
162		0.55
163	0.55	0.55
164	0.55	0.55
165	0.60	0.75
166	0.60	0.60
173		0.55
175	0.55	0.55
193	0.60	0.75
194	0.50	
240	0.65	0.89
240		0.89
241	0.65	
241		0.79
242		0.29
243		0.79
244	0.65	0.89
244	0.95	
245	0.80	0.95
257	0.50	0.55
273	0.65	0.89
280	0.75	
354		0.85
356	0.65	
366	0.40	0.59
367	0.40	
373	0.65	0.95
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Recent m.o.s. transistors remove historical limitations to pulse-duration modulated amplifiers and bring new power and performance to industrial applications.

BARRY FRIEDMAN

Advances in m.o.s. power transistor technology, plus fresh circuit thinking, have propelled pulse duration modulation power amplifiers from technological backwaters to the forefront of sophisticated power deployment. Modulated-pulse technology provides a new level of compatibility with a surprising range of applications. Besides competing against s.c.rs at the upper levels of 'smart' power, and providing an alternative to linear amplifiers where size, weight, heat dissipation and efficiency are issues, p.d.m. devices span an impressive application range, outlined on page 416. Pulse-duration modulated power sources now provide off-the-shelf answers for fast-response four-quadrant d.c. supply needs, shrink the size and heat dissipation of variable-frequency a.c. sources and line conditioners, and contribute high efficiency and ease of voltage stabilization to u.p.s.s. They also provide new solutions to magnet coil energization in nuclear accelerators and high energy physics research, plus fresh responsiveness and power ratings for d.c. motor drives.

Low distortion, excellent linearity, and bandwidth of 12kHz, plus improvements that are in the offing, add audio and public address systems to the expanding roster of new p.d.m. power amplifier applications. The technology's inherently high efficiency – upward of 90% is standard, 98% is not unknown – maximizes operating life and minimizes heat generation in mobile equipment for robots, in-plant vehicles and research submarines. Small size and low weight promote mobility and portability, and enable electronic control to be packed into tight spaces without the cost and complexities of water cooling.

Applications that demand a combination of power and what might be called electronic agility are particularly compatible with p.d.m. High power function generators are widely used in nuclear research, vibration testing, sonar excitation, and automatic test equipment, where subtle computer programming must be capable of choreographing kilowatts, or even hundreds of kilowatts, of electrical power, and in many cases p.d.m. amplifers do a significantly better job than any other technology.

A linear amplifier is inherently inefficient because of the balance of power supply voltage not applied to the load is developed

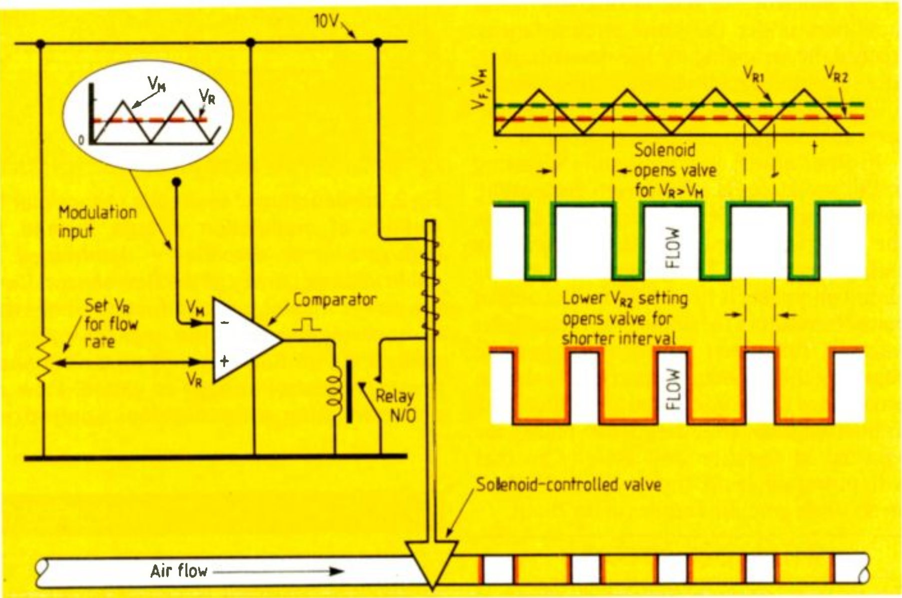
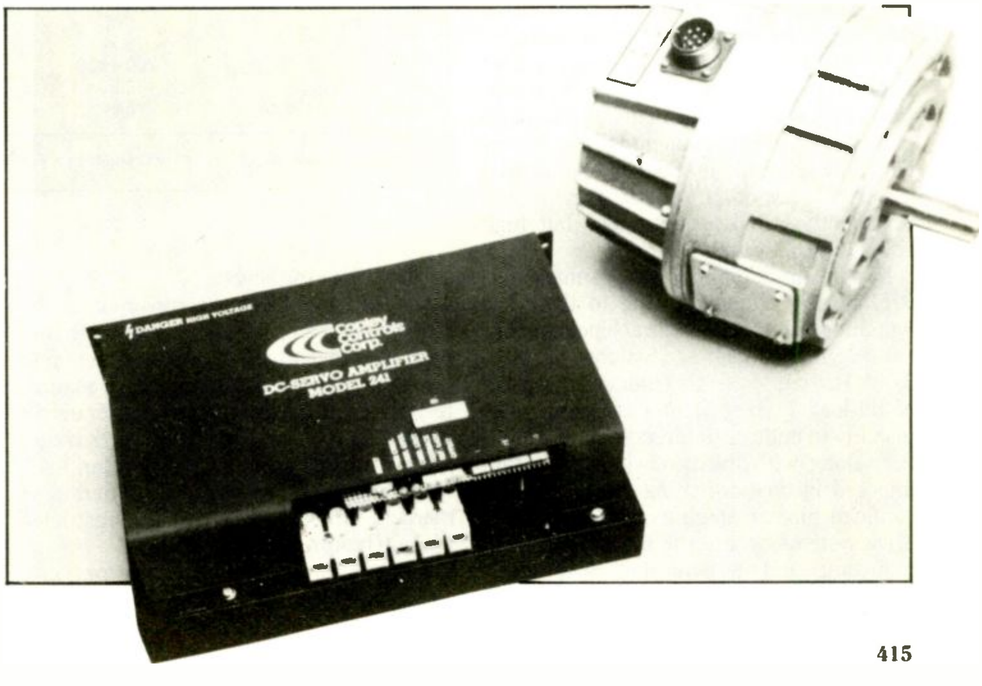


Fig.1. Simple open-loop system adjusts air flow by controlling the solenoid-powered valve's on/off duty cycle in accordance with flow rate voltage V_R set by potentiometer. So long as modulation voltage V_M is less than flow voltage V_R the comparator switches to +10 volts output, energizing relay and solenoid, hence opening valve for air passage. When modulation triangular waveform V_M exceeds flow voltage V_R, comparator output switches to zero, releasing relay and solenoid to halt air flow. Waveforms show how higher values of flow voltage V_R produce longer valve-open periods.

Highly compact p.d.m. amplifier develops 4,50C watts heat dissipation (98% efficiency) and is smaller than a telephone directory.



across the output transistors. In essence, whatever the load does not recieve the transistors dissipate. Pulse modulation amplifiers skirt this fundamental difficulty, rather than confront the heat dissipation issue head on.

The panel on p.419 shows how the efficiency of the simple circuit rises to a theoretical 100% when an ideal transistor handles rectangular wave signals. This is the principle that p.d.m. amplifiers harness: the power output stage is arranged to handle only rectangular waves – hence apply full power supply voltage to the load – regardless of the kind of signal that the amplifier processes. Accordingly, even though the p.d.m. amplifier might deliver 50kW of sinusoidal energy to a vibration transducer, efficiency is not limited to the theoretical 78.5% efficiency ceiling of ordinary linear amplifiers under the same circumstances. Instead, by arranging for the power transistors to switch rapidly between fully on and fully off conditions, the output stage preserves a close approximation to the ideal.

In other words, ideal transistors operating in this mode would exhibit zero dissipation, hence provide 100% efficiency, regardless of the input waveshape. This is the essence of class D operation. The design task faced by circuit engineers is to arrange for the output power transistors to handle only rectangular waves at full power supply voltage, while adjusting their conduction periods to vary in accordance with input signal amplitude. The fixed-amplitude, fixed-frequency pulses are adjusted in duration and polarity so that with output filtering, the amplifier develops an accurate amplified replica of the input.

WHAT TOOK SO LONG?

What's new is today's generation of m.o.s. power transistors, which remove the historical limitations imposed by early bipolar designs. Today's m.o.s. power transistors provide current and voltage ratings comparable with bipolar types, but the feature that distiguishes them most for modulated pulse amplifiers is their speed, leading to wider bandwidth operation, which puts the technology into the mainstream of industrial usage. In addition, with today's switching frequencies far above the human hearing range, audible noise at the modulation frequency has been completely eliminated.

In absence of output filtering, p.d.m. amplifiers feed the load with fixed-frequency, variable-width pulses whose amplitude is equal to the supply voltage. Naturally, only a limited number of applications can handle raw output pulses: they need to be smoothed into a continuous but high power copy of the input.

Early p.d.m. amplifier designs made output filtering difficult, owing to their low switching frequency. A typical bipolar amplifier designed a decade ago switched at 500 to 5,000 Hz: consequently, inductors capable of full-load filtering become enormous. The inability to build such filters into the amplifier, along with the bandwidth limitation imposed by low switching frequency, has confined bipolar amplifiers to servomotor drive systems, where the motor's inherent inductance and mechanical inertia provides a natural filtering effect.

Indeed, because most servomotors demand modest amplifier performance, there's been little incentive for servo system manufacturers to exploit new m.o.s. transistor technology. As a result, much of the current ferment in p.d.m. amplifier design comes from firms outside the servomotor field, where entrepreneurial manufacturers seek markets far removed from the restricted niche of motor powering.

Today's m.o.s. power transistors give creative circuit designers the wherewithal to extend pulsed amplifer capability to performance levels previously the sole province of linear amplifiers. The upshot is an industry-wide upgrading of amplifier specifications, where an order-of-magnitude higher switching frequency raises noise far beyond human hearing, achieves 12kHz bandwidth, and permits a built-in filter to hold switching frequency ripple below 1% of the output voltage.

Growing compatibility between

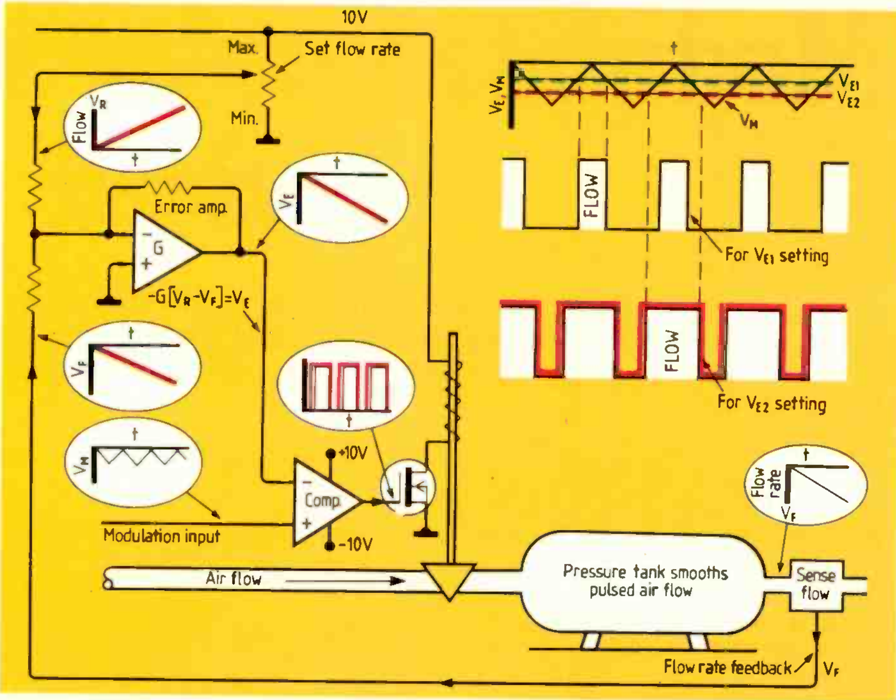


Fig.2. Introduction of feedback reduces air flow's dependence on linearity and amplitude stability of modulation voltage. Instead, flow rate depends on gain stability of the high-gain error amplifier – determined by the three external resistors – and the calibration accuracy of the flow sensor. Comparator develops positive pulses for driving the power mosfet into conduction whenever error voltage (which has negative polarity), is more negative than the negative-going modulation voltage. Pressure tank's ability to smooth the air flow depends on tank capacity, modulation frequency, and rate at which pressure control voltage is varied. Flow control system mimics the electrical p.d.m. power amplifier, which develops a pulsed output in absence of filtering circuits.

AMPLIFIER COMPARISONS

Traditionally modulated-pulse amplifiers have been confined by bandwidth and output distortion limitations to a niche market powering servomotors. Availability of recent m.o.s. power transistors has eliminated historic performance limitations, enablihg p.d.m. amplifiers to compete with a wide range of linear and thyristor power sources. In addition, they can function as bipolar four-quadrant programmable supplies, variable frequencies a.c. sources and line conditioners, as well as high-power function generators.

Comparison between commercial linear amplifiers, p.d.m. amplifiers, and thyristor power sources

	First generation p.d.m. units	Linear power units	Thyristor systems	Second generation p.d.m. units
Power ceiling	20 kW	100 kVA	MW	MW
Switching frequency	5 kHz	–	60 Hz	80 kHz
Bandwidth	500 Hz	50 kHz	5 Hz	10 kHz
Linearity, d.c.	5%	0.1%	–	0.05 – 0.5%
Distortion	5%	0.5%	–	0.1 – 0.5%
Efficiency	80%	30 – 60%	90%	90 – 98%
Watts per pound*	200 – 500	5 – 50	15 – 50	500 – 1500
Dollars per watt	2.00	3 – 0.6	1.00 – 0.25	0.50 – 0.30
Watts per cubic inch	5.00	0.15 – 0.5	0.7 – 2	15 – 30

* Excludes power supply; varies with cooling method. Thyristor systems don't require separate supply.

modulated-pulse amplifiers and music reproduction will probably lead to distributed music systems with an amplifier built in to each loudspeaker. Instead of using a large centralized power amplifier, low-level music signals will then be piped, probably in digital form, to the widely dispersed speakers. By adding address information to each digital music word, a jukebox-like music source will then be able to send individual music selections to self-amplified speakers in each separate location.

LOW HEAT GENERATION

Reduced heat dissipation leads to lower transistor junction temperature hence enhanced m.t.b.f. In addition, heat removal is simplified, room air conditioning requirements are eased, and the amplifier's bulk and weight are significantly decreased. Water cooling, necessary with many linear amplifier applications, is also eliminated. In turn, these attributes lead to notable application benefits: equipment mobility for instance, or integrally mounted electronics instead of a separate equipment rack. Another is drastically reduced operating cost.

If a linear amplifier delivers 50kW of sinusoidal power to a vibration transducer for on-line reliability testing, it is very likely to convert another 50kW into waste heat, and total power consumption will be in the 100kW range. Ideally, of course, the linear amplifier should operate at 78.5% efficiency when handling sinewave signals (Page 419). In reality, real rather than ideal transistors, imperfect load matching and the need to provide a safety margin of supply voltage bring the efficiency nearer this 50% figure than the theoretical 78.5%.

Replacing the 50% efficient linear amplifier in this application with a 90% efficient class D amplifier (whose efficiency is independent of signal waveform), reduces total energy consumption from roughly 100 to 55kW. The benefit: a tenfold reduction in waste heat; the amplifier can pay for itself in energy savings alone, without the simplification of heat removal, air conditioning, and other support needs.

PULSE DURATION MODULATION REFRESHER

A mechanical example of pulse modulation probably affords a more graphic and intuitive introduction to p.d.m. principles than a direct electrical one. Figure 1 simply outlines basic principles, rather than extol pulse duration modulation as a superior method for air flow control.

Assume for explanation's sake a frequency of 2Hz for the triangular modulation waveform, V_M, so that the solenoid-controlled valve has an opportunity to open and close twice per second, with the control circuit determining the duration of the intervals. The comparator energizes the relay and holds the valve open for as long as the instantaneous value of triangular modulation voltage V_M is less than flow voltage V_R. Viewed differently, so long as the comparator's inverting input terminal is negative to the non-inverting input terminal the comparator output remains at 10V. When the

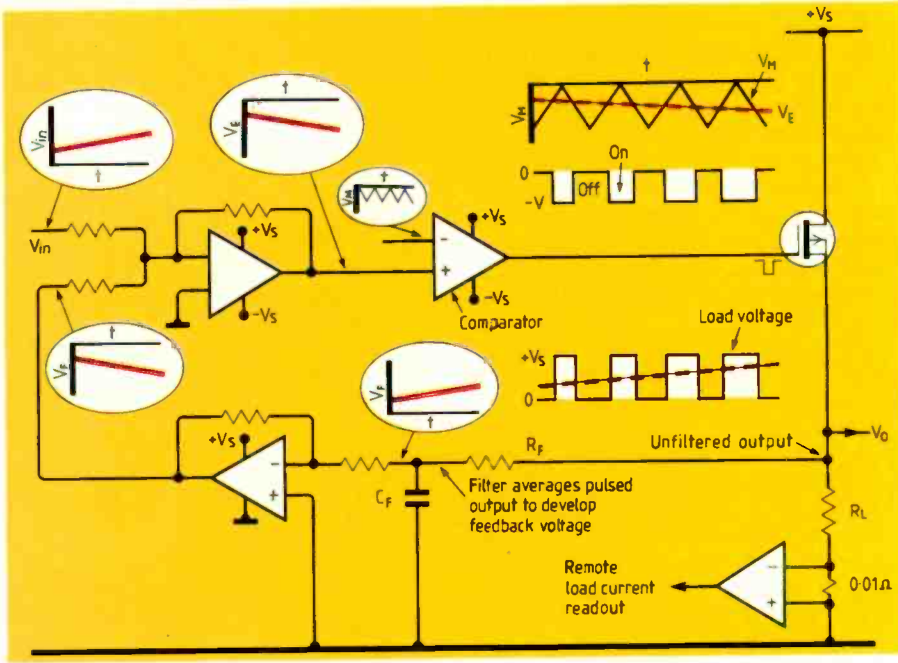


Fig.3. Early p.d.m. power amplifiers were constrained by available bipolar transistor performance to operate at modulation frequencies in the 500–5000 Hz range, which meant that filter circuits capable of smoothing significant load currents would be larger than the amplifier itself. Servomotors, which present highly inductive loads to the amplifier, provide an inherent filtering effect, eliminating the need in many instances for any series inductor-capacitor network. This compatibility between p.d.m. amplifiers and servomotors has probably led the industrial world to overlook application possibilities in the mainstream of power usage.

In this simplified p.d.m. amplifier configuration, which only handles positive inputs, a mosfet develops a positive output across the external load, a fraction of which is tapped off and filtered to form the error-correcting feedback signal. The output transistor is driven into conduction by the comparator's negative going output; in turn, the comparator's output goes negative whenever the error voltage is more negative than the triangular modulation voltage.

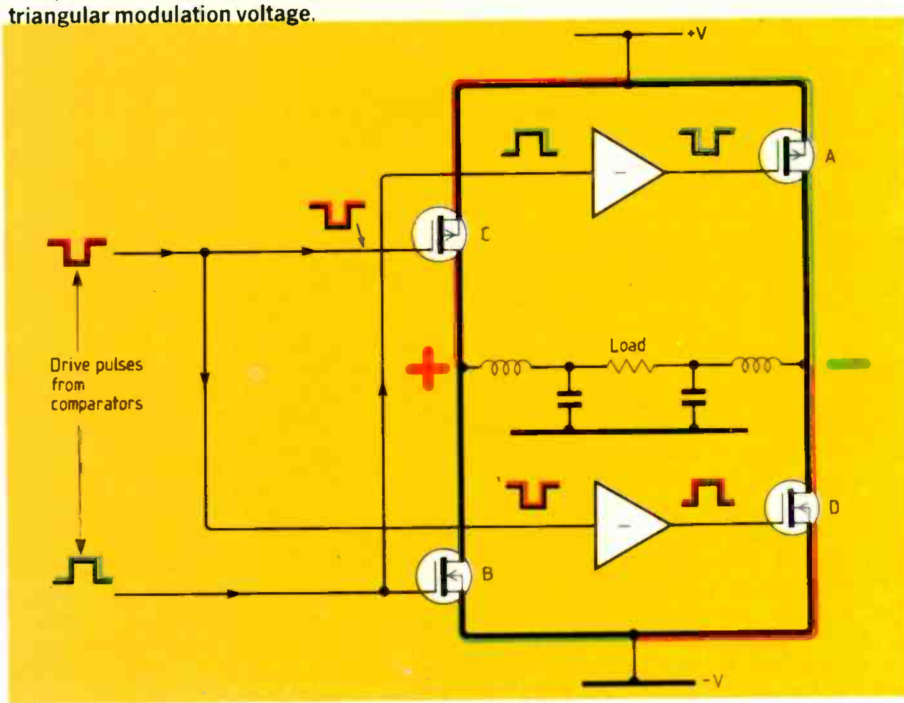


Fig. 5. Full-bridge output circuit, based on pairs of series connected transistors A + B and C + D, permits bipolar operation from single-polarity d.c. supply. One constraint lies in the need for a floating (non-grounded) load, although this drawback disappears when a.c.-only applications permit a transformer to be interposed between amplifier and grounded load. Modern amplifier designs minimize power transistor switching losses by sophisticated circuit design that confines pulse modulation to only one transistor in each active pair. For instance, if a positive input signal activates series transistors A and B, it is only necessary to apply modulated pulses to transistor A; transistor B in this pair can remain fully on for the duration of the positive input. Likewise, transistor D can be held fully conducting for negative inputs, while transistor C provides the pulse modulation.

modulation waveform exceeds the flow voltage, the inverting input is positive relative to the non-inverting terminal, which drops the comparator's output from 10V to zero and closes the valve.

Different levels of flow voltage established by the control potentiometer, produce comparator triggering earlier or later in the modulation cycle. Higher V_R values mean that the modulation voltage exceeds V_R for only brief periods at the tip of each modulation cycle.

Comparators may have an open-loop gain of 100,000:1 upwards. For 10V operation, this means that a 10V/100,000 = 0.1mV potential difference between the comparator's input terminals will develop maximum output. If the comparator is operated from dual-polarity d.c. supplies, the output can swing to maximum in either direction, depending on whether the inverting input terminal is more positive (negative output), or more negative (postive output), than the non-inverting terminal. It takes a 0.2mV difference between V_R and V_M to switch output polarity from −10 to +10V.

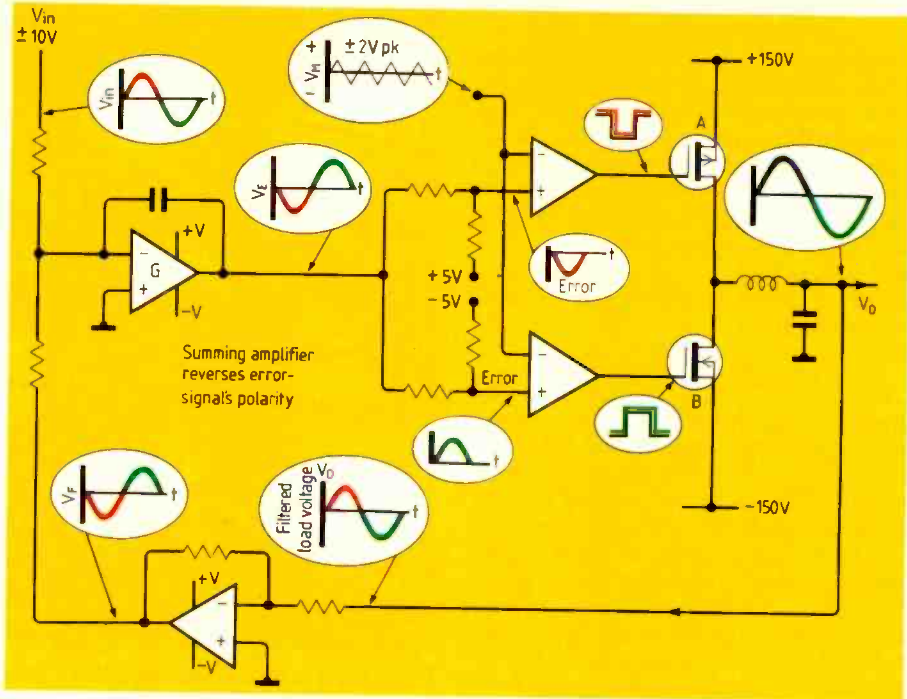
CLOSING THE LOOP

Feedback, V_F, from the flow sensor introduces sensor calibration as the system parameter responsible for flow rates commensurate with potentiometer setting, Fig.2. In the open-loop arrangement, Fig.1, system accuracy depended on the linearity and amplitude stability of the triangular modulating voltage V_M, as well as comparator d.c. stability, potentiometer supply voltage stability, and so forth. A whole collection of error sources get into the act.

Use of feedback eliminates most error sources and ties performance to the flowmeter reading. Feedback also accelerates the system's response to a change in flow setting, because increased flow setting immediately produces an exaggerated error voltage and an overcompensating initial flow rate. As the tank pressure builds up and forces a faster flow through the sensor, increased feedback reduces the excessive voltage until equilibrium is attained at the high flow setting.

The pressure tank smooths out air flow pulsations, but also prevents the output flow from responding immediately to new flow settings. One can visualize computer controlled applications in which a digital-to-analogue converter replaces the manual potentiometer for generating flow voltage. For rapid computer-commanded changes in flow rate, tank capacity becomes an important factor in the system's responsiveness. Modulating frequency is another crucial ingredient in responsiveness.

Since air flow control is analogous to a p.d.m. amplifier's power control, these conflicts between responsiveness and output smoothness also arise in amplifier design and application. Modern p.d.m. amplifiers minimize the effect of this conflict by using modulating frequencies in the 100 kHz region. Doubtless, future mosfet circuits will push the switching frequency higher, and useful bandwidth with it.



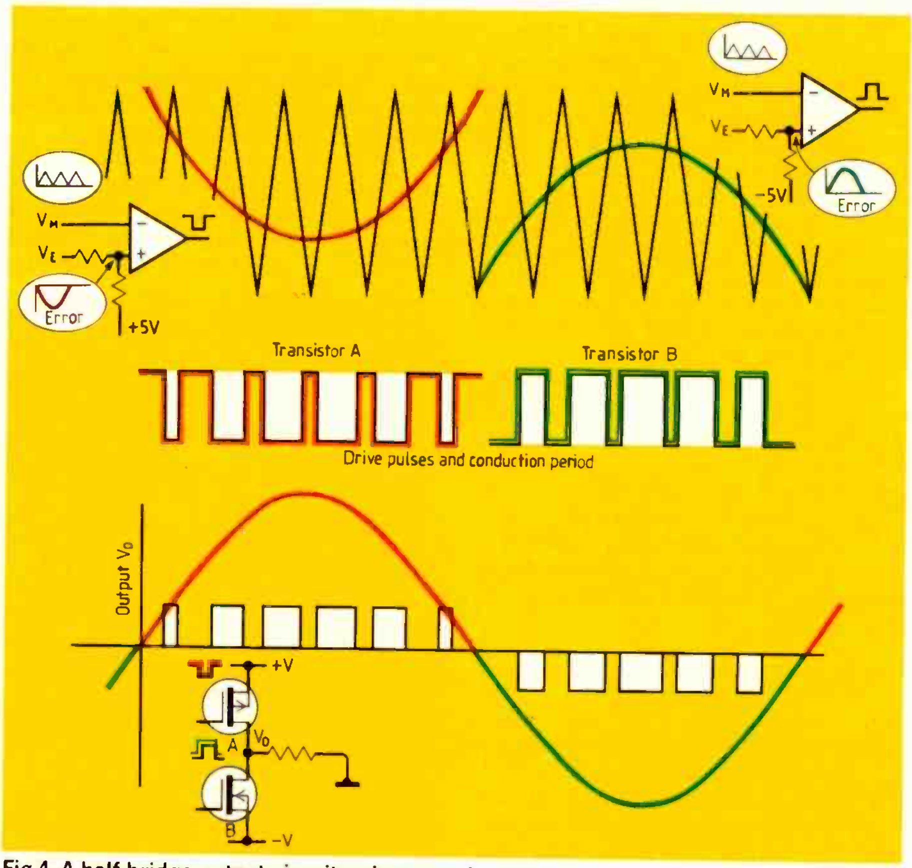


Fig.4. A half-bridge output circuit, using complementary p-channel and n-channel power transistors, enables the p.d.m. amplifier to handle both positive and negative input signals, including the sinusoidal waveform shown. The drawback to this simple output circuit is its requirement for a costly dual-polarity d.c. power supply. The full bridge output circuit of Fig.5 permits bipolar operation from a single-polarity d.c. source. Modern amplifiers incorporate internal converters to provide the various operating voltages required by the amplifier's signal handling circuitry.

Upper transistor A develops positive output pulses in response to positive input signals (and negative error voltage), while transistor B develops the negative output pulses in mirror image fashion. The waveforms show how the amplifier's internal filter smooths the variable width output pulses to produce a sinusoidal replica of the input. Actual waveforms shown are representative (for the sake of explanation) of an unfiltered resistance load. A choke input filter alters the voltage pulses and causes a phase lag in the sinusoidal output. Modern p.d.m. amplifier designs operate at high modulation frequencies so that a relatively small filter can reduce the output component at modulation frequency to acceptable levels.

SIMPLEST PDM AMPLIFIER

The simplest p.d.m. amplifier handles only positive inputs, and develops a train of output pulses having the same polarity as the input – Fig.3. The non-inverting amplifier operates much as the feedback-controlled air flow system, Fig.2, but requires an inverting amplifier to develop a negative-going feedback signal from the amplifier's positive output. The feedback voltage then opposes the amplifier's input to produce error voltage V_E, which adjusts the duration of output current pulses. The comparator develops negative drive signals for the power transistor whenever error voltage amplitude exceeds (is more negative than), the modulation voltage. For ease of intuititive circuit understanding, the sawtooth modulation waveform is presented in both Fig.2 and Fig.3 with negative-going polarity: the idea is to maintain the appearance of compatibility with the error signal's inverted polarity. In reality, the sawtooth modulation voltage would ordinarily vary uniformly about zero, and the error amplifier would automatically adjust its output to produce whatever transistor drive pulses were necessary for the desired on-off duty cycle.

For description's sake, this primitive amplifier incorporates no output filter. Instead, a small internal RC filter smooths a fraction of the pulsed output for use as feedback. Remote current readings are provided by a low value resistance in series wih the load: a highly stable d.c. amplifier feeds current signals to a remote indicator.

Fancy footwork is necessary to create a power amplifier capable of developing ±150 volts output. Fig.4, output p-channel mosfet A operates during positive amplifier input signals and develops a positive train of 150V output pulses in response. Conversely, the second power transistor B, an n-channel mosfet, responds to negative amplifier inputs with −150V output pulses. The filter smooths the pulsed output to create an amplified replica of the original input.

One disadvantage of the half-bridge power output circuit of Fig.4 is the need for two power supplies, which adds considerably to system cost and bulk. Another drawback occurs when driving highly reactive loads: reactance can cause a transfer of power supply to the other, building up excessive and damaging power supply voltages.

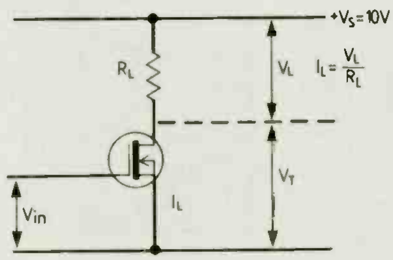
Commercial amplifier designs may use many output transistors connected in parallel to achieve desired power levels. A fortunate attribute of m.o.s. power transistors is their positive temperature coefficient for on-resistance. This characteristic aids load sharing between transistors. A negative coefficient would decrease resistance with temperature, causing the hottest semiconductor junction to hog most load current and immediately launch into a self-destruct spiral of ever-worsening temperature rise and current imbalance.

Biasing the comparators (one positive, one negative) and using a modulating voltage with peak-to-peak amplitude slightly less than the sum of the bias voltages ensures that each comparator responds only to its assigned error voltage polarity. (Note

EFFICIENCY DEPENDS ON WAVESHAPE

Chart shows how efficiency of an amplifier circuit depends on the waveshape being amplified: a fact of physical reality that prevails even though ideal transistors are used. A varying fraction of the power supply voltage is developed across the transistor, leading to transistor energy dissipation in the form of heat, but for a rectangular wave signal, the entire power supply voltage is developed across the load, permitting a theoretical 100% efficiency.

In normal operation, many factors conspire to reduce linear amplifier's efficiency below the theoretical ceiling established by signal waveshape. For instance, less-than-ideal transistors introduce resistance into the circuit, contributing loss of output voltage and internal heat dissipation. Also, it is necessary to provide a safety margin between peak output voltage and the power supply voltage; this too violates the conditions for maximum theoretical efficiency. Operating linear amplifiers at reduced power – equivalent to using a larger amplifier than the application requires – is another source of efficiency degradation. Driving low resistance loads is no problem for p.d.m. amplifiers, which can feed short circuits without efficiency degradation or loss of stability; linear amplifiers suffer extreme efficiency losses when driving low resistance values – most of the power supply voltage is developed across the output transistors rather than the load.



Instantaneous power dissipation

Load power, $W_L = V_2 \times I_L = V_L^2/R_L$

Total power, $W_T = V_S \times I_L = V_s V_L/R_L$

Averaged over time, T

Load power $= \frac{1}{T}\int_0^T V_L^2/R_L\,dt$

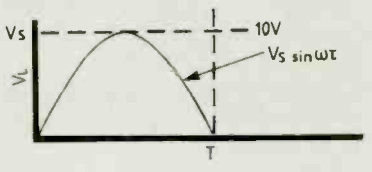
Total power $= \frac{1}{T}\int_0^T V_S V_O V_L/R_L\,dt$

Amplifier efficiency is ratio of useful power ÷ total power × 100% $= \dfrac{\frac{1}{T}\int_0^T W_L\,dt}{\frac{1}{T}\int_0^T W_T\,dt} = \dfrac{\frac{1}{T}\int_0^T \frac{V_L^2}{R_L}\,dt}{\frac{1}{T}\int_0^T \frac{V_S V_L}{R_L}\,dt}$

$$100\% \times \frac{\frac{1}{R_L T}\int_0^T V_s^2 \sin^2 \omega t\,dt}{\frac{1}{R_L T}\int_0^T V_s^2 \sin 2\omega t\,dt}$$

$$= 100\% \times \frac{\frac{1}{ZR_2T}}{\frac{Z}{\pi R_L T}} = 100\% \times \frac{\pi}{4}$$

For sinusoidal signals (consider only half cycle signals because simple amplifier will not handle complete cycles) maximum efficiency becomes

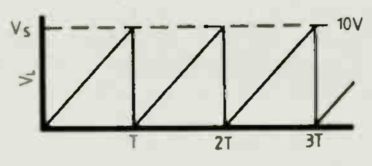


For sawtooth signals

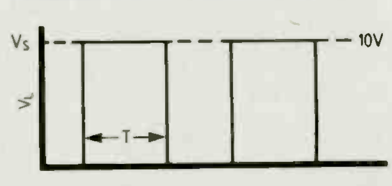
$$V_L = \frac{t}{T}V_S$$

so maximum efficiency becomes

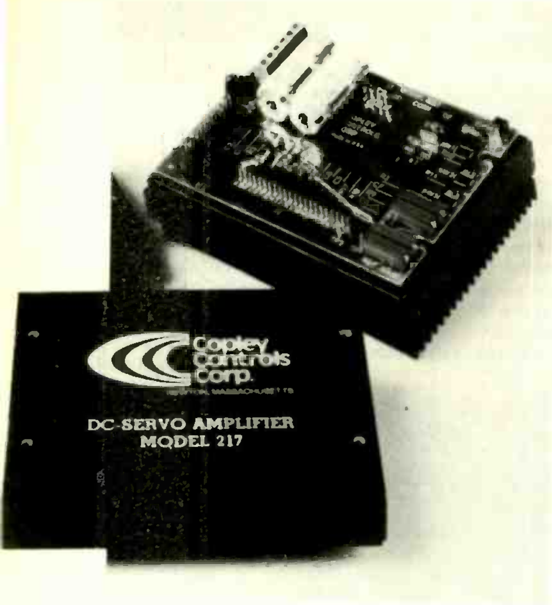
$$\frac{\frac{1}{R_L T}\int_0^T \left(\frac{t}{T}V_S\right)^2 dt}{\frac{1}{R_L T}\int_0^T \frac{t}{T}V_S{}^2\,dt} = \frac{\frac{1}{3}}{\frac{1}{2}} = 67\%$$



For square wave signals the ideal transistor would dissipate no power because it would apply the entire power supply voltage to the load.
Efficiency is therefore 100%.



Input signal	Wave shape	Ratio W_L/W_T	Percent efficiency
Sine		π/4	78·5
Sawtooth		2/3	66·7
Square		1	100



Off-the-shelf p.d.m. modules with 500W continous rating 1500 peak, provide elegant solution to control c.c.t.v. camera's illumination.

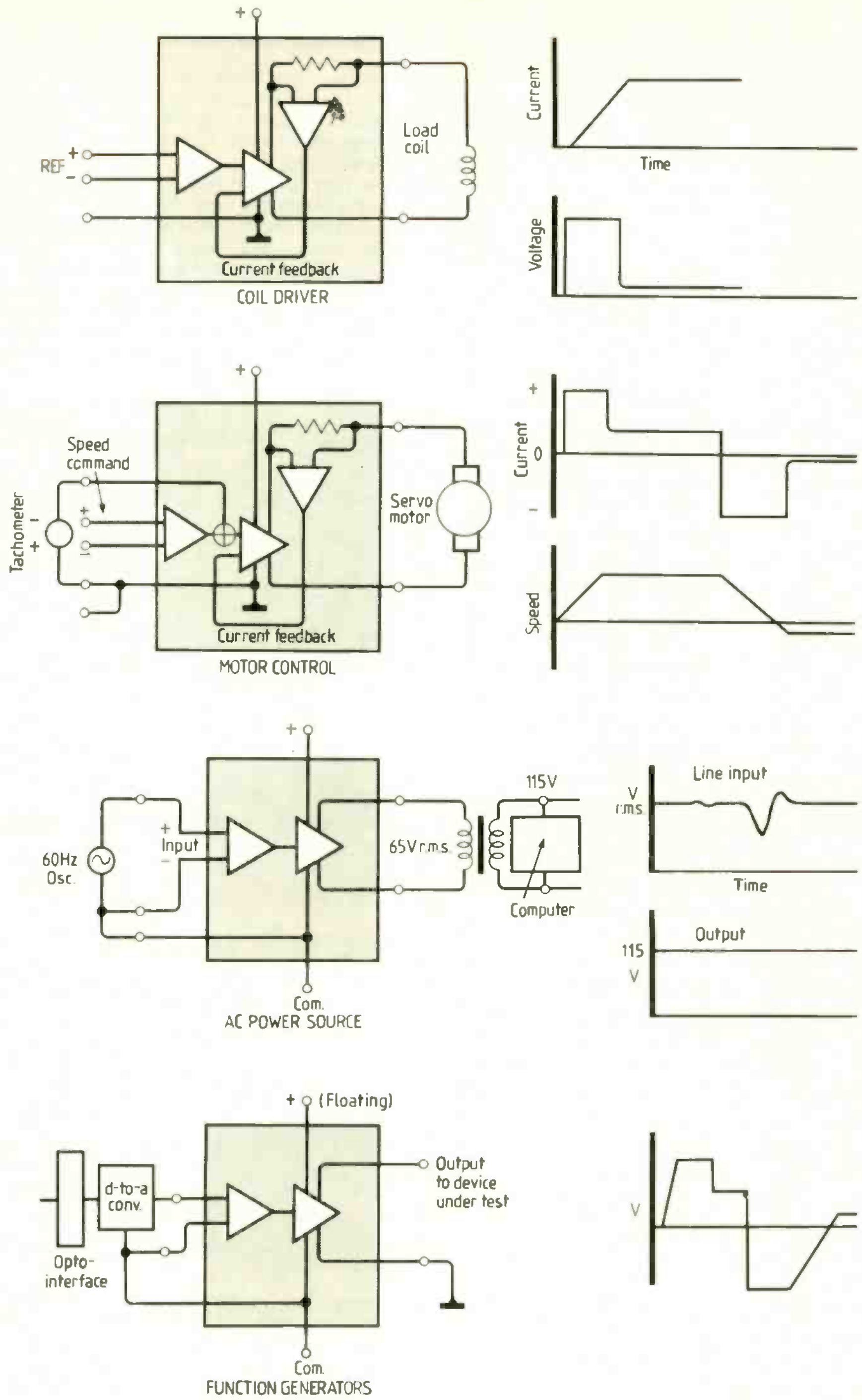


Fig.6. Four basic schematics illustrate use of p.d.m. technology in different application categories: coil drive; motion control; power delivery and function generation. Each category spans many different kinds of amplifier uses and power levels.

that the error amplifier produces an error voltage of opposite polarity to the amplifier input). The waveforms of Fig.4 illustrate the biased comparator operations, which are perhaps less readily understood than the configurations of Fig.2 and Fig.3.

A full-bridge power output circuit reduces power supply cost by permitting bipolar operation from single-polarity supply, Fig.5. Each comparator in this basic configuration now commands the operation of two series-connected power transistor pairs A+B and C+D. In high power amplifiers, of course, many parallel-connected transistors are represented by each single transistor.

Today's new levels of p.d.m. amplifier power and performance expand applications into the full spectrum of industrial usage, where they provide compact economical alternatives to linear amplifiers on the one hand, and fast-response competition to thyristor power systems on the other. Figure 6 outlines the basic schematics for coil drives, function generators, and smart power sources, in addition to traditional motion control applications. Once the rebirth of p.d.m. technology is widely appreciated, further innovative uses will enlarge the roster of p.d.m. problem solving.

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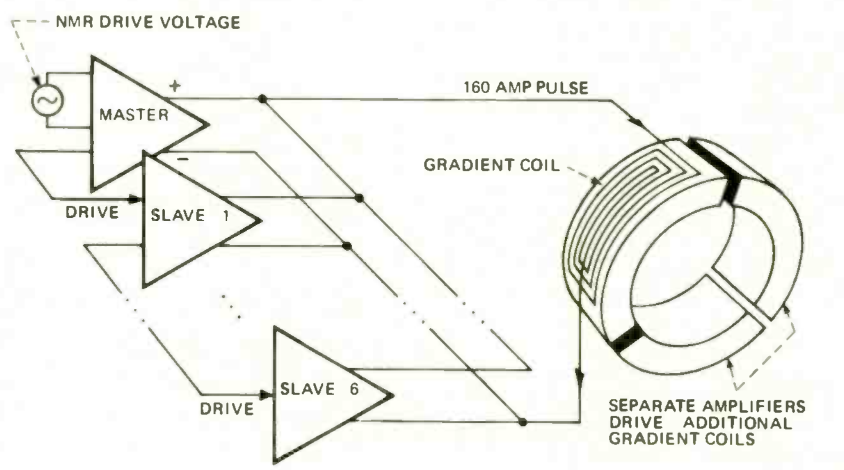

Seven p.d.m. power amplifiers are paralleled to feed fast-rise computer-contoured 160-amp current pules into magnetic resonance imaging system's 500 μH, 50 mΩ gradient coils. Data compiled by magnetic resonance imaging by equipment manufacturer compares new design based on p.d.m. technology with earlier system built around linear amplifiers. Size and weight reductions permit development of compact mobile imaging system. Figures show results for single-axis gradient coil supply; entire system uses three identical supplies.

Multi to single-element transform

A suggestion for overcoming the two-source limitationn of the inverse square law by resolving complex force situations, both those involving non-point sources and those involving any number of point sources.

BY J.C. BELCHER

SUMMARY

The multi-element transform effectively extends the application of the two-source basic force equations to the solution of more complex force situations involving any number of sources.

In practical terms, it also provides a useful application in the determination of the centre of force or centre of gravity of a body or source of force, whether of regular or irregular profile. In certain source configurations it also predicts the existence of a new form of force, potentially thousands of orders of magnitude greater than the force normally predicted by the basic force equations.

The concept of force is by way of being the most important concept in physics, simply because it is the basis of all natural phenomena. Moreover, it is the one feature common to the three main types of phenomena – gravitational, electrical, and magnetic. It is embodied in the classic force equations of both Newton and Coulomb, normally expressed as $F_G = GM_1M_2/d^2$, and $F_E = Q_1Q_2/\epsilon_0 d^2$, respectively.

These equations describe particular situations involving two sources of force. In more general situations involving three or more sources of force, these particular equations or concepts are not applicable. The difficulty which this brings about is exemplified by what are variously described as the many-body problem, the three-body problem and the three-charge problem.

Be that as it may, the general problem can only be overcome by arriving at a high-order concept of force, which is to say a general concept as distinct from the particular concepts of the force equations.

The thinking used in scientific research today has its basis in inductive logic, a technique notoriously prone to error. Thus, whereas some progress can be made from the level of fact to the level of theory – on a level with a first-order concept – any development toward higher-order concepts becomes well nigh impossible. It is for this reason that scientific theories in general tend to be particular concepts describing particular situations.

The application of recursive logic, by contrast, enables a researcher to develop high-order concepts at will, and in consequence it has been found possible to arrive at a higher-order, more general concept of force[1].

In what follows, an introduction to this concept is made by way of a transform, a device which literally transforms the many-body situation to its more recognisable two-body form. In use, the transform is subject to a certain imposed discipline, one aspect of which is the recognition of a zeroth element or body, known as the reference element. Because of this, the two-body situation becomes a single-element situation, involving a reference element and a single source element.

To illustrate the potential value of the transform in research, an examination is made of simple configurations of elements, chosen for the short computer programs which describe them. The use of the transform in arriving at the centre of force of a body is also demonstrated, and the opportunity is taken to effect a convincing introduction to cataclysmic force!

MULTI-ELEMENT TO SINGLE-ELEMENT TRANSFORM

The force exerted on a reference element, A_0, by a number of elements N is defined as

$$F_n = kA_0A_E/R_E^2 \qquad 1$$

where k is a constant of proportionality, A_0 the magnitude of the reference element, typically unit mass, unit charge, or unit pole, A_E the resultant magnitude of the N sources which equals $A_1\cos\theta_1 + A_2\cos\theta_2 + \ldots + A_N\cos\theta_N$, R_E the resultant distance between A_E and A_0 in the direction of the reference vector, which equals $R_1^{A_1\cos\theta/A_E} \times R_2^{A_2\cos\theta_2/A_E} \times \ldots R_N^{A_N\cos\theta_N/A_E}$ (A_x is the magnitude of the xth source, R_x the radial distance of A_x from A_0, and θ_x the angle subtended by R_x to the reference vector.

This general equation simplifies to the more particular equation expressed by the classical equations when N = 1, which is to say when it involves two sources A_0 and A_1.

$$A_E = A_1\cos\theta_1$$
$$R_E = R_1^{A_1\cos\theta_1/A_E} = R_1$$

from which

$$\mathbf{F}_1 = kA_0A_1\cos\theta_1/R_1^2. \qquad 2$$

Two important features of this equation are

– The presence of the direction cosine, $\cos\theta$, which correctly describes $\mathbf{F}_1$ as a vector quantity, a feature not normally brought to light in the customary expression of the classical force equations (apart from one notable exception, the definition of Coulomb's equation in Harnwell's text[2]).

– The implication that F_1 is the force exerted on A_0 by the presence of A_1, and not *vice versa*. In more complex applications of equation 1, in which A_0 is itself a multi-element array, there are occasions when the force exerted on A_1 by A_0 is not equal to the force exerted on A_0 by A_1.

In the general analysis of arrays of elements, the presence of the constant k becomes an irritating accompaniment. The convention adopted, therefore, is to make units of such value that becomes equal to unity and can be disregarded.

In the general case, therefore, when A_0 = 1 and k = 1, equation 1 simplifies to

$$F_N = A_E/R_E^2$$

ARRAYS OF ELEMENTS

Any array of point sources, simulating a massive body or charged body, is conveniently represented by an array of elements of unit magnitude, each occupying unit volume of space or unit volume of area, as the case may be. In this manner, each element is located in two or three dimensions relative to the centre of the array, this centre being ideally the centre of force of the array, or more often its geometric centre. A typical arrangement involving a circular array is shown in Fig.1.

The analysis of array characteristics is essentially an analysis of the array's force characteristics, followed by its *proximity-profile* characteristics*, each set of characteristics being divided into the external characteristics, common to all arrays, and the internal characteristcs, often peculiar to the type of array in question.

In this short article, only the force characteristics of arrays are examined, because a meaningful study of proximity effect and

* Sources of force in the basic force equations are essentially point sources, having no linear dimensions, and taking up no volume in space. When such sources can no longer be regarded as point sources – when they are in close proximity – then the basic equations no longer hold true. What happens is that the force equation is subject to a qualifying factor, the 'proximity-profile' factor, the value of which depends on the proximity to the source, and to any irregularity in its profile.

profile effect calls for a detailed analysis of many types of different arrays of elements and constitutes an article in its own right.

The force characteristics of a spherical array of elements – simulating the classical spherical body – in which distance is measured in terms of radius, are found to be as follows.

- Magnitude A_E is essentially equal to the intrinsic magnitude A_I, the arithmetic sum of all the magnitudes of the elements within the array.
- Distance R_E is essentially equal to the true distance between the reference element and the centre of the array.
- Force F_N is A_E/R_E^2.

The internal characteristics of such an array, although essentially in agreement with classical theory, nevertheless give a more detailed explanation of the factors involved:

1. Magnitude varies directly with the distance d from the centre, being maximum at the surface and zero at the centre, i.e. $A_E = A_I d$.
2. Distance is unity, i.e. $R_E = 1.0$.
3. Force is $F_N = A_E/1^2 = A_I d$.

The force characteristics are, of course, modified by proximity effect. This effect is most noticeable over the range defined by the two inverse points of the array, d = 2 × radius and d = 0.5 × radius, and reaches a maximum value at the surface or perimeter of the array. Its effect can be determined, however, at distances as great as 1000 × radius, and as small as 0.001 × radius.

RING ARRAY OF ELEMENTS

The force characteristics of a ring array of elements are exceptional in that they demonstrate a capacity in natural phenomena to combine a pleasing simplicity of form with a mathematical complexity of structure. More to the point, these characteristics are entirely open to discovery by even the most casual researcher.

The analysis is conveniently undertaken by the use of program 1*, a self-contained program in BBC Basic which both simulates the necessary array of elements, and carries out the required analysis. On running the program, it calls for an input of the number of elements, N, and then goes into a repeat cycle for the input of the distance in terms of the radius along the x-axis between the reference element and the centre of the array itself. Within the repeat cycle two for-next loops determine the value of A_E using PROCcalc1 and of R_E using PROCcalc2, which two procedures essentially carry out the required transform.

Because the simulation of a uniform ring is effected by a series of discrete point sources, simulation error is likely to be encountered if the value of N is very small. By contrast, if the value of N is very large, then the analysis calls for the calculation of trigonometrical functions involving very small angles and computing error becomes prominent. Thus a value of N = 100 is an optimum figure to input on running the program.

* Pressure on space led us to hold back these simulation programs – they are available from the editorial office in return for an s.a.e.

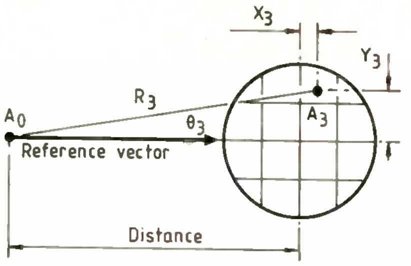

Fig. 1. The simulation of any non-point source of force of uniform material is conveniently effected by dividing it into unit or partial areas or volumes with a point source of unit charge or magnetic pole at each centre of gravity. Each point source is identified by its value, A_3 for example, and located relative to the origin by coordinates, X_3, Y_3, and Z_3. (Dimensions are in terms of the effective radius of the body which is of unit-length.) The analysis of the array of elements thus simulated is carried out relative to the reference element, A_0, conveniently located on the x-axis at a distance measured in terms of the radius. The reference vector is normally concurrent with the x-axis, although this can be rotated in steps over a full 360° to provide data for a polar diagram of the force exerted on the reference element. Relative to the reference element, an element is located in terms of the polar coordinates, R_3, θ_3, where cos θ_3 is the direction cosine relative to the reference vector.

In the print-out, the relationship between the computed results and the theoretical results for A_E and R_E are given at the side as an assessment of the accuracy of the simulation and computation.

At d=10,000, the value of A_E = 100, showing no sign of proximity error. The value of R_E < 10,000, and this shows the presence of computing error. At = 100, both values properly show the presence of proximity error, and computing error is essentially absent. Proximity error is predictably greatest at d = 1, and this is seen to be the case.

At d < 1, the value of A_E varies directly with half the distance. The value of R_E, on the other hand, is essentially equal to the base of natural logarithms, $R_E = e^1 = 2.7182818$. This becomes most obvious at d = 0.001, whereas at smaller distances, i.e. 0.0001, computing error once again become prominent.

It is interesting to compare the following results internal to the array perimeter, with statements 1, 2 and 3:

4. Magnitude varies directly with half the distance from the centre, being maximum at the perimeter, and zero at the centre, i.e. A_E and A_I d/2.
5. Distance is equal to the base of natural logarithms, i.e. $R_E = e^1 = 2.71828$ etc.
6. Force is $F_N = A_I d/2e^2$.

SHELL ARRAY OF ELEMENTS

The hollow enclosed spherical shell, or equipotential surface, is an important feature in contemporary physics. Since, by assuming the validity of the inverse square law, an attempt is made to demonstrate that the force on a reference point source within such a surface must be zero everywhere. Conversely, proof that such a force is indeed zero thence confirms the validity of the inverse square law.

This reasoning would appear to be based on a misconception of the three-body problem and its rigorous solution. Since, it argues, a source of magnitude 9 units at a distance of 3 units, exerts the same force as a source of 4 units at a distance of 2 units. In isolation, the two sources do indeed exert a force of $9/3^2 = 4/2^2 = 1$ unit. Taken together, however, this simplicity no longer applies, and use of the multi-element transform will show that, where the two sources are opposing, the resultant force is 0.290389882 units in the direction of the larger source. It is at this point, therefore, at which the transform comes into dispute with contemporary theory.

Be that as it may, the success achieved with the simple ring array of elements led directly to similar research on the shell array, where the problem has been one of array simulation, since poor simulation produces not only incorrect results, but entirely misleading results. The simulation of the shell array itself suggests something on the lines of locating dimples on golf balls, but the spherical trigonometry involved does not make for easy calculation where uniform distribution of surface area is to be achieved.

The final simulation had its basis in a regulation pattern, drawn with a felt-tip pen on a six-inch rubber ball and composed of eight 90° spherical triangles, each with three quadrants of radius 45° drawn at each right-angle together with a smaller spherical triangle at the centre, making a 36-element array. Although composed of a small number of elements, this array is nevertheless exceptionally accurate in its representation of a spherical surface.

The simulation and analysis of the shell array is embodied in program 2, the simulation details being held in the DATA statements. Because the number of elements is fixed at 32, the user need only input the required distance. In numerical terms, the intrinsic magnitude of the array is set at A_I = 1.0, which makes for ease of analysis.

As $e^{1/2} = 1.648721271$, and it appears fairly obvious that, in the general case within the surface of the shell, $R_E = e^{1/2}$. Under similar circumstances, $A_E = (2/3)A_I d$.

The internal force characteristics of the shell array of elements, therefore, may be expressed as

7. Magnitude varies directly with two-thirds of the distance from the centre, being maximum at the surface and zero at the centre, i.e. $A_E = 2A_I d/3$.
8. Distance is the square root of the base of natural logarithms, i.e. $R_E = 1.658721271$.
9. Force $F_N = 2d/3e = 0.245253338$ distance.

CENTRES OF FORCE OF HALF-SHELL ARRAYS

A useful facility afforded by the use of Multi-element Transform is the determination of the centre of gravity, or in more general terms the centre of force, of any given body or array of elements. In the case of symmetrical arrays, of course, such a centre is at the geometrical centre of the array itself. A problem arises, however, when the profile of the body or the array is highly irregular in outline, since under these circumstances a formal solution presents difficulties.

This particular use of the transform can be conveniently demonstrated by calculating the centre of force of a half-shell array.

The simulation of the shell array is effectively that of two half-shells in close juxtasposition. If the reference element is at some distance greater than the radius, then the half-shell adjacent to it is composed solely of elements having negative x-ordinates, and the half-shell remote from it is composed soley of elements having positive x-ordinates. The convention adopted here is to refer to these two half-arrays as the adjacent array and the remote-array, respectively.

To determine the centre of force of the adjacent array, run program 2 after having deleted lines 80 and 100, thereby exculding the elements having positive x-ordinates. Enter the program with distances of 4000, and 1000. The results are

distance	R_E	(distance – R_E)
4000	3999.464226	0.535774231
1000	999.4644563	0.5355436802

Reload the program, this time deleting lines 70 and 90, thereby simulating the remote array. Thence repeat the above sequence obtaining the following results

distance	R_E	(R_E – distance)
4000	4000.535907	0.535407
1000	1000.53616	0.53616

The mean value of these four difference values is 0.5357, and it follows from this that the centre of force of a half-shell in general terms is at a point approximately 0.5357 radius from its centre of curvature.

'CATACLYSMIC' FORCE

A significant development arising from early studies involving the transform, it is unexpected prediction of the existence of a particular type of force of extreme magnitude. Over the years, this force has been identified with a certain type of force in Nature which gives rise to events of cataclysmic proportions, and has been called a cataclysmic force. That the predicted force and the actual force are indeed one and the same thing, would appear to have become well established. This is confirmed in particular by the application of the transform to the analysis of gravitational tidal forces obtaining within the Sun's core, in which its prediction of solar phenomena is in excellent agreement with recorded observation.

Which is to say 'cataclysmic' force exerted essentially by a configuration of slow-moving planets over a period of weeks or months, coincides with the occurrence of large sun-spots or eruptive prominences. The same force, on the other hand, exerted by a configuration of fast-moving planets over a few days, coincides with the presence of minor sunsports and minor prominences. In complete contrast, a notable period of

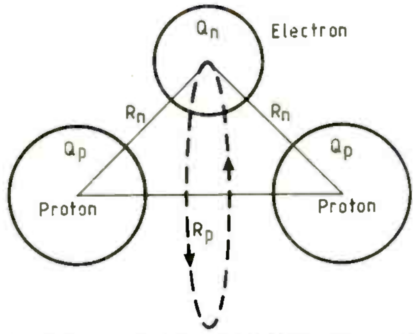

Fig. 2. The negatively charged electron is normally bound to the group by virtue of the electrical attraction of the two positively charged protons, and by the gravitational attraction of their combined larger masses, causing the electron to orbit the pair about their common axis in a state of equilibrium. In the absence of the electron, the two protons would normally experience mutual repulsion and fly apart, but the 'cataclysmic force' set up by the presence of the electron in this the three-charge situation effectively guards against this.

little of no solar activity, the period of the controversial Maunder Minimum, is seen to have taken place during a time when the application of the transform points to a near absence of planetary configurations found to have given rise to cataclysmic tidal force.

An examination of 'cataclysmic' force, on paper at least, suggests it to be the outcome of some form of mathematical chicanery. This is understandable, since it has its basis in a certain mathematical paradox, the *dominant negative direction cosine*. Under normal circumstances, negative direction cosines exhibit no abnormal behaviour when paired off with their counterparts, the positive direction cosines, and we have seen evidence of such normality in the simulation and analysis of both the ring and shell arrays of elements. If, however, a hollow array is opened out at one side to produce an open hollow array, the balance between positive and negative direction cosines becomes lost. In consequence, should the negative direction cosines predominate, the resultant distance, exhibits a net negative index, so much so that, in the ultimate, R_E = zero, and by the same token, F_N = infinity. This, then, is the essential basis of 'cataclysmic' force.

A demonstration of this force, entirely innocent of any form of chicanery, can conveniently be arranged by running program 2 in an adjacent array mode, inputting values of distance in incremental steps from d = 0 to 0.5837 × radius.

THE THREE CHARGED-BODY PROBLEM

Careful examination of the multi-element transform, in its association with 'cataclysmic' force, shows the resultant distance will exhibit a negative index if the magnitudes of the sources or elements themselves exhibit negative signs. Although not a feature of gravitational force involving massive bodies, it is nevertheless perfectly obvious that such a condition can obtain when electrical charges or charged bodies of opposite polarity are involved.

The ultimate example of the three charged-body problem is perhaps the best represented by the simulation and analysis of the forces obtaining within the atomic nucleus. In this demonstration it will be assumed that the nucleus consists of two nucleons, a positively charged proton and a neutron exhibiting a net charge of zero. Because a neutron can be likened to a postively charged proton orbited by a negatively charged electron, this substitution will be assumed, giving rise to three charged bodies, two positive and one negative.

It seems likely that the negatively charged electron will see the two positively charged protons as being a single composite source, having twice the mass and twice the positive charge of a single proton. Under these circumstances, the electrons is likely to orbit the two protons in combination, as shown in Fig.2, from which it is seen that at any given time the three elements are likely to form an isosceles triangle in space, with the electron at the apex of the triangle, and the protons at its base.

The forces exerted on one or other of the two protons can be determined by running program 3 and inputting selected values of the apex angle in the range, 0 – 180°.

The force exerted by the opposing proton is shown as F_+ and is normally repulsive in nature as indicated by the negative sign. By contrast, the force exerted by the electron, F_-, is attractive in nature as indicated by the positive sign.

Predictably, when the angle is zero, the two protons are infinitely close together and the Coulombian force is a repulsive force of infinite magnitude. Thus the two protons suffer mutual repulsion. When the angle is 158° or more, however, the 'cataclysmic' force experienced between each proton and the solitary electron is one of mutual attraction of infinite magnitude. Hence, the two extremes of force. That the forces on the protons are zero when the angle is 180°, is not a serious restriction, because the orbital motion of the electron will immediately restore the *status quo*.

The cataclysmic energy involved in the atomic nucleus is, of course, well recognised as nuclear energy. A potentially less hazardous form of cataclysmic energy, however, would appear to be a feature of the *cataclysmic array*, and, editor willing, this will form the subject of a further article.

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2. Harnwell, G.P., Principles of Electricity and Electromagnetism. McGraw-Hill, New York, 1949, 2nd Edition, p11.

John Charles Belcher, MIERE, retired from British Telecom in 1984, but since 1967 a major concern has been research into research techniques, particularly successful, he says in the case of the powerful thinking technique, recursive logic, which led to an "extensive and detailed understanding of natural phenomena in general, described by some 300 original equations."

RESEARCH NOTES

£2.5 million for advanced vision system

A major research project to produce a prototype Advanced Vision System is to involve four UK organizations:

Thorn-EMI Central Research Laboratories;

Laser-Scan Laboratories (Cambridge);

Royal Signals and Radar Establishment (Malvern); and

University College London

The project cost is £2.5M to be spread over three years. The Alvey Directorate is providing £1.6M, the remainder being met by the non-university collaborators.

The vision system's principal function is to process stereo images of a scene to produce an array of depth values, which are the distances from the viewpoint to surfaces of objects. Like the human visual system, the machine will utilize stereo parallax to calculate depth, having determined the correspondence between points in the different images. The depth arrays constitute 2.5D representations of scenes providing important, but not full, information on the 3-D shape of objects present. The machine will employ photogrammetric techniques, including the recognition of control features, so that absolute measurements can be obtained.

There are numerous applications for such a system. One example is industrial inspection, where images are produced by two or more television cameras, and the 2.5-D representation forms the basis for automatically measuring shape variations. Another example occurs in the preparation of maps and terrain data bases, where images are obtained from spaceborne or airborne sensors in two or more viewing positions. Here the 2.5-D information can form the basis for a relief map. Both these applications are to be used in the research programme, the data coming from an industrial inspection cell for the first example, and from the French SPOT satellite for the second.

The market potential for a 2.5-D vision system is considered to be substantial – provided that it is accurate and fast. To achieve the necessary accuracy, further development of existing stereo matching techniques is required, and is included in the research programme. To achieve the necessary speed, the system is not being implemented on a conventional single-processor computer but on a network of processors running in parallel. In this way, the intensive computation required can be speeded up by a factor approaching the number of processors in the network. The processors in the network will be transputers, manufactured by Inmos. The complete 2.5-D vision system, running in real time, is to be operational by the end of the three-year project.

Star wars laser?

Formerly classified details have recently emerged of a development in free electron lasers that could become a front runner in the race for a directed-energy beam weapon. An 11-member group from the Lawrence Berkeley and Livermore Laboratories has demonstrated a mirror-less laser amplifier that uses an electron beam from an accelerator to boost the energy from a 50kW magnetron to nearly 1.9GW. The 4kA electron beam is pulsed once per second and comes from an experimental test accelerator (ETA).

Energy transfer from the electron beam to the microwave beam takes place in an 'undulator' (also called a 'wiggler'). The name derives from the interaction which takes place along an oscillating path. The undulator consists of a linear array of pulsed, air-cored electromagnets generating alternating dipole fields. If the dipole field, the electron energy and the input microwave radiation are in step, then lasing action occurs. For maximum energy transfer (up to 40%), the laser output wavelength is related to the undulator period divided by the square of the electron beam energy.

Extending the laser wavelength from microwaves to the more militarily useful near-infra-red therefore demands a considerable increase in beam energy. Increasing the overall power demands also an increase in the electron beam pulse repetition rate, something which various US teams are working on.

The Los Alamos National Laboratory are, for example, developing a radio-frequency electron injector with a significantly increased 'brightness'. This is important because the laser output can be no greater than the power of the beam that pumps it.

To produce an effective SDI-type infra-red beam weapon demands not only that these problems be solved: there are other fundamental physical constraints. Microwaves of the frequency used (around 35GHz) can be kept parallel by means of waveguides using well known technology. Shorter wavelength infra-red radiation will depend for its guidance on focussing effects which, as yet, are still at the theoretical stage.

SDI, it seems, still has some way to go.

Biocomputers Japanese style

Japan's Ministry of International Trade and Industry's Agency of Industrial Science and Technology (MITI/AIST) is planning to launch a biochip research project that will cost an estimated 110M yen for the first two years alone. It's an attempt to circumvent what the Japanese see as the inherent limitations of silicon technology itself and of von Neumann architecture. The aim of the MITI project is to design an artificial intelligence capability based on the information processing principles employed in the nervous systems of relatively simple animals. As yet, MITI are saying little about which organisms they have in mind or indeed what biomolecules or modelling techniques they'll be employing.

To begin with, scientists will develop non-invasive means of analysing the workings of animal nervous systems to try and discover how memory and learning are accomplished. The resulting data will then be used to design models that mimic these processes. Later in the project they'll be looking at how living molecules and cells organize themselves to carry out highly complex functions.

Ultimately the intention is to develop chips based on biological principles that can circumvent the limitations of today's systems. MITI gives no indications of what architecture might be employed – or even what fabrication technology. But, however futuristic this approach might seem, the prospect of ultimately developing a highly intelligent, low-consumption computer, based on relatively slow active devices, isn't as far-fetched at it might seem. Each of us already has one sitting inside our skulls!

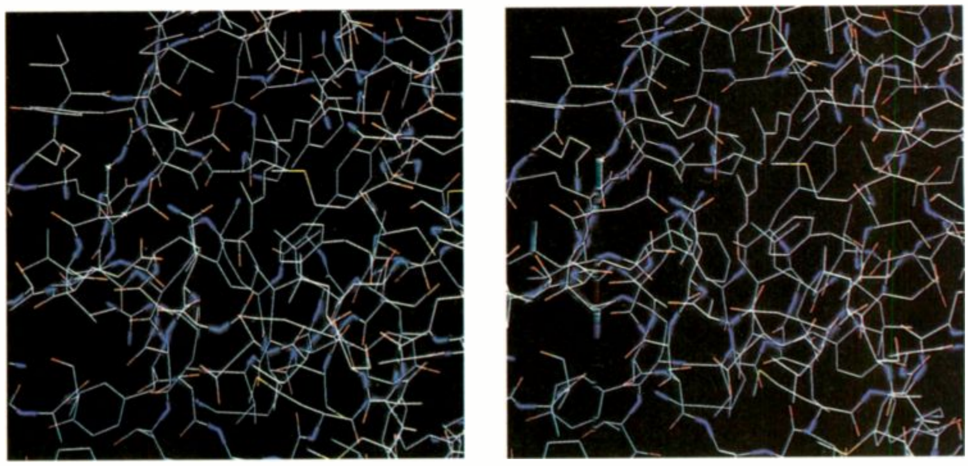
Biocomputers Russian style

According to G. Ivanitskiy, Director of the Institute of Biophysics of the USSR Academy of Sciences, microtechnology based on organic substances will become a major force in computer research and development in the next 10 to 15 years. Ivanitskiy starts from the basic premise that living systems employ highly efficient energy conversion processes that operate at room temperature. Soviet efforts are therefore being directed towards a biocomputer based on energy-efficient 'organically grown' sensors and switching devices.

Many such devices, says Ivanitskiy, already exist in primitive form. Molecular biology has made it possible to design transducers with high sensitivity and selectivity. At the Institute of Biophysics, protein-based devices have already been developed to measure tiny changes in chemical reactions. Optical transducers based on bioluminescence are also the subject of research that could extend to the development of new non-volatile biological memories. For example, the bacterium *Halobacterium halobium* uses a pigment called bacteriorhodopsin to convert light into electrochemical energy. It's a process very similar to that which takes place in the retina of the human eye.

According to Ivanitskiy, bacteriorhodopsin could be used not just as a transducer but as the basis of a memory device. Scientists at the Institute of Biophysics have discovered that dehydrated bacteriorhodopsin can be stopped at one stage of the transduction process without losing the image printed on it. Films based on bacteriorhodopsin could thus, in principle, be acted on by lasers to record, read and erase data. The Russians believe that the contents of a large library could be stored on one 30cm 'biochrome' disc.

As for processing data, Ivanitskiy predicts that systems based on discrete bits will give way to biological films in which data is processed through waves of chemical reaction. He speculates that protein crystals could act as media through which moving plane waves could perform the equivalent of 10^{12} operation/s in the space of $1cm^2$



Stereo pair of molecular graphic. To see in 3-D these pictures should ideally be cut out and placed in a binocular viewer. Alternatively the illusion may work if the pictures are separated by a sheet of thin card, normal to the paper.

Compute-a-drug

Dr Lindsay Sawyer is one of a team from the Department of Biochemistry at Edinburgh University who is using 3-D computer graphics to perform what amount to conjuring tricks with complex protein molecules. Anyone who has seen even simple biochemical molecules modelled with coloured sticks and balls will know immediately how complex these structures are. When it comes to larger molecules of the sort that abound in our bodies this 'meccano' approach is hopelessly inadequate.

Dr Sawyer has been attempting to study the reactions of a milk protein, beta lactoglobulin (BLG), using an Evans and Sutherland PS300 vector display device in conjunction with a host computer and a Leeds l.c.d. stereopsis viewer. The viewer consists of a pair of spectacles with l.c.d. shutters in place of the usual lenses. This enables alternate frames (which correspond to each half of the stereo image) to be presented sequentially to the right and left eyes.

Using a molecular graphics package called FRODO, developed by Alwyn Jones of the University of Uppsala, it is possible, using any input device such as a keyboard or a mouse, to manipulate the images in real time. It's possible, for example, to turn a 'molecule' around and see how it best fits with another molecule. Using this approach, Dr. Sawyer has been able to provide an 'intelligent guess' as to the structure of the chemical complex that forms when BLG binds to certain other molecules such as vitamin A. This is valuable because such complexes are not always easily amenable to X-ray crystallographic analysis. The images, if viewed in 3-D, display all the atoms in their different colours.

The value of this research isn't just in its ability to speculate on complex molecular processes. Given the structure of one protein, it should be possible in theory to design another molecule that would fit onto or into it to modify the protein's properties in predictable way. That in turn is a possible route to new drugs. There remains of course the job of actually creating the new molecule using some sort of genetic engineering. And when you have created it, it may turn out to be toxic when tested on animals. Ah well, back to the (3-D) computerized drawing board!

Magnetic fields – the health risks

An international meeting held last summer at the A.N. Marzeev Research Institute of General and Communal Hygiene in Kiev examined the biological effects of exposure to static and time-varying magnetic fields at extremely low frequencies of up to 300Hz. The job of this task group was to produce a final agreed version of a document initiated by the International Radiation Protection Association (IRPA) and commissioned by the World Health Organization (WHO).

The document, which is summarized in a paper published by the National Radiological Protection Board (Bulletin No 78), provides an extremely clear and concise overview of what is presently known of the dangers of magnetic fields.

Of static fields, the group considered that there is no evidence of any adverse effects on human health due to short-term exposure to static fields of up to 2 Tesla(T) or to chronic exposure to fields of less than 100mT. However, it is felt that there is insufficient knowledge of possible effects in certain key areas:

- long-term exposure to the nervous system and the cardiovascular system;
- certain metabolic reactions that involve radical pairs; and
- the use of magnetic resonance systems for medical diagnosis involving fields over 2T.

More studies, says the group, should be carried out into the cellular tissue and whole body responses to such static fields.

Turning to alternating fields, the task group was particularly concerned about reports of an increased incidence of cancer in the vicinity of a.c. power lines. Such fields are commonly no greater than 0.1-1.0μT. The group concludes that studies so far have been inconsistent and raise more questions than they answer. Further well-designed epidemiological studies are deemed necessary.

Laboratory studies, however, show no adverse clinical or physiological changes in subjects exposed to 50Hz fields of up to 5mT. At greater flux densities, people sometimes report seeing flashing lights – magnetophosphenes – caused by induced currents in the retina of the eye. At extremely high e.l.f. fields of 0.5T or greater, acute health hazards, such as heart fibrillation exist. It isn't known, however, whether the hazard is a direct result of the magnetism or of the electrical currents which are induced as a consequence.

In respect of alternating fields, the task group concludes that comprehensive new studies are needed to assess the risk, if any, of cancer; also the risk to embryos in the case of exposure during pregnancy and finally the effects of induced currents on nerve tissue.

What seems to emerge overall, however, is the extreme difficulty of demonstrating any physiological effect at all, let alone a hazard, of the sort of magnetic fields that are likely to be encountered in the average laboratory or workshop.

Research Notes is written by John Wilson.

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Tone decoding using a microprocessor

A simple approach to microprocessor-controlled tone decoding results in excellent performance in noisy conditions.

C.H. GOUGH

Land-mobile radio telephones usually operate through a repeater site overlooking the service area. So that many user groups can use the same r.f. channel through a particular repeater, it is common for user groups to be allocated a certain sub-audible tone which is continuously transmitted along with the speech. This continuous tone-controlled suppressed squelch, abbreviated t.c.s.s., enables the f.m. receiver output only for that particular user group. In this way, users are not subjected to a torrent of unwanted transmissions. The system commonly uses one of about thirty tones in the band 67 to 250.3Hz.

Because decoder input noise comes from an f.m. receiver, the noise characteristics are difficult either to calculate or to measure. This article discusses measurement of f.m. noise characteristics of a typical f.m. mobile receiver and specific microprocessor techniques used to produce a useful decoder.

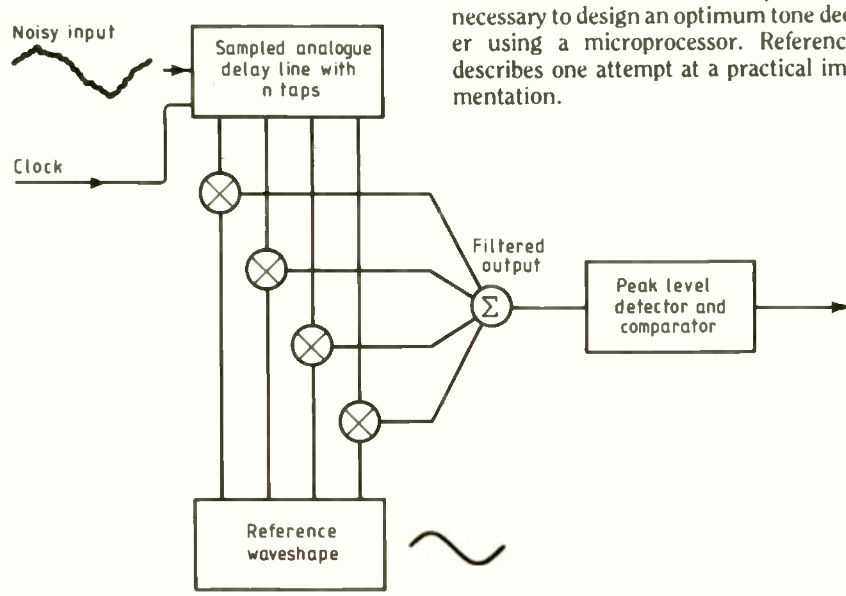
Two basic approaches to implementation are period measurement which is capable of modest s-to-n ratio performance for tones up to around 10kHz, and correlation filtering giving excellent s-to-n ratio performance for tones up to around 500Hz.

Quality of the output voice channel is measured by means of a sinad meter giving signal+noise+distortion/noise+distortion and this measurement is done at 1kHz. Sensitivity of an r.f. receiver is commonly defined as that r.f. level which gives a 12dB sinad reading on the audio output. A characteristic of any f.m. receiver is that output signal quality degrades slightly towards the 12dB sinad point as r.f. input level is decreased, but then degrades very rapidly below that point. Further, the output noise characteristic is 'clicky' or 'raspy' and quite different to Gaussian noise.

For a mobile receiver, signal level varies rapidly by perhaps 20 or 30dB as the vehicle travels down the road. Any decoder must be relatively immune to noise bursts from this variation, and yet capable of detecting the presence or absence of tone within about 250ms. Further detection bandwidth may be limited to ±2.5% or less. References one and two partially define the characteristics of such a decoder.

Usually decoders like this are preceded by an analogue filter, then a hard limiter to remove decoder dependence upon the audio signal level. However, this process is very non-linear – it removes some noise spikes and emphasizes others. Also the analogue filtering never completely suppresses voice-channel signal and the hard limiter can emphasize this problem.

With the introduction of microprocessors into f.m. land-mobile radio telephones, it is necessary to design an optimum tone decoder using a microprocessor. Reference 3 describes one attempt at a practical implementation.



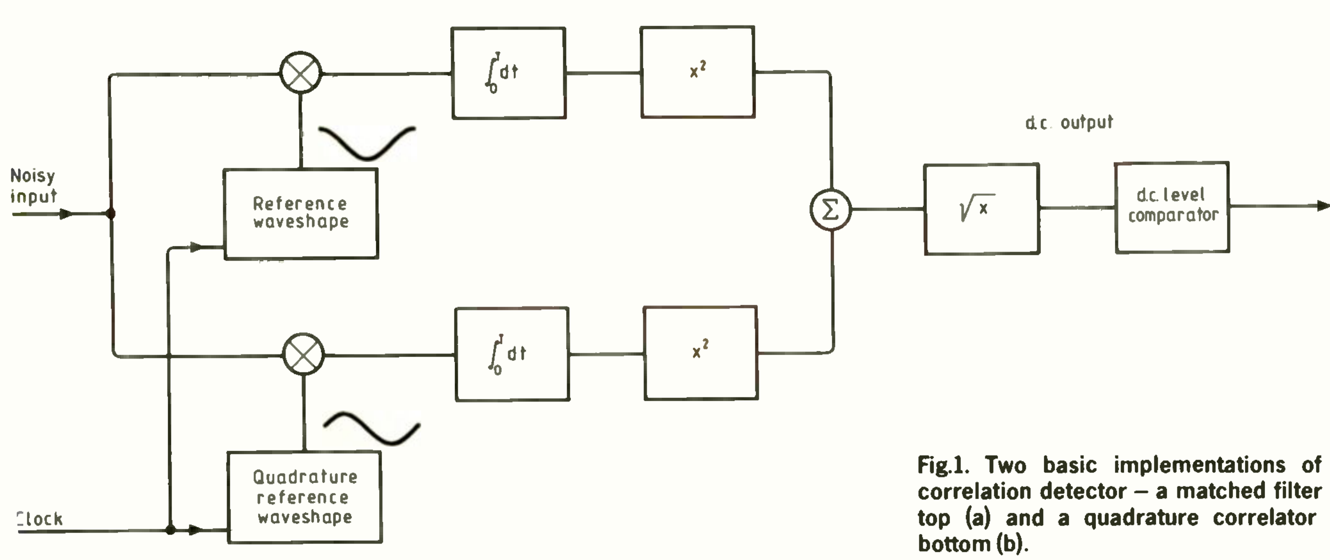


Fig.1. Two basic implementations of a correlation detector – a matched filter at top (a) and a quadrature correlator at bottom (b).

GENERAL CORRELATION

Two basic approaches to the detection of a tone are shown in Fig. 1. In (a), the matched filter uses the complete stored replica of the reference waveform after each shift through the shift register to determine correlation between the reference and the incoming signal. Between each sample, n multiplications and n additions must be performed. In Fig. 1 (b), after each sampling, only two multiplications and two additions into the integral are required.

This approach however inherently increases decoding time. At the end of the integration period, the integrators are reset to zero. If the incoming sinusoid started at the middle of the integration period, it is unlikely to be recognized for 1½ integration periods; worst-case delay approaches two integration periods.

A matched filter gives optimum detector performance in the presence of Gaussian noise[4-6]. Figure 2 gives the basic frequency behaviour of such a filter and Fig.3 shows typical amplitude response as the normalized input frequency is swept from zero to 2f.

There are two important features of Fig.3:

– For low values of n the output is skewed, which is quite correct. As n becomes large, the integral approaches the Fourier transform, the curves approach sinx/x and the asymmetry disappears.

– If a sinusoid is cross-correleated with another sinusoid, frequency selectivity is poor unless many cycles are used.

As the number of cycles cross-correlated is pushed up, so is filter selectivity. However, two other factors are important. Firstly the number of taps along the delay line is not infinite, because finite time is required for generation of the integral. Secondly, the filter can respond to multiples of the fundamental because of aliasing.

From the Nyquist criterion at least two samples per cycle are required at the maximum frequency. However for equal sampling at two samples per cycle, the relative phase of the reference and the incoming sinusoid is important, since a phase shift of 90° makes the difference between full output and no output from a matched filter.

Referring to Fig. 1(a), output sample sequence E(k) from the stepped delay line is

$$\sum_{n=0}^{M-1} = (f(k-n)\,h(n))$$

where k is output sample number, incoming sinusoid f(k) is $\cos((k2\pi/M)+\theta)$, filter correlation pattern h(n) is $\cos((n2\pi/M)+\delta)$, and θ, δ are relative phases.

$$E(k)=\sum_{n=0}^{M-1} \tfrac{1}{2}\cos\left[\frac{(k-2n)}{M}2\pi+\theta-\delta\right]+$$

$$\tfrac{1}{2}\cos\left[\frac{k}{M}2\pi+\theta+\delta\right]$$

$$=\frac{M}{2}\cos\left[\frac{k}{M}2\pi+\theta+\delta\right]+$$

$$\tfrac{1}{2}\sum_{n=0}^{M-1}\cos\left[\frac{(k-2n)}{M}2\pi+\xi-\delta\right]$$

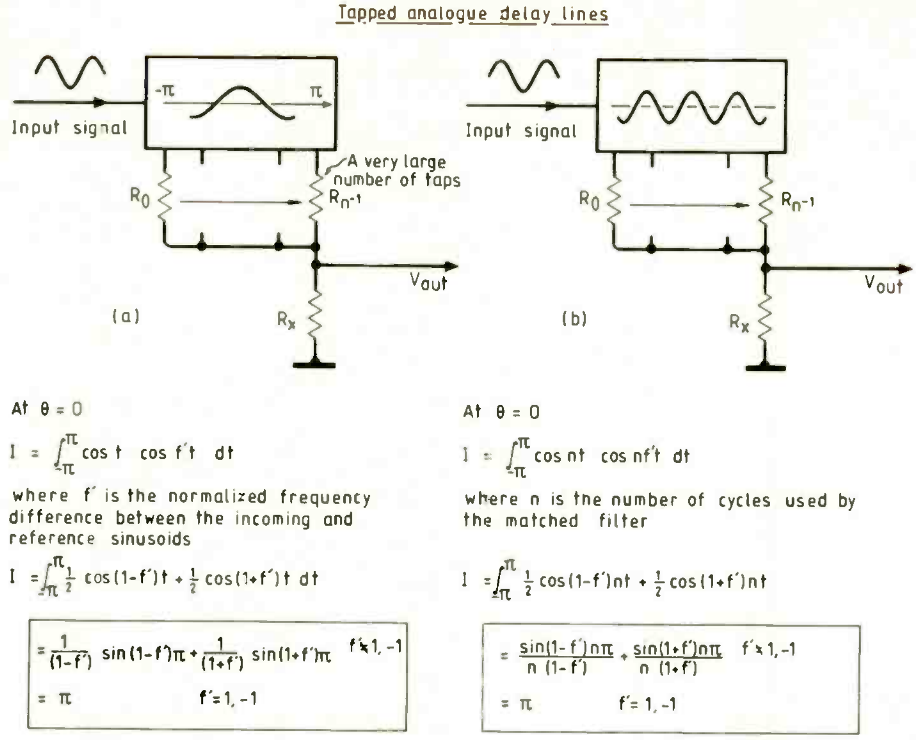


Fig.2. Tapped delay line detector using a single sinusoid cycle (a) and using multiple sinusoid signals (b).

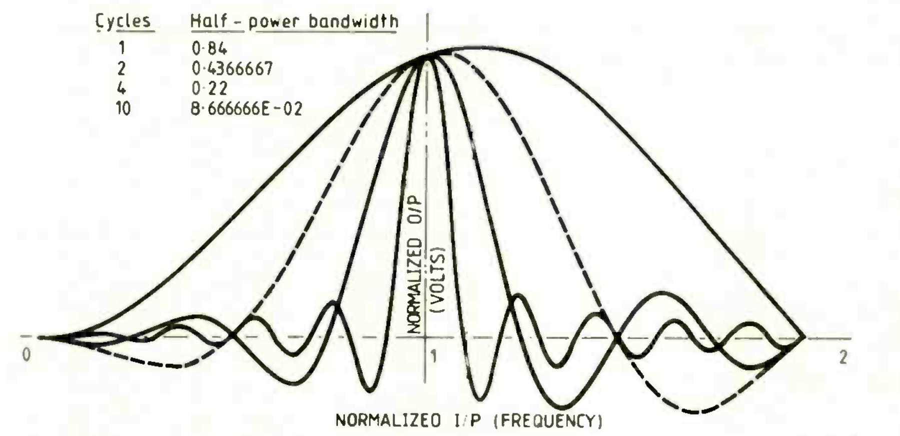


Fig.3. Peak output and half-power bandwidth for the detector of Fig.2 (b) using 1,2,4 and 10 cycles.

The first term is desired output, while the second is an error term. If M≥3, then the second term is zero so the minimum integer sampling rate is three samples per cycle.

Figure 4 gives plots of proportional bandwidths versus number of cycles in the matched filter for a number of waveshapes. As the waveshape used for cross-correlation progresses from a sinewave to a 1:1 squarewave then to a 16:1 rectangle wave (all of zero mean value), fewer and fewer cycles are required to achieve a given bandwidth. The limit is reached when the waveshape used is reduced to an impulse; in this case, barely more than one cycle is required to determine frequency of the incoming waveshape.

Such selectivity is bought at a high cost since a correlation detector like this will respond to almost any incoming signal or noise. A sinusoid waveshape gives excellent noise immunity and rejection of harmonics, but from Fig. 4, a bandwidth of 5% (i.e. ±2.5%) requires 16 cycles for correlation. Figure 4 includes the curve for the common analogue filter approximation for rise time.

If incoming signal f(t) consists of N cycles, each cycle with period T, then energy in the ensemble, E, is

$$\int_{-\infty}^{\infty} f^2(t)dt=\int_0^{NT} f^2(t)dt$$

$$=NT\int_0^{2\pi} f^2(\theta)d\theta.$$

Table 1 shows this evaluated for four particular waveshapes. If it is accepted that filtering over a number of cycles will reduce noise to a

Table 1. Sine and squarewave zero means.

Waveform, zero mean	Energy in wavetrain	Scaling factor K
Sine	πTNA^2	1
Rectangular 1:1	$2\pi TNA^2$	2
1:7	$0.2857\pi TNA^2$	0.2857
1:15	$0.1333\pi TNA^2$	0.1333

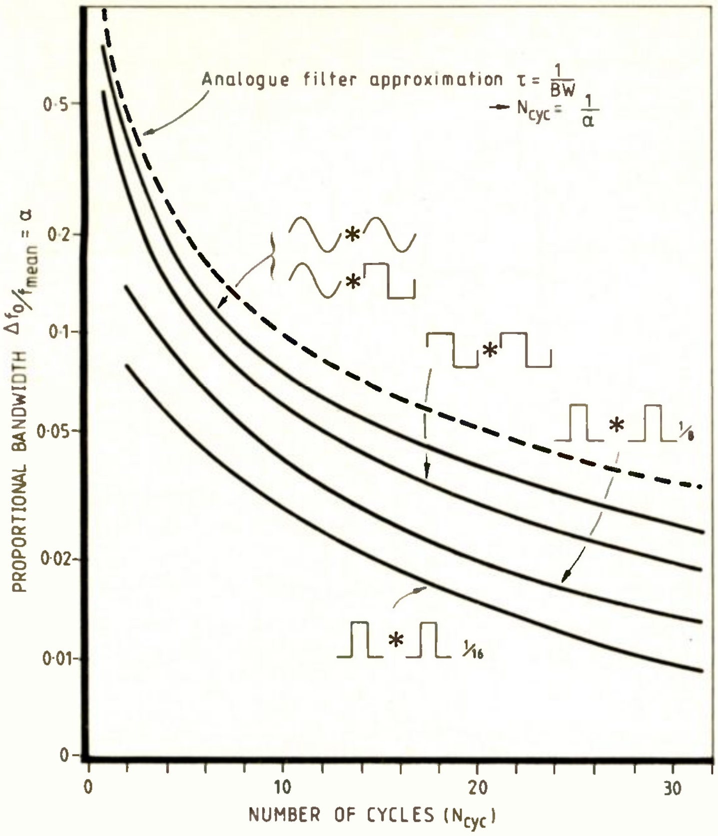


Fig.4. Numerically calculated graph showing the relationship between correlation waveshape and normalized bandwidth.

near-Gaussian noise characteristic, then standard matched filter theory may be used.

Average s-to-n ratio for a sinewave plus noise is

$$SNR_{AV}=\frac{A^2/2}{N_0}.$$

Standard matched filter theory gives the peak-output s-to-n ratio as

$$SNR_{PK}=\frac{2E}{\eta}=\frac{2E}{(N_0/B)}=\frac{2EB}{N_0}$$

where η is noise spectral density with white noise characteristic, N_0 is total noise power and B is noise bandwidth. Substituting from Table 1, then for the previous equation.

$$SNR_{0(PK)}=2\frac{B}{N_0}\pi TNA^2K=4\pi B.TNK.SNR_{i(AV)}$$

Design of a tone decoder for the t.c.s.s. application revolves around a trade-off between bandwidth given in Fig.4 and factors T, N and K in the previous equation.

If limited spurious response to odd harmonics can be tolerated, then the square-wave has a clear s-to-n ratio advantage over other waveshapes.

However, for the t.c.s.s. application, the reference may be rectangular but the incoming signal is merely a hard-limited noisy sinusoid. For low s-to-n ratio operation, the reference waveshape should emphasize the signal where the peak of the sinusoid is.

In practice the reference waveform is not critical; a rough three-level or five-level approximation to a sinewave is quite acceptable.

PERIOD MEASUREMENT

If the incoming signal is relatively noise free before hard limiting, a microprocessor equipped with a hardware timer can readily make a period measurement to an accuracy of the maximum instruction execution time.

Thus, an incoming sinusoid period can be determined accurately to within a few microseconds if the sinusoid is guaranteed to be free of any d.c. or transient offset. This is most easily implemented if the microprocessor is given an interrupt pulse on each positive (or negative) zero crossing; this is approximately equivalent to the incoming tone being reduced to an impulse.

For a high s-to-n ratio, probability density of zero crossings can be found if some approximations are made:

- If the noise passband extends beyond the frequency of the sinusoid to be decoded, then distribution in time of one zero crossing is statistically independent of the previous zero crossing.
- Around the point of the zero crossing, the sinusoid may be approximated by a straight line of slope $A\omega$.
- The noise voltage has a Gaussian distribution.
- There is only one zero crossing per half-cycle.

This requirement implies a high s-to-n ratio and a relatively low upper cut-off frequency for the bandpass filter.

A noise voltage sampled infrequently with respect to the upper cut-off frequency of a passband filter has this Gaussian amplitude distribution

$$p(y,t_i)=\frac{1}{\sqrt{2\pi}\sigma}\exp-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2$$

where σ is the r.m.s. voltage and μ the mean direct voltage.

At the point of zero crossing of a sinewave, the amplitude distribution of sinewave plus noise can be scaled to give a distribution in time at the instant of zero crossing.

$$\sigma_t=\frac{\sigma_y}{A\omega}=\frac{\sigma_y}{A2\pi}$$

when normalized to a frequency of 1Hz.

Input s-to-n ratio should be such that the instant of zero crossing is within a certain error bound Δ. For example, a t.c.s.s. system may require a 5% bandwidth so Δ is ±0.025 in this case. Since the point of interest is at the zero crossing of the noise-free sinewave, the mean μ is zero and the error limit on the time axis is:

$$\Delta=\frac{Z\sigma}{A2\pi}\rightarrow\frac{A}{\sigma}=\frac{Z}{2\pi\Delta}$$

$$SNR=\tfrac{1}{2}\left(\frac{A}{\sigma}\right)^2\rightarrow SNR_i=\tfrac{1}{2}\left(\frac{Z}{A2\pi}\right)^2.$$

However, if the decoder averages the periods over each cycle, then the required SNR_i reduces by $\sqrt{N}$ where N is the number of cycles:

$$SNR_i=\frac{1}{2\sqrt{N}}\left(\frac{Z}{A2\pi}\right)^2.$$

For the example of a 5% bandwidth, SNR_i reduces to 5.5 for 16 cycles. This derivation is not suitable for use when s-to-n ratio is less than four. It does however indicate that at modest s-to-n ratios fast decoding is possible. Further, using a small timer interrupt-service routine it is possible for a microprocessor to directly decode a 10kHz tone without use of aliasing techniques.

DISTRIBUTION OF ZERO CROSSINGS

Figure 5 shows the arrangement used to measure the period between adjacent positive zero crossings of the output signal from an f.m. receiver. It is necessary to eliminate all noise contamination from mains frequencies for these results to be valid.

Figure 6 shows normalized distribution of periods between successive positive zero crossings. The normalized measurement intervals were 0.05 and 1000 samples were taken for each curve. These graphs show that a received tone is more likely to be contaminated by a spurious zero crossing if it is low in the analogue-filter passband.

For the particular receiver, the 12dB sinad sensitivity is -118dBm. At this level, probability of correct detection of a tone by period measurement, i.e. correlation with an impulse-like reference, is poor, particularly when the tone is low in the filter passband.

These results indicate that best decoder performance is achieved when the most analogue filtering is done before hard-limiting the signal.

To be continued.

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Chris Gough works as a design engineer with Tait Electronics in New Zealand. Before that he worked as an electronics technician for the DSIR, and in 1984 he gained his BE (Hons) from the University of Canterbury. His interests include r.f. design, signal processing and instrument design.

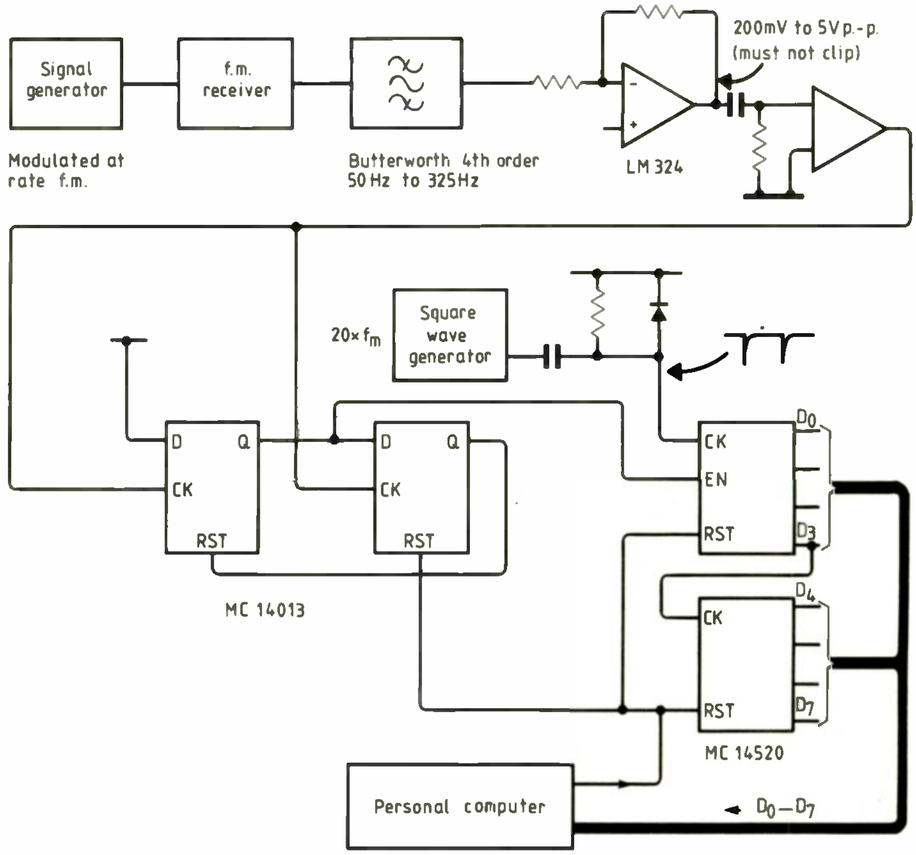
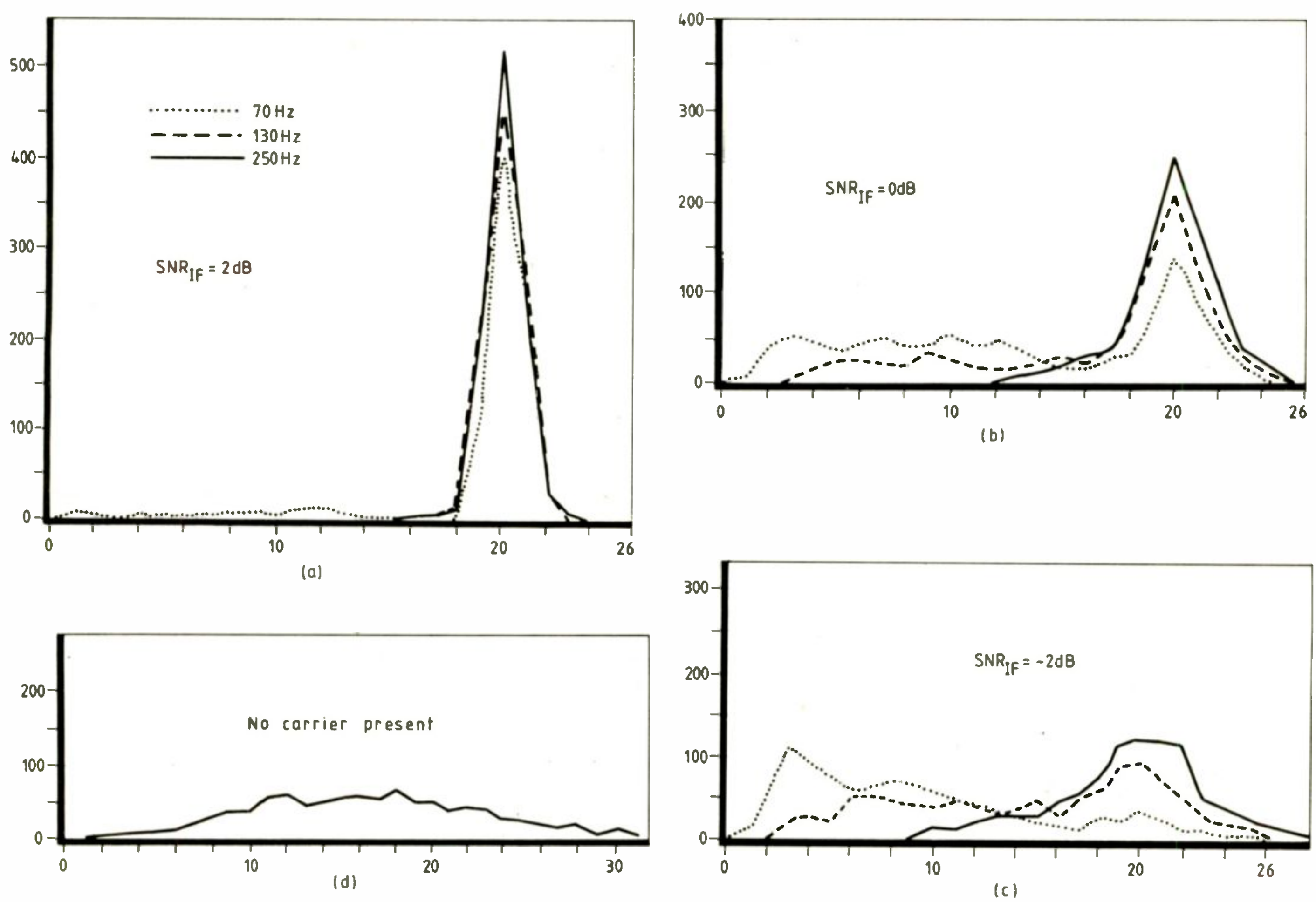


Fig.5. Hardware test arrangement for measuring the period between adjacent positive zero crossings.

Fig.6. Normalized distribution of periods between adjacent zero crossings in a noisy f.m. signal using 1000 samples for each curve and 0.05 measurement intervals.



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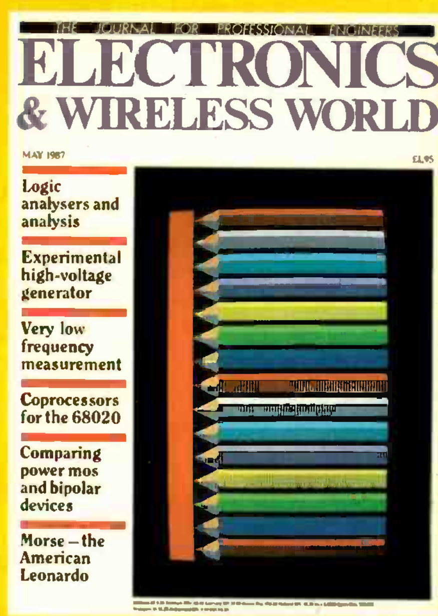

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SOLDERING

Soldering to solder

The problem of soldering metal components to an existing pre-soldered joint has been solved by the use of a bismuth-tin alloy with a melting point well below that of ordinary solder. Melting at 137°C, the alloy is used in an extruded wire form to ensure the accuracy frequently necessary when soldering components for electronic equipment. The manufacturers can adjust the composition of the alloys across a wide range of low melting points, anywhere between 20° and 300°C. MCP 137 – one of the most popular alloys in the MCP range – has the further advantage, unlike conventional solder, of having no lead content. Mining and Chemical Products Ltd, Alperton, Wembley, Middlesex HA0 4PE. Tel: 01-902 1191.

Conveyor system for automatic soldering

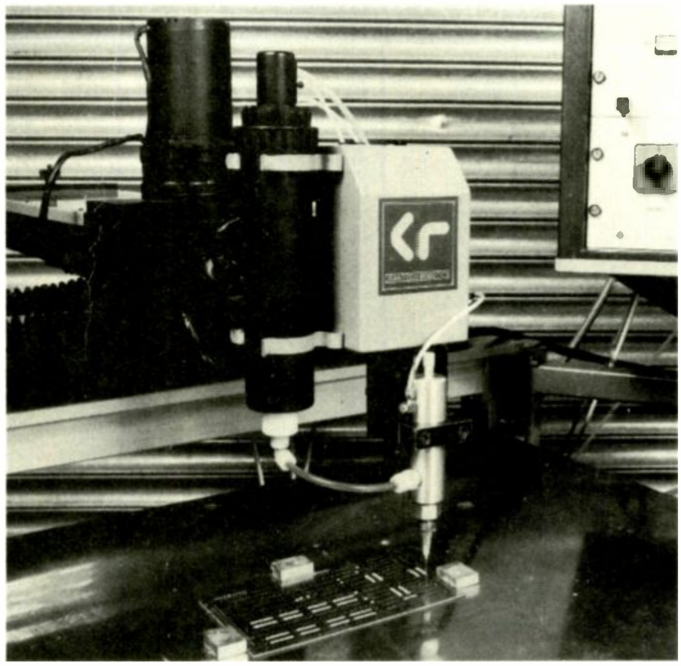
Closed-loop conveyor lines are the speciality of PAF Ltd. Each of the lines, in a typical installation, is on a single level in the shape of a rectangle, and uses PAF's twin-tape conveyors to transport the cards which are fitted in jigs on carriers. This highly-efficient closed-loop system incorporates PAF's 90° twin-tape transfer units at three corners, automatically synchronized with the carriers, and an Electrovert flow-soldering and board cleaning machine.

To facilitate the processes involved in flow soldering and cleaning, the boards are raised as they pass through the machine, and a higher-level conveyor takes the carriers a short distance to a PAF twin-tape lift and transfer unit.

The component inserters sit along the outside of each line and are in easy reach of the parts, which are held in 10 or 20 tray, foot-operated PAF rotary carousels located opposite them on the inside of the line. PAF Systems, Sanders Road, Fineden Road Industrial Estate, Wellingborough, Northants NN8 4NL. Tel: 0933 222195.

Soldering equipment

A range of tools, machinery and materials for soldering is available from Solbraze Ltd. They produce a wide range of soldering irons from 30 to 500W; flame, induction and resistance heating tools; and a large number of different solder pots for dip soldering. The company specialises in tailoring machines and jigs for specific applications. Solbraze Ltd, Bilton Road, Erith, Kent DA8 2AN. Tel: 0322 341411.



Robot for solder masking

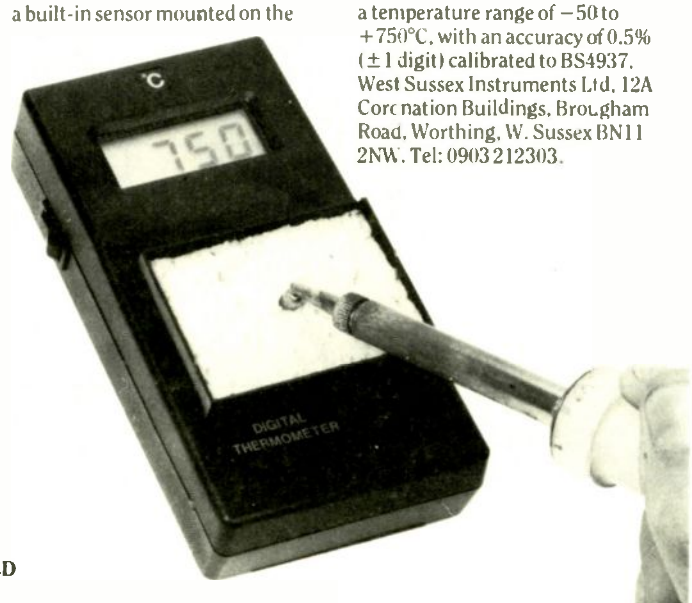
A low-cost robot has been developed for the application of solder-resist materials to printed-circuit boards. The Polar Robot comes from Crantech Robotics. The machine can be programmed easily and quickly on the production line to deal with any spot-masking configuration required, in any combination of mask patterns – lines, dashes, dots, squares, etc, as intricately as the application requires.

In batch production, the machine can recall a number of preset programs at the touch of a button. Even different combinations of head thickness can be incorporated into the same program by use of an inbuilt device known as the speed multiplier. The Polar is claimed to carry out its task far more accurately, swiftly and economically than is possible by hand application.

As the robot can deal accurately with solder masking, it can also be used for other applications, such as the dispensing of solder paste, adhesives and encapsulating materials. All that is needed is a change of dispensing valve and product feed line; the substitution of solder paste (or adhesives or encapsulant) for solder mask; and calling up of the appropriate program. At its basic installed price of around £13 000, payback is between six and eighteen months, depending on the type of application. Crantech Robotics Industrial Systems Ltd, Unit D3, Gedding Road, Hoddeston Herts EN11 0NT. Tel: 0992 445935.

Soldering thermometer

Where the temperature of a soldering iron may be critical, it is possible to use the WSI 500 thermometer. It has a built-in sensor mounted on the front panel, surrounded by a bit-cleaning sponge, with a liquid-crystal readout. The instrument has a temperature range of −50 to +750°C, with an accuracy of 0.5% (±1 digit) calibrated to BS4937. West Sussex Instruments Ltd, 12A Coronation Buildings, Brougham Road, Worthing, W. Sussex BN11 2NW. Tel: 0903 212303.



Static-free desolderer

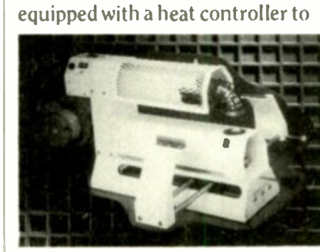
A low-cost static-free desoldering tool has been added to the anti-static range of OK Industries. It has been manufactured in accordance with UL and MIL standards and satisfies MIL/B/817025 2nd barrier electrostatic free material requirements. It is provided with a bayonet type conductive tip which is easy to clean and change.

The DP3 is available ex-stock and costs £5.75 (+ tax & delivery). Tips are 95p. OK Industries UK Ltd, Dutton Lane, Eastleigh, Hants SO5 4SL. Tel: 0703 619841.

Hot-air resoldering

Designed for repairing surface mount boards, the new System 1000 uses directed hot air exhaust to desolder and resolder s.m.ds and dual-in-line components. The system features an X and Y board-holding mechansim on linear bearings, with a panel size from 0 to 600 by 400mm and two hot air tubes which can be individually extended or retracted by means of a control knob. Additionally, the temperature of either of the tubes can be individually controlled, for a particular application.

The System uses a blower fan to pass air through both the upper and lower tubes, each of which is equipped with a heat controller to



monitor the temperature of the air as it passes through the tube. Once the tubes are extended forward, hot air is directed through a special disc plate fitted to the tube's end and onto the substate for repair. The system has been designed to be portable, and weighs only 10kg. Sohlberg-Surtech Ltd, Intec 2, Wade Road, Basingstoke, Hants RG24 0NL. Tel: 0256 470848.

Wave soldering

Good soldering is combined with pleasing design and good, sound manufacture in the Iemme Italia range of wave soldering machines; according to Electrautom Ltd, who are the UK agents.

The IM range is well established in Europe but is newly imported to the UK. Their design has improved the image of such machines which are traditionally dirty and smelly. Electrautom Ltd, Etom Buildings, Quarry Wood, Aylesford, Kent ME20 7NA. Tel: 0622 70188.

LANGREX SUPPLIES LTD

Climax House, Fallsbrook Rd., Streatham, London SW16 6ED

RST Tel: 01-677 2424 Telex: 946708 RST

SEMICONDUCTORS

AA119	0.10
AAY30	0.17
AAZ13	0.30
AAZ15	0.30
AAZ17	0.30
AC107	0.55
AC125	0.35
AC126	0.35
AC127	0.40
AC128	0.35
AC141	0.35
AC141K	0.45
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AC176	0.35
AC187	0.35
AC188	0.35
ACY17	2.25
ACY18	1.55
ACY19	1.80
ACY20	1.50
ACY21	1.55
ACY39	4.00
AD139	1.00
AD161	0.50
AD162	0.60
ADZ11	12.50
ADZ12	12.50
AF106	0.60
AF14	3.50
AF115	3.50
AF116	3.50
AF117	4.00
AF139	0.55
AF186	0.75
AF239	0.65
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AFZ12	5.00
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CRS3 60	0.90
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A2900	15.00
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DET24	49.00
DF91	1.75
DF96	1.75
DK91	1.75
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DY802	1.50
E55L	50.00
E80CC	15.00
E80CF	11.27
E80F	14.19
E80L	13.73
E81CC	8.00
E81L	13.27
E82CC	8.10
E83CC	8.40
E86C	8.25
E88C	8.25
E88C	10.33
E90CC	9.47
E90F	9.90
E91H	6.25
E92CC	8.75
E99F	9.10
E130L	18.50

E180CC	10.50
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FW4-500	3.50
FW4-800	3.50
G1.371K	35.00
G551K	12.00
G180.2M	17.50
G240.2D	12.00
G400.1K	17.50
GN4	9.00
GN4A	9.00
GS16	16.00
GT1C	25.00

GU50	20.00
GU51	20.00
GXU1	15.35
GXU2	30.00
GXU3	25.40
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GY501	3.00
GZ32	4.00
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GZ37	4.75
KT61	5.00
KT66	15.00
KT77 Gold Lion	12.00
KT88 Gold Lion	20.00
KTW61	2.50
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M8079	12.34
M8080	8.25
M8081	9.82
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N78	15.00
OA2	3.25
OA3	2.50
OA4	6.00
OB3	2.50
OC2	4.35

OC3	2.50
OD3	2.50
OZ4	3.50
PC86	2.50
PC88	2.50
PC95	1.75
PC97	1.75
PC900	1.75
PCC84	1.50
PCC85	1.50
PCC88	2.00
PCC89	1.75
PCC189	2.50
PCC805	1.60
PCC806	1.60
PCE82	2.00
PCF80	2.00
PCF82	1.50
PCF86	2.50
PCF87	2.00
PCF200	3.25
PCF201	3.25
PCF801	2.50
PCF802	2.50
PCF805	1.70
PCF806	1.70
PCF808	1.70
PCL82	2.00
PCL83	3.00
PCL84	2.00
PCL85	2.50
PCL86	2.50
PCL805/85	2.50
PD500	6.00
PE06-40N	45.00
PFL200	2.50
PL36	2.50
PL81	1.75
PL81A	2.00
PL82	1.50
PL83	2.50
PL84	2.00
PL504 5	2.50
PL508	5.50
PL509	6.00
PL519	6.00
PL801	1.50
PL802	6.00
PY33	2.50
PY81	1.50
PY82	1.50
PY83	1.25
PY88	2.00
PY500A	4.00
PY800	1.50
PY801	1.50
QF451	82.50
QQV02-6	38.00
QQV03-10	26.25
QQV03-20A	48.38
QQV06-40A	46.00
QQV07-50	76.65
QQZ06-40A	62.20
QU37	12.50
QV03-12	6.80

QV04-7	3.50
QV08-100	197.40
QY3-65	63.24
QY3-125	78.48
QY4-250	74.00
QY4-400	87.20
QY5-500	208.00
QY5-3000A	566.80
QZ06-20	46.00
R10	6.00
R17	3.00
R18	3.00
R19	9.24
R20	2.50
RG3-1250	59.50
RG3-250A	32.68
RG4-1250	61.60
RG4-3000	99.45
RR3-250	40.00
RR3-1250	45.75
S130	6.00
S130P	6.00
STV280-40	14.00
STV280-80	21.00
SU41	5.00
SU42	10.00
TD03-10	35.00
TD03-10F	35.00
TT15	50.00
TT21	37.50
TT22	37.50
TT100	60.00
TY2-125	78.75
TY4-400	88.20
TY4-500	124.26
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TY6-5000B	395.00
TY6-5000W	523.00
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U18.20	3.50
U19	13.75
U25	2.50
U26	2.50
U37	12.00
UABC80	1.25
UAF42	2.50
UB41	3.00
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UBF89	1.50
UCC84	1.75
UCC85	1.85
UCF80	2.00
UCH42	2.50
UCH81	2.50
UCL82	1.75
UCL83	2.75
UF41	2.00
UF42	2.10

UF80	1.75
UF85	1.75
UF89	2.00
UL41	5.00
UL84	1.75
UM80	2.00
UY41	4.00
UY85	2.25
VLS631	15.00
XG1-2500	100.00
XG5-500	30.00
XG2-6400	185.00
XR1-1600A	53.75
XR1-3200	110.00
XR1-3200A	
XR1-6400	165.00
YD1120	395.00
YD1240	588.00
Z803U	25.00
Z259	27.59
ZM1001	8.00
ZM1020	9.00
ZM1020	9.00
ZM1022	9.00
ZM1023	9.00
ZM1040	19.36
ZM1041	16.66
ZM1042	17.77
1B3GT	3.00
1B24	25.00
1B35A	48.00
1B63	64.00
1R5	1.75
1S5	1.75
1T4	1.75
2AS15	11.50
2C39A	60.00
2C43	70.00
2D21	3.25
2E26	8.25
2J4Z	98.00
2J55	245.00
2J70A	383.00
2J70B	336.00
2K25	125.00
3400Z	115.00
3500Z	100.00
3A5	3.00
3B24	11.00
3B28	15.35
3B29	20.05
3B240M	17.50
3B241M	17.50
3C23	25.00
3C24	12.00
3CX100A	47.00
3E29	45.00
3S4	2.00
3V4	1.75
4-65A	60.00
4-125A	60.00
4-250A	80.00
4-400A	87.00
4B32	20.00

4C35	120.00
4CX250B	58.00
4CX350A	105.00
4X150A	60.00
4X150D	56.00
511E12	65.00
5B254M	35.00
5B255M	35.00
5C22	160.00
5J180E	2500.00
5R4GY	5.50
5U4G	3.00
5U4GB	2.50
5V4G	2.50
5Y3GT	2.50
5Z3	4.00
5Z4G	2.50
5Z4GT	2.50
6-30L2	1.75
6AB4	1.75
6AB7	3.00
6AC7	3.00
6AF4A	4.25
6AG7	3.00
6AH6	5.00
6AK5	5.99
6AK6	2.50
6AL5	1.50
6AM4	4.00
6AM5	9.69
6AM6	6.02
6AN5	4.75
6AN8A	3.50
6AQ5	3.25
6AS6	8.66
6AS7G	8.75
6AT6	1.25
6AU5GT	5.00
6AU6	2.50
6AV5GA	4.50
6AV6	1.50
6AX5GT	3.00
6B7	3.25
6B8	3.25
6BA6	1.50
6BA7	5.00
6BA8A	4.00
6BC4	4.00
6BR6	1.50
6BH6	2.50
6BJ6	2.25
6BK4	4.50
6BL6	125.00
6BL7GT	4.50
6BM6	115.00
6BN6	2.00
6BQ7A	3.50
6BR7	6.00
6BT8A	3.50
6BS7	6.00
6BW6	6.00
6BW7	1.50
6BX7GT	5.00
6BZ6	2.75
6C4	1.25
6CB6A	2.50
6CD6GA	5.00
6CG7	2.50
6CH6	13.00

6CL6	£3.75
6CW4	8.00
6D2	1.50
6DK6	3.00
6DQ6B	4.75
4EA8	3.00
6EB8	2.50
6EW6	2.25
6F6	3.00
6F23	1.60
6F28	1.60
6F33	33.50
6H1	14.00
6H3N	2.75
6H6	3.00
6J4	5.50
6J6	8.93
6J7	4.75
6JE6	7.50
6K4N	2.50
6K6GT	2.75
6K7	3.00
6K8	3.00
6KD6	8.00
6L6G	5.00
616GA	3.50
6L6GC	5.75
6L6GT	3.00
6L7	2.50
6N2P	2.50
6N3P	2.50
6N7	3.00
6P225	4.00
6Q7	3.75
6K7	3.25
6R1H18 6KN8	10.00
6SA7	3.00
6SC7	2.75
6SF7	2.50
6SH7	3.00
6SJ7	3.25
6SK7	3.50
6SL7GT	3.00
6SN7GT	3.00
6SQ7	3.40
6SR7	4.00
6SS7	2.75
6U5G	3.50
6U8A	2.25
6V6GT	4.25
6X4	3.00
6X5GT	1.75
7B7	2.50
7C3	4.00
7C6	2.50
7H7	4.00
7R7	4.25
7S7	3.50
7Y4	2.25
7Z4	2.00
12AH8	5.00
12AT6	1.50
12AT7	1.75
12AU6	2.50
12AU7	1.75
12AV6	2.50
12AW7	3.50
12AX7	1.75

12AY7A	4.00
12B4A	3.50
12BA6	2.50
12BE6	2.50
12BH7	2.75
12BY7	3.00
12E11TT	28.00
12E14	65.00
12E1	20.00
13E1	170.00
19H5	47.50
24B9	67.25
30C15	2.00
30C17	2.00
30C18	2.00
30F5	1.60
30FL1 2	1.38
30FL12	1.80
30FL14	2.00
30L1	1.50
30L15	2.00
30L17	2.00
30P4	2.50
30P19	2.50
30PL1	3.00
30PL14	1.80
30PL15	1.80
35W4	1.00
50C4	1.50
75B1	6.05
75C1	4.50
85A1	7.50
85A2	6.45
90AG	20.00
90AV	20.00
90C1	6.00
90CG	14.54
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92AG	20.00
92AV	20.00
95A1	8.45
150BA	6.50
150B3	8.35
150C2	3.25
150C4	6.00
211	35.00
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803	25.00
805	45.00
807	3.75
811A	18.33
812A	47.50
813 valve	65.00
833A	193.16
866A	35.03
872A	20.00
922	6.00
931A	18.50
1624	4.00
1625	3.50
2050	7.50
4212E	300.00
4212H	300.00
5544	110.00
5545	150.00
5551A	120.00
5552A	165.00
5642	9.00
5654	3.00

5651	4.45
5670	4.50
5675	28.00
5687	6.00
5696	4.50
5718	7.50
5725	5.50
5726	11.37
5727	7.05
5749	2.50
5751	4.00
5763	4.50
5814A	4.00
5840	4.00
5842	12.00
5876A	31.50
5879	5.00
5886	17.50
5963	2.50
5965	3.50
6005	2.25
6021	4.50
6057	12.25
6058	12.34
6059	6.00
6061	6.00
6063	3.75
6064	10.25
6067	11.75
6072	6.00
6080	14.00
6097A	235.00
6097B	200.00
6146A	12.00
6146B	12.00
6159B	19.00
6189	9.50
6201	11.40
6442	20.00
6550	10.00
6883B	12.50
6973	7.50
7025	4.50
7027A	8.00
7551	6.25
7586	15.00
7587	23.00
7609	56.00
7868	6.00
7895	12.00
8068	16.50
8136	2.50
8417	6.00
18042	11.53
18045	10.49
18046	11.53

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B9A Skirted	0.50
B9D	0.55
Int Octal	0.40
Loctal	0.55
Nuvistor base	2.00
Valve screening can all sizes	0.40

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2BP1	9.00
3BP1	20.00
3DP1	5.00
3EG1	10.00
3FP7	6.00
3GP1	6.00
3JP1	8.00
3JP2	8.00
3JP7	10.00
3KP1	15.00
3RP1	35.00
3WP1	20.00
5ADP1	55.00
6CP1	10.00

5CP1A	40.00
5P15A	15.00
5UP7	25.00
DG7-5	63.32
DG7-31	58.07
DG7-32	58.07
DG7-36	65.00
DH3-91	56.83
DH7-11	113.12
VCR138	12.00
VCR138A	12.50
VCR139A	8.00
VCR517B	10.00
VCR517C	10.00

CRT sockets
Prices on
application

IC sockets
Texas
low profile

8	pin	10p
14	pin	10p
16	pin	10p

INTEGRATED CIRCUITS

7400	0.16
7400	0.35
7401	0.36
6402	0.36
7403	0.36
7404	0.42
7405	0.42
7406	0.48
7407	0.55
7408	0.36
7409	0.36
7410	0.36
7411	0.40
7312	0.42
7413	0.36

7416	0.48
7417	0.48
7420	0.48
7422	0.36
7423	0.36
7424	0.36
7427	0.36
7428	0.36
7430	0.36
7432	0.36
7433	0.55
7437	0.36
7438	0.36
7439	0.36
7440	0.36

7441	0.48
7442	1.25
7450	0.30
7451	0.30
7453	0.30
7454	0.30
7460	0.30
7470	0.48
7472	0.30
7473	0.48
7474	0.36
7475	0.65
7476	0.48
7480	0.32
7483	0.48

7484	0.72
7486	0.54
7490	0.72
7491	0.36
7492	0.54
7493	0.54
7494	0.78
7495	0.65
7496	0.60
7497	3.90
74100	0.84
74107	0.36
74109	0.54
74110	0.48
74111	0.51
74116	1.50
74118	1.20
74119	1.50

74120	0.75
74121	0.54
74122	0.70
74123	0.60
74125	0.60
74126	0.54
74128	0.55
74136	0.70
74141	0.46
74143	1.30
74145	0.72
74147	1.50
74148	1.40
74150	1.60
74151	0.36
74154	1.40
74155	0.60
74156	0.48

74159	1.75
74170	1.20
74172	4.00
74173	0.72
74174	0.60
74175	1.00
74176	1.00
74180	1.48
74190	1.20
74191	1.20
74192	1.10
74193	0.60
74194	1.10
74195	0.72
74196	1.00
74197	1.00
74198	2.20
74199	2.20

TAA570	1.75
TAA630S	1.75
TAA700	3.00
TBA480Q	1.50
TBA520Q	1.50
TBA530	1.50
TBA550Q	1.75
TBA560Q	1.75
TBA673	1.75
TBA700	1.50
TBA700Q	1.75
TBA750Q	1.50
TBA800	1.00
TDA920	1.75
TBA990Q	1.50
TCA270Q	1.00
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NEW PRODUCTS

SPECTRUM ANALYSERS

HP portable

Also from Livingston Technical Sales, comes the The Hewlett Packard 8590A RF Spectrum Analyser, offering features previously found only in high-performance models, but it comes in a lightweight, sturdy package weighing only 13.5kg. It is equally suitable for bench applications, in r.&d, manufacturing environments and for field use; for stand-alone or systems applications. It has the versatility to handle virtually any r.f. signal measurement requirement.

The instrument covers the 10kHz to 1.5GHz frequency range (1.8GHz optional), with −115 to +30dBm amplitude range. Designed for easy manual operation, the 8590A is the first HP spectrum analyser to have both dedicated pushbuttons, for frequently-used functions, and menu-based softkeys, with access to more than 80 additional functions. Most measurements require only frequency, span and amplitude selection, the analyser automatically adjusting remaining parameters for an optimized c.r.t. display. Optional HPIB, HPIL RS232c interfaces enable fully programmable, and direct output of results to printer or plotter.

More than 100 built-in functions aid measurement and data handling, including signal track and marker functions, automatic performance of complex measurements, trace arithmetic and trace storage.

Coupled with the HP 8444A tracking generator, the HP8590A performs evaluations such as stimulus response measurements, e.g. frequency response and insertion loss. Further addition of the HP 10855A broadband amplifier and the new HP 11940A close-field probe yields a swept, broadband sysem for e.m.i. troubleshooting.

The unit is available for sale ex stock from Livingston Technical Sales or on short term rental from sister company, Livingston Hire, at £200 a week.

Portable analyser for satellite reception

Especially designed to cope with tv.r.o. installation and service problems, the Avcom PSA-35 is a lightweight portable instrument, which operates from a.c. mains or internal rechargeable batteries. The frequency coverage is from under 10 to over 1500MHz and from 3.7 to 4.2GHz in 6 bands (including the current 12GHz for l.n.bs. The instrument has a built in power block and power for l.n.as and b.d.cs. It will accurately measure wide band signals commonly used in the tv.r.o. industry, and is ideal for accurate and rapid testing and alignment of satellite equipment.

Optional extras include a signal sampler, a terrestrial interference survey horn and a carry case. For further details contact Fieldtech Heathrow Limited, Huntavia House, 420 Bath Road, Longford, Middlesex, UB7 0LL. Tel: 01-897 6446.

Synthesized spectrum analyser

Up to 3.6GHz from 10khz with an input sensitivity of −131dBm and a minimum resolution bandwidth of 30Hz are provided on the TR4135 synthesised spectrum analyser from Advantest.

The increased use of the upper u.h.f. band a tighter control of frequency harmonics have created a demand for measurements to be made up to and beyond 3GHz. This analyser costs less than £16,000

An in-built frequency counter with 1Hz resolution is included, together with adjustable marker display of frequency and level. Log. frequency displays are possible with a direct hard-copy capability. Facilities are provided for field-strength and CISPR interference measurements for ATE applications. GPIB controls are available with an optional tracking generator to 3.5GHz.

Advantest products are available from Chase Electronics Ltd, St. Leonards House, St Leonards Road, Mortlake, London, SW14 7LY. Tel: 01-787 7748.

1GHz analyser from Farnell

From Farnell comes the 352C portable spectrum analyser, designed for ease of use in monitoring spurious radiations in teh range 300kHz to 1GHz. Five sweep ranges have three measurement bandwidths from 2MHz on the widest range to 9kHz on the narrowest, (3MHz) range. The instrument may be used as a fixed tuned receiver over the full frequency range and both a.m. and f.m. demodulation is provided with an internal loadspeaker for output.

The display has long persistence green phosphor with 488 lines on a c.r.t. screen. All control functions, including error reduction and system monitoring are microprocessor controlled. Up to six front-panel settings can be sored and controlled. The internal picture store can be output to a printer for hard copy. Farnell Instruments Ltd, Sandback Way, Wetherby, W.Yorks LS22 4DH. Tel: 0937 61961.

Portable Tek analyser

Tektronix has introduced a new generation v.h.f./u.h.f. spectrum analyser priced at around £7 500; the 10kHz to 1.8GHz TEK 2710. The instrument provides a 5MHz i.f. bandwidth filter, 10^{-5} frequency accuracy, four-trace digital storage, full marker/delta marker control, a comprehensive time domain measurement capability; and many "built-ins" not available on current lower cost spectrum analyzers.

The standard TEK 2710 has resolution bandwidths down to 3kHz; there is an option for 300Hz resolution. Frequency accuracy is 10^5 or ±10kHz at 1GHz centre frequency on the standard 2710, with an option for accuracy of 5×10^7 or ±500Hz at 1GHz centre frequency. An optional built-in frequency counter provides readout resolution to the nearest hertz and rapid frequency measurement when in wide spans; any signal 10dB above displayed noise will be counted. When the counter is used in zero span (time domain), it will measure the frequency content of the demodulated signal e.g. modulation frequency.

On-screen dynamic range is 80dB and vertical scaling is selected from 10, 5 and 1dB/div with reference level units of dBm, dBmV, dBV, dB/μv dBμW, and dBμV/m available. The TEK 2710 accommodates both 50Ω/dBm and 75Ω/dBmV operation.

Sensitivity is −117dBm at 3kHz resolution. A built-in preamp may be switched into the conversion chain which will boost sensitivity to −129dBm. An additional 10 dB of sensitivity is available if the 300Hz resolution option is included. The comprehensive time domain capability of the instrument makes it of particular value in making communications measurements. Included are 1μs to 2 sec/div sweep in a 1-2-5 sequence for maximum flexibility in expanding the display. Analogue display for gray-scale enhancement and 5MHz system bandwidth (including c.r.t.) that minimizes amplitude measurement distortion. A.m./f.m. detectors with audio amplifier, built-in speaker and headphone jack permit listening to demodulated audio. A new, optional video monitor mode permits viewing the demodulated, rasterized video on the c.r.t. of the TEK2710.

The instrument includes marker/delta markers with tront panel control for peak find, next right and next left manoeuvres. Other marker-related functions are available via a frequency/marker menu. Markers function in both the time and frequency domain and include off-screen measurement capability.

Digital storage display includes a four-trace capability. A,B and C displays may be stored and viewed, with the D display always remaining current. This results in enhancement of signal comparison. Acquisition of the analogue signal may be on the basis of positive/negative peak processing where signals "buried in the noise" may be discerned; or positive-peak-only processing that provides best horizontal-scale display resolution. Ensemble signal averaging may be selected between min, max, mean or min/max values. Ease of use is enhanced by logically grouped; dedicated front panel controls for primary functions. The TEK 2710 includes comprehensive secondary control capabilities that are accessed via a set of five clearly marked menu keys. A user-definable key provides single keystroke measurements that are programmed and executed from the front panel. Operation is further simplified by an auto calibre routine, and automatic resolution, sweep and r.f. attenuation modes which eliminate operator traps and keep the analyser in a calibrated state.

Additional options available include Centronics interface, battery operation and rackmount configuration. GPIB and RS232 interface and a tracking generator will be available at a later date. Tektronix U.K. Ltd.; Fourth Avenue, Globe Park, Marlow, Bucks. SL7 1YD. Tel: 06284 6000.

NEW PRODUCTS
SPECTRUM ANALYSERS

Analyser for test and education

Part of the Lab-Volt analogue communications training system is the 9405 Spectrum analyser. It has been designed for the study of audio and r.f. signals in the frequency domain. Combined with an oscilloscope, the power levels of the frequency components of an input signal can be displayed on the oscilloscope screen.

The analyser can display frequency components from 0 to 30MHz, or from 85 to 115MHz, with the centre frequency being displayed on a digital readout. The input signal level is from −70 to +30dBm. The output spectrum can be directed to the oscilloscope or a recorder/plotter.

The input impedance is switch-selectable between 50 and 1MΩ and inputs can be attenuated in five steps from 0 to 40dB. The bandwidth resolution is set automatically to the optimum for the range selected, between 100 and 50kHz.

The analyser incorporates a digital memory for the oscilloscope display with a refresh rate of 30Hz. Frequency scan is selectable between 2khz and 1MHz/volt. With the oscilloscope set to 1V/div, a total span of 20khz to 10MHz can be displayed. A 'no scan' position can also be selected. Lab-Volt UK, Unit 6, Cromwell Mews, St. Ives, Cambs PE17 4BH. Tel: 0480 300695.

Analysis of power-line spectra

A new disturbance waveform analyser from Dranetz is claimed to be the first of its kind to feature screen-based operation. The touch-sensitive screen displays self-explanatory menus for easy operation, and full disturbance waveform detail derived from high-speed sampling detectors.

The Series 656 not only monitors power line disturbances on four channels but also offers the option of an eight-channel environment analyser enabling monitoring of temperature, humidity, r.f.i. etc. By capturing, displaying, analysing and storing vital information, the instrument helps to eliminate the hazards that threaten reliable operation of sensitive electronic equipment.

Setup and report parameters are simply programmed using the screen or keyboard, and an RS232c interface is provided for remote operation. The disturbance waveform is stored in non-volatile memory for analysis and display, mass storage being provided to allow an extended period of disturbance monitoring. Disturbances are analysed on-screen, stored on a disc, or printed out using the integral thermal printer. A zoom facility enables areas of the disturbance waveform, selected on the touch-sensitive screen, to be expanded for further analysis. The 656 can also be programmed to select disturbances with user-defined characteristics for investigation.

Software support includes a variety of standard report formats for the generation of records, including easily-interpreted summaries and relevant disturbance waveforms, to help production of site histories.

The eight-channel environmental input board accepts 0 to 10V or 4 to 20mA inputs from external probes and transducers.

Livingston Technical Sales Limited, 2-6 Queens Road, Teddington, Middx TW11 0LR. Tel: 01-977 0055.

Analyser and DSO combined

Having the functions of both a spectrum analyser and a digital storage oscilloscope, the Scopadaptor 9060 is used with a 'host' two-channel oscilloscope. The instrument is a two-channel digital signal processing unit with input attenuators-amplifiers, anti-aliasing filters and a-to-d converters. It provides analogue outputs to the oscilloscope together with a trigger.

In the FFT mode it acts as a spectrum analyser with a bandwidth of 40kHz. The high-speed monolithic d.s.p. allows updating the display, at the slowest frequency, every four seconds and at high frequencies, every second. Averaging in binary steps from 1 to 128 is provided, which is useful when testing equipment using white noise. Other features include the ability to compare, or subtract the signals.

The instrument will also convert an oscilloscope into a digital storage device. The Scopadaptor has 512-bytes/channel. Memory is read continuously by the screen refresh circuitry at the sweep rate of the oscilloscope.

Both functions can be combined in one display for a single signal. This can be used for a continuous signal but is particularly useful for single-shot capture and analysis. Data Acquisition Ltd, Electron House, Higher Hillgate, Stockport, Cheshire SK1 3QD. Tel: 061 477 3888.

Analyzer in software

Structured Software's Spectrum Analyser II runs on the BBC microcomputer and provides facilities previously found only on expensive dedicated hardware. Typically, a waveform is displayed, windowed if necessary, and its spectrum computed and displayed in approximately 15 seconds using FFT. Digital readout of waveform and calibrated spectrum are available under cursor control.

For transfer function and transmission loss measurements, input and output waveforms are considered together: both the amplitude ratio (in dB) and the relative phase can be displayed.

The analyser software is disc-based, and is easily adapted to process files in any format generated by the user. As supplied, it is directly compatible with the Data Harvest VELA data recording system: the combination provides a complete analyser working from analogue input signals.

The price of the Spectrum Analyser II software is £200. Further details from Structured Software, 15 Athelstan Close, Bromborough, Wirral, Merseyside. L62 2EX. Tel: 051 334 3290.

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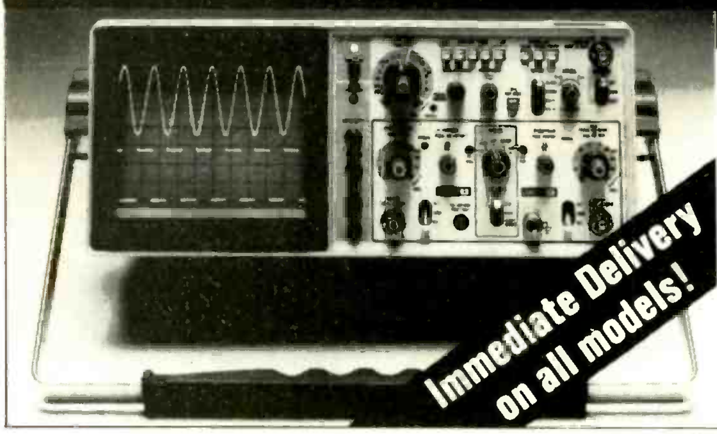

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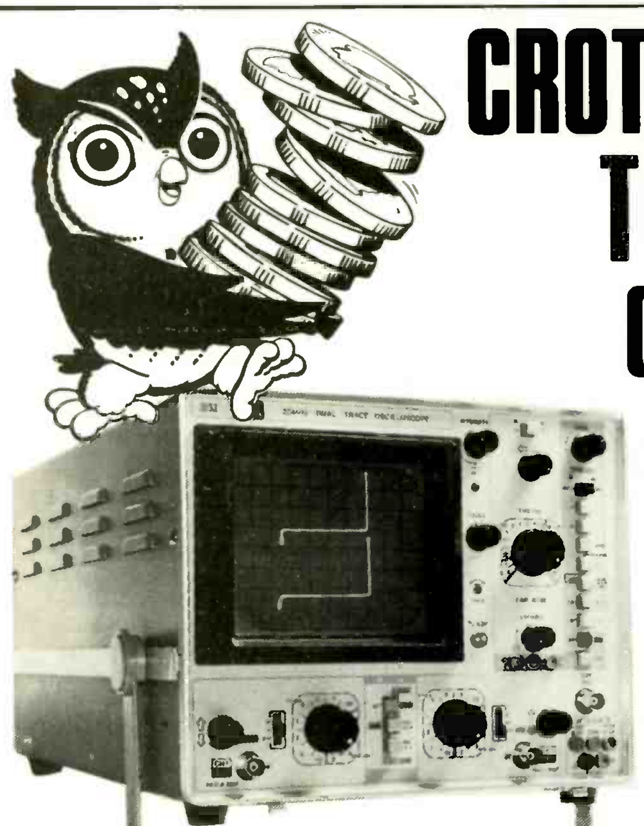

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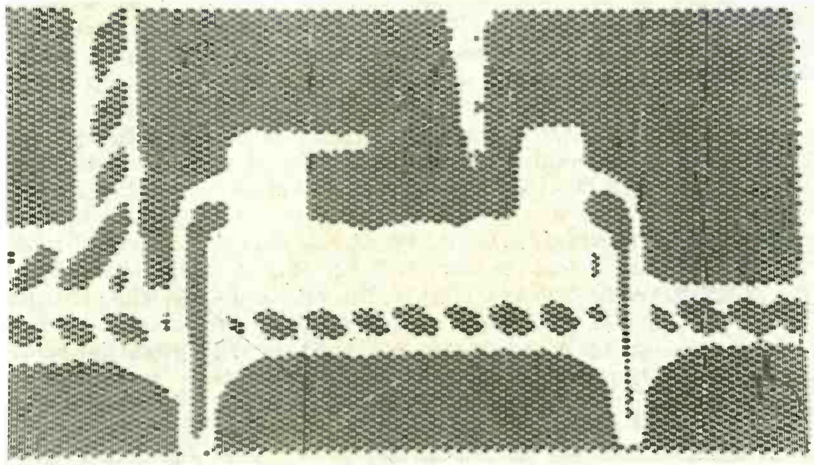
Image acquisition system

G.J. AWCOCK, F.W. STONE AND R. THOMAS

A low-cost solid-state sensor, coupled with suitable image-processing software, is more than adequate for many applications in robotics, security and character recognition.



In many cases the broadcast tv format is selected as the basis of an image processing system for no better reason than its familiarity, or ease of display on standard monitors. However, the quantity of data required to represent a high-resolution image is a major factor contributing to the inaccessibility of computer vision; and so it is essential that very careful consideration of the the system requirements should result in a sensor specification which is adequate, and *no more*.

A conventional tv camera produces an analogue video signal which is continuous in the horizontal axis but discrete in the vertical axis, by virtue of the raster scan method of picture reconstruction. The maximum resolution in the vertical axis is approximately 574 lines, with interlace, and because the horizontal:vertical aspect ratio of a standard tv screen is 4:3 this implies a horizontal resolution of approximately 765 picture elements (pels, or pixels). Thus the number of pels required to represent a full-resolution picture is $574 \times 765 = 439\,110$.

If, in addition, each pel is represented as one of 64 grey levels, i.e. a grey-scale resolution of six bits, the quantity of data which must be acquired for each picture will be a grand total of 2 634 660 bits for a monochrome signal! Thus the scale of the problem of acquiring images and storing them in a personal computer becomes obvious.

In addition, a new picture is generated every 40ms, leading to a throughput requirement which makes real-time camera/computer interfaces both complex and costly. This problem has been tackled to some extent for static or slowly changing images by the development of slower multi-frame tv interfaces, which build up their images over a number of consecutive frames. This eliminates the problem of video-rate a-to-d conversion and considerably reduces the cost of an interface, but it does nothing to ease the problem of storing this quantity of data within the computer.

Fig.1 (above). Raw image acquired by the IS32 sensor: the picture shows light falling on another IS32.

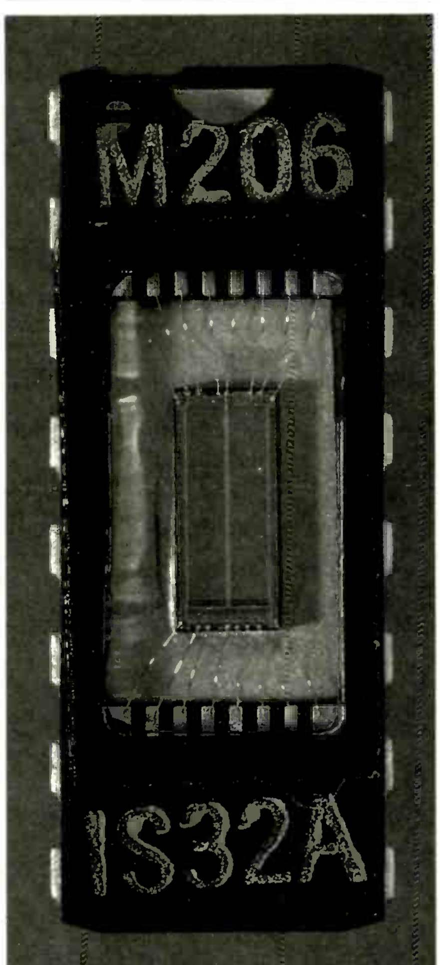


Fig.2. Micron Technology's IS32 optic d-ram: a 64K memory device with a transparent lid. Price is about £40.

Solid-state image sensors should offer hope of a simpler interface, since the data is inherently discrete in both the horizontal and vertical axes. Generating distortion-free raster scan video is then a relatively simple problem for digital electronics.

Unfortunately, the best known of solid-state sensors, the charge-coupled device (c.c.d.), does not have many advantages over conventional vacuum tube cameras in low-cost applications.

In general, c.c.ds have been designed with the full tv standard specification in mind, offering spatial resolution of typically 380×488 pels with continuous grey-scale dynamic range of typically 1000:1. Thus they do very little to ease the problem of excessive image data; and a sensor free of blemished photosites (i.e. light-sensitive cells that are defective in some way) costs considerably more than a complete normal tv camera.

There is, however, a relatively new solid-state image sensor which is ideally suited to experiments with computer vision. The device is the IS32 optic d-ram (Fig.2) from Micron Technology, which is based upon a 64K dynamic ram and thus offers 65 536 pels, each having a one-bit grey-scale. The pels are organized into two banks of 128×256, separated by a thin dead-zone, which effectively makes one of the banks redundant for use with normal optical systems. Hence the working resolution of the device is 128×256, making it well suited to the high-resolution screen modes of many popular computers. The one-bit grey-scale maps well on to the limited range of colours usually offered in such modes.

The hardware interface to be described here uses only half of one bank of pels (a 128×128 'quadrant'), because the elongated shape of each pel (13.6×8.8 microns) makes this resolution match the aspect ratio of the

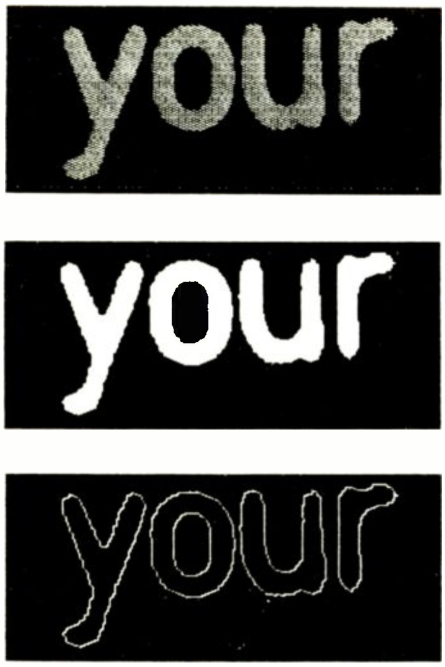


Fig.3. The raw image (top) can be enhanced by software (middle) and processed further (bottom) into a form suitable for character recognition purposes.

computer monitor screen most accurately. Image data from a quadrant may conveniently be stored in 16K-bits (or 2K-bytes).

The binary grey-scale of the system may at first seem a limitation, but it should be remembered that many image processing schemes 'threshold' their grey-scale data at an early stage to produce binary images for their descriptor extraction algorithms to work on.

However, this system should not be thought of merely as an educational toy, since many applications such as robotics, security and character recognition (Fig.3.) etc., are perfectly well served by binary images. Indeed, with the careful use of lighting to emphasize the features in the scene, some industrial inspection tasks could be undertaken by systems making use of this sensor. In addition, the small physical size of the IS32 opens up some unique and exciting applications: for example, in the field of robot vision, with the sensor mounted in the end-effector of a robot arm, the so-called eye-in-hand mode of operation*.

OPERATION OF THE OPTIC D-RAM

A 64K d-ram consists of 65 536 memory cells, which, for reasons of economy of silicon and efficient access, must be organized as a matrix; or, as in the case of the IS32, two matrices, each of 128 rows by 256 columns (Fig. 4). Thus when row and column addresses are supplied to a d-ram matrix the row address is responsible, initially, for selecting the bank of cells to be accessed and, ultimately, for selecting which of the rows of cells is connected to the set of column data input/output lines. Each of these lines is terminated by a bidirectional sense amplifier; and the column address must meanwhile select which of these sense amplifiers is connected to the data in and/or data out buffers during read and write cycles.

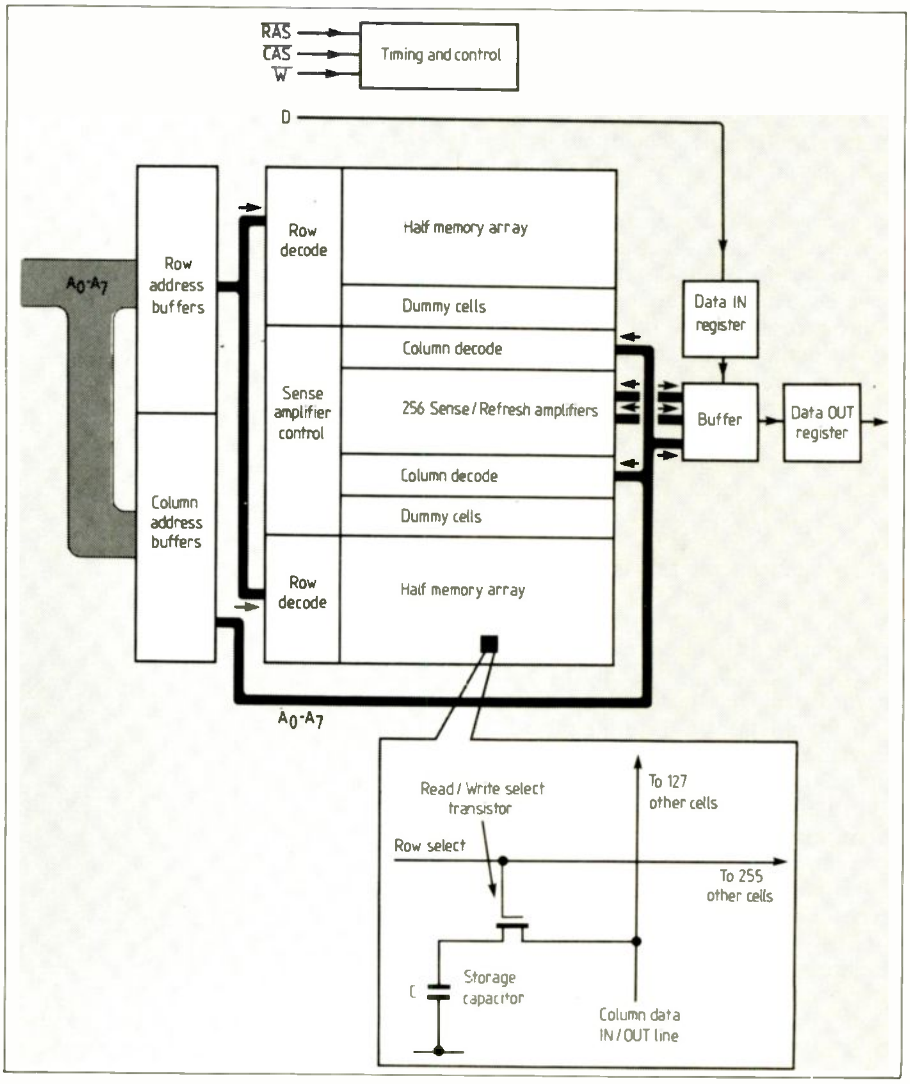
Each photosite in the IS32 is one d-ram cell, consisting of a small capacitor connected to a fet analogue switch, which allows the row-selection of its associated capacitor as the target for write or read operations. When row-selected, all the cells in this row will be connected to their column data in/out lines, but only one sense amplifier will be activated and connected to the outside world. Then the process of writing to the target cell involves storing a voltage on its capacitor, whilst reading it involves conduction of the charge stored there to the selected sense amplifier for regeneration.

In isolation, regeneration would not be a difficult task, but since the cells are connected in a matrix the output of each selected cell switch is connected to a column data in/out line along with 127 other cell switches in their off-state. This results in a considerable capacitive loading upon the data line, of the order of 20 times the cell storage capacitance. Thus, when a cell capacitor is connected to the data line, the charge it stores must be re-distributed between itself and the line capacitance now connected in parallel, this results in an attenuation of the voltage used to represent the data by a factor of approximately 21. The specification of the IS32 states that in the normal, memory, mode of operation a voltage greater than 2.1V on the cell capacitor will be interpreted as a logic 1 ; and assuming an attenuation factor of 21, this implies a threshold for the sense amplifier of 100mV!

There is a further task, related to regeneration, to be dealt with by the d-ram's internal circuitry: that of refresh. if the capacitor in the cell were totally loss-free there would be no need for refresh, since any voltage stored on the capacitor would remain constant for ever. However, capacitor leakage is inevitable, and it is necessary to provide a mechanism that can read the contents of each cell and, upon regeneration to the required logic level, write it back into the appropriate capacitor. This is a job that the sense amplifiers are well able to perform, and indeed their design ensures that refresh takes place automatically when any cell is read. Alternatively the user may initiate a refresh-only cycle which performs the same function but without enabling the data output buffer.

It is left to the user to ensure that the refresh operation takes place sufficiently often to avoid loss of data in normal memory applications. To reduce the problem of time overhead due to refresh, a read or refresh cycle to any address in a row will cause

Fig.4. Block diagram of 64K d-ram, showing basic memory cell configuration.



*Pugh, A., Second generation robotics and robot vision: Robotic Technology pp. 1-9. Peter Peregrinus Ltd on behalf of the IEE, 1983.

refresh of that whole row to take place, in addition to accessing the particular cell as desired. This thoughtful aid to normal d-ram applications proves to be rather less than helpful when the device is used as an optical sensor, as we shall see later.

Loss of charge on the cell capacitor is a nuisance with regard to data storage, but is tolerated because of the significant space and power savings that d-rams offer over other, static, memory cells. However, a relatively recent development has allowed this same mechanism to be exploited as a light sensor, since it can be shown that when these capacitors are subjected to light energy, the rate of discharge becomes proportional to the intensity of the incident light, as well as time elapsed since regeneration. Light sensitivity is well known in other applications of silicon and is due to the generation of an electron when a photon is absorbed in the bulk of the material.

In the case of d-ram cells, the plates of the capacitors are fabricated in silicon and the electrons which result from photon absorption serve to reduce the charge stored there. Thus the decay of capacitor voltage with time exhibits a characteristic such as that shown in Fig.5; it is clear from this that the time taken to decay below the logic 1/logic 0 threshold is now dependent upon the level of incident illumination.

Conversely, a fixed time delay between initialization (or re-generation) of the cell and its subsequent interrogation will effectively set a threshold level of illumination. If the incident light is above this threshold then the cell voltage will be interpreted as a logic 0; if below, the sense amplifier will read, and re-generate a logic 1.

The net result is two-state, or binary, detection of illumination, provided that no refresh operation has been performed in the interim. Extreme care should be taken to avoid reading or refreshing any cells in the same row of the matrix as those undergoing exposure, and careful thought must be given to the initialize-expose-interrogate cycle to be employed.

It is also necessary to be aware of some peculiarities of the IS32, which stem from its having been designed primarily as memory device, rather than as an image sensor. Firstly, the two banks of cells store their data differently, so that the least significant, or upper bank (rows 0 to 127), must be initialized to logic 1, whilst the most significant, lower bank (rows 128 to 255), must be initialized to a logic 0. Thus, after exposure, if the cell remains in the same state as that to which it was initialized, then the pel must be interpreted as dark (black); if it has changed state, it must be treated as white.

If data from the IS32 is to produce a

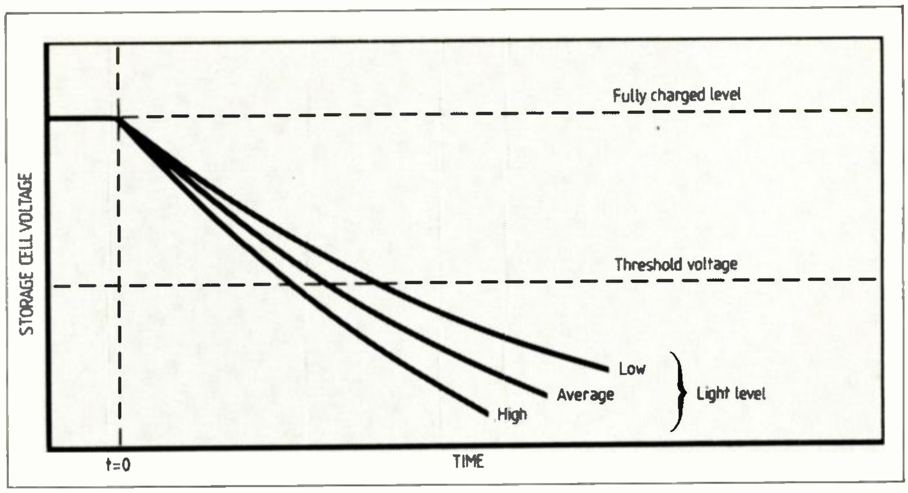


Fig.5. Characteristics of storage cells in the IS32 optic d-ram. Decay time of the capacitor depends on the incident light level.

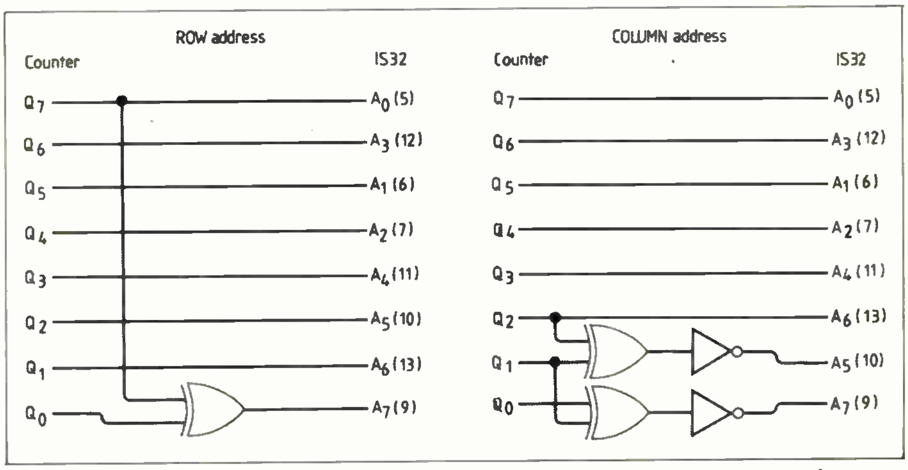


Fig.6. The IS32 chip is designed primarily as a memory device, not as an image sensor. To correct image distortions caused by the irregular layout of its photosites, a two-stage linearization process is required. The first step consists of manipulating the row and column addresses.

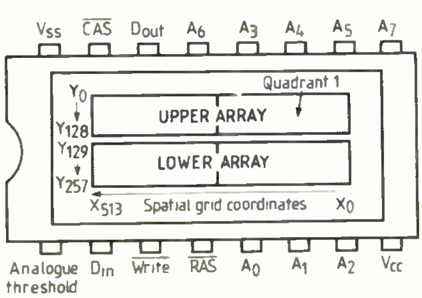


Fig.7. Layout of the IS32 device. A dead-zone between the upper and lower arrays makes half the device unusable in most optical systems. Only one quadrant is used in this design; it gives a working resolution of 128 × 128 picture elements.

Fig.7b. This close-up of Quadrant 1 illustrates local scrambling of addresses which remains after the hardware address descrambling of Fig.6. Software correction is needed to eliminate it and so linearize the resulting image. Blank cells represent points having no light sensitivity, such as the fet associated with each photosite.

X256	X255	X254	X253	X252	X251	X250	X249	X248	X247	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
Y120		R119 C127	R120 C125			R119 C125	R120 C123			. . .
Y121	R121 C126			R120 C126	R121 C124			R120 C124	R121 C122	
Y122		R121 C127	R122 C125			R121 C125	R122 C123			
Y123	R123 C126			R122 C126	R123 C124			R122 C124	R123 C122	
Y124		R123 C127	R124 C125			R123 C125	R124 C123			. . .
Y125	R125 C126			R124 C126	R125 C124			R124 C124	R125 C122	
Y126		R125 C127	R126 C125			R125 C125	R126 C123			
Y127	R127 C126			R126 C126	R127 C124			R126 C124	R127 C122	
Y128		R127 C127				R127 C125				. . .

meaningful picture, the screen pels must be mapped with exactly the same spatial interrelationship as the photosites on the surface of the chip. Unfortunately, this is not a trivial task because the logical addresses of the cells of the IS32 do not correspond directly to their physical positions: consecutive addresses applied to the device will not necessarily access adjoining cells on its surface. This makes it necessary to apply a two-stage linearization process, of which the first stage consists of the application of the address de-scramble logic recommended by the IS32's manufacturer (Fig.6).

The mapping that results is shown in Fig.7(b). Notice that there is still an element of local scrambling and also that only half the surface area of the chip is available for photosites, the rest presumably being occupied by the switching fet that each cell needs. Thus, the second stage involves generating a mapping scheme which has twice the resolution in the column axis to accommodate 'space-pels' which represent the inactive areas of the chip surface, since these must be included for a picture of the correct aspect ratio.

Additionally, an algorithm must be applied to sort out the local scrambling evident in Fig.7, and, furthermore, a slightly different algorithm is required for each of the two

Table 1: characteristics of IS32 quadrant

Number of active pels	16384
Layout	256 × 128 grid
Array dimensions	2210 × 876.8 microns
Pel dimensions	6.4 × 6.4 microns
Array aspect ratio	2.52 : 1

cell banks. In the picture which emerges from this process, 50% of the pels represent active photosites in the IS32 and can take either black or white states, whilst the remainder are space-pels which may be displayed in the user's chosen background colour. The use of an enlarged mapping matrix with the inclusion of space-pels results in subjectively pleasing images with an absence of the annoying 'cogging' at straight black/white boundaries that would otherwise be present.

If required, simple picture pre-processing may be carried out to cause the 'space-pels' to agree with the majority of their nearest neighbours.

This type of enhancement will be essential if the image is to be used for further work such as edge detection, and has been applied in Fig. 3 (middle).

In the next article, the authors introduce a hardware interface for the IS32 which enables it to be driven via a personal computer over an RS-232 serial link.

Graeme Awcock is a lecturer at Brighton Polytechnic and is reading part-time for a doctorate in computer vision techniques for low-cost robotic systems. Previously he worked as a senior design engineer at Computing Devices, which he joined after graduating from the polytechnic in 1979.

Bill Stone designed the prototype imaging system as his final-year project at Brighton Polytechnic. Since graduating he has been working as a development engineer for MEL at Crawley and is currently involved in the design of electronic support measure systems.

Ray Thomas gained his Ph.D. researching into high-permeability magnetic materials. Subsequently he spent seven years in the electronics industry before joining Brighton Polytechnic as a lecturer in 1977. His interests are in microprocessor applications and computer vision systems.

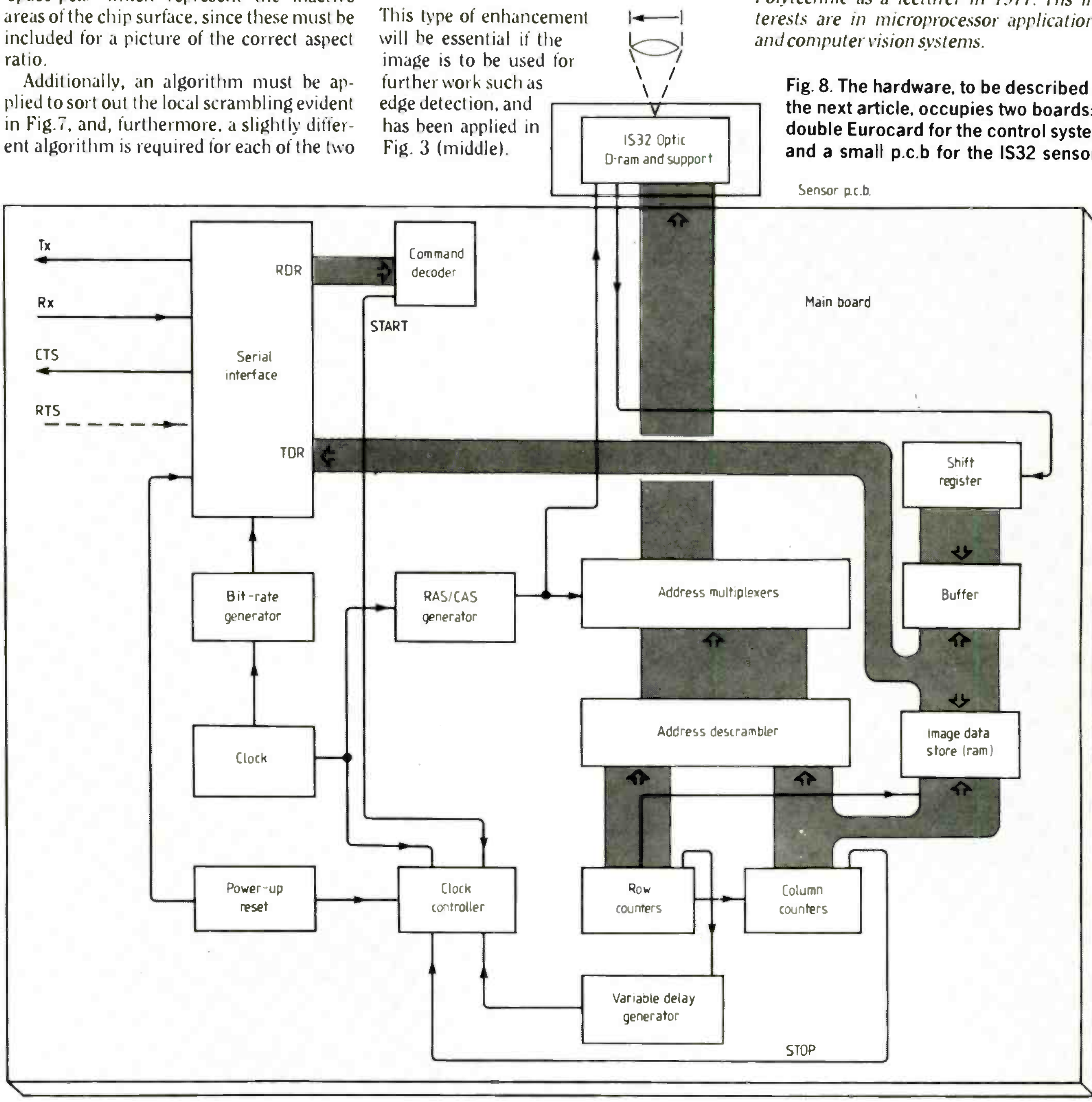


Fig. 8. The hardware, to be described in the next article, occupies two boards: a double Eurocard for the control system and a small p.c.b for the IS32 sensor.

TELEVISION BROADCAST

Digital tv

There is a deep-rooted belief among broadcasters, including some engineers, that television technology is changing at a faster rate than ever before. It is forgotten that d.b.s. has been under development since 1965 (and was implied in Arthur C. Clarke's 1945 article in this journal); that digitalization of broadcast-quality video was first demonstrated in the mid-sixties at Bell Telephone Laboratories; and the concept of "The digital future of television studio centres" was propounded by John Baldwin (IBA) as long ago as 1972. He suggested then that while the time when domestic receivers would receive tv signals in digital form was still some way off, and not likely to have significant practical impact "before about 1990", studio complexes based on the use of digital techniques would be possible *"now"* (i.e. 1972) and that it could well be that "by 1976 the cost of a digital studio complex would be less than its analogue equivalent."

By 1987 it *is* possible to build experimental component digital production units (such as the ITCA one at Thames Television, Teddington described in the February "Update" column, pages 197 to 198) using the by no means low cost Sony DVR1000 recorders now in production and due to be delivered to customers very soon. There are also in widespread use many "digital islands" within studios including the special effects and picture manipulators that, in order to justify their cost, now seem to be used (over-used?) on every possible occasion.

But the large all-digital studio complex at comparable cost to current analogue "production factories" still seem as far away today as they did at IBC72!

What has happened is that analogue systems have continued to develop and, indeed, analogue-component systems promise to provide most of the promised advantages of digital video at substantially less cost. The industry is buzzing with speculation as to the future role of the ½-inch all-purpose M.II component v.t.r. machines rather more than about the over-£100,000 DVR1000 machines, though these, offering superb quality even after 20 generations, will certainly fill post-production role in studios producing high-cost commercials. A major problem with digital v.t.r. machines is that their high power consumption largely rules out their application in portable battery-operated machines.

Communication engineers in the early 1970s were in the habit of suggesting that if valves had been developed after transistors they would have been hailed as the answer to all problems. Towards the end of a well-attended IEE colloquium, TV studios from A/D, Brian Scott (Thames Television) echoed this by commenting that if analogue television had just been discovered we would all be hailing it as a marvellous system with a big future. He added that new technology has improved the stability of analogue systems, although we will still need digital techniques, even where they remain more expensive, for some things that cannot be done analogue. The pressure for more digits is now coming more from production teams than from engineers.

Better pictures

There remain engineers who believe that the first priority, ahead of h.d.tv, should be to ensure that the pictures transmitted on the existing 625-line 50Hz interlaced standard are of the highest possible quality. In due course this could be followed by the improvements possible with "component" rather than "composite" working, MAC transmission on d.b.s. and steady, flicker-free displays with progressive (sequential) scanning made possible by digital processing in the receivers, and, later, for d.b.s. wide-screen pictures by means of compatible, enhanced systems.

In recent years, despite many improvements, the quality of the transmitted pictures, particularly with material acquired from overseas, has tended to fall, partly due to distribution on multi-generation tape rather than on 16 or 35mm film. Similarly, UK producers have strained after "realistic" mood lighting that often results in "noisy" pictures when compared with programmes produced in well-lit studios.

Bits all round

An interesting three-part presentation by BBC research engineers (A. Oliphant, J.T. Zubrzycki and N.H. Gilchrist) showed how digital signals could be routed in a flexible manner around a large studio complex using optical-fibre cables and a combination of time-division and frequency (wavelength) division multiplexing. There is no requirement to "switch" the optical cables, since all sources will be available at all destinations.

It became clear that this is still largely a "paper" design though virtually all of the technology is currently being developed elsewhere for broadband telecommunications applications, including local area networks, c.a.tv etc. The BBC work is seen as meeting a possible requirement for the BBC Television Centre in the mid-1990s.

Essentially the system uses optical fibres in conjunction with distributed feedback (d.f.b.) lasers. Each laser would be modulated by a 2 Gbit/s stream and would produce a narrow line-width output at a specific optical wavelength. The d.f.b. laser is a semiconductor laser diode with a diffraction grating etched over the active region, resulting in coherent light output at only the one wavelength strongly reflected by the grating. This optical part of the system follows the work of Olson *et al* at Bell Labs. At present d.f.b. lasers are commercially available for only the two main optical wavelengths now being used or advocated for telecommunications.

It was claimed that the system, though conceived as being used to route 4:2:2 digital signals, would be capable of carrying h.d.tv signals. These would use the capacity required for four or five 4:2:2 channels, but could be multiplexed into the 2Gbit/s bit streams.

Television in bits?

Certainly the IEE colloquium brought forth many expressions of continued faith in digital techniques in the studios and post-production areas. Duncan Thomas (BBC) while showing himself by no means fully committed to bits, stressed that it was now too late to put the clock back and that eventually digital tv will win through.

Most of the papers described systems based firmly on CCIR Recommendation 601, the 4:2:2 component-digital standard with an initial bit-rate of 213 Mbit/s. While this system includes provision for hierarchical systems, both upwards and downwards, the basic system, as several speakers pointed out, imposes a "brick-wall" filter on luminance at 5.5 MHz and would require a complete re-think for h.d.tv. (higher-definition television). There was, however, nothing but praise for the trend to digital sound. This is seen as an entirely practical means of removing many of the traditional degradations of analogue sound.

What could have been foreseen as a confrontation between component and composite digital v.t.r. machines was the juxtaposition of a paper by Carlos Kennedy (Ampex) on his companies development of the ACR225 composite "cart" machine – and the proposed use of this composite system for studio and transportable machines – with the paper by John Ive (Sony) on the DVR1000. But the sparks did not fly. Indeed, Carlos Kennedy made a convincing case that, because of the strained economic situation of many US production companies, it is certain that composite 525-line NTSC will remain in use for many years. Composite machines can fit comfortably into composite environments without discouraging Ampex from continuing development of 4:2:2 component machines.

Television Broadcast was written by PAT HAWKER.

RADIO BROADCAST

Portable stereo

The difficulty of receiving "noise-free" stereo from v.h.f./f.m. broadcast transmissions without the aid of a reasonably good roof-top aerial array is well-known. The problem has been with us for a long-time. The BBC is in process of an expensive conversion to mixed (circular) polarization in order to improve reception with portable telescopic aerials and car radio whip aerials, but there remains the basic 12dB or so difference between what is needed for mono and that required for good stereo.

The growing popularity of large stereo portable receivers and walk-about headphone sets incorporating radio as well as tape-cassette facilities has tended to highlight the problem.

A couple of years ago, CBS, in collaboration with the US National Association of Broadcasters, began testing their compatible FMX system. This was claimed as permitting good stereo reception (on sets fitted with a special decoder) over virtually the same coverage area as the mono transmissions. CBS promoted the system in Europe. Some engineers were doubtful as to the performance of FMX and its effect on conventional receivers in severe multipath conditions, but the BBC undertook to investigate the system provided that CBS would loan FMX encoding and decoding units. Many months went by, however, with no sign of the experimental equipment reaching the UK. The situation has been further complicated by the reported closure of the CBS laboratories concerned with FMX, although presumably CBS still holds the patents. The prospects for any early UK trial, let alone operational use, now seem remote.

Some listeners are suggesting that the UK national and local v.h.f. services should be replanned with extra transmitters to provide much stronger signals in the centres of towns. This would not only be a horrendously expensive undertaking but would also upset the current frequency planning under the 1984 WARC allocations.

More realistic are the suggestions that receiver front-ends should be made more sensitive by reverting to the use of at least some discrete transistors alongside the integrated-circuit devices. It would also be sensible for portable receivers, if providing stereo, always to have co-axial sockets fitted to permit their use with effective external aerials. There also still seems to be a need to get the message through to more listeners that it takes a great deal more signal to provide good stereo reception than is necessary for mono.

A listener in Paignton suggests that the problems faced by v.h.f. broadcasting in the UK go back a long time, with little serious effort by either broadcasters or Government to promote "superior" v.h.f. as the main service, but rather only as supplementary to m.f. services. In many areas v.h.f. (even mono) is too weak for good reception on a lot of portable radios, although the increasing use of circular polarization helps (unfortunately it can in some areas increase multipath distortion on high-fidelity equipment). Manufacturers, he suggests, aim at selling portable radios as cheaply as possible with little regard to their sensitivity or audio quality. When coupled with "unfriendly" tuning arrangements and unclear tuning dials this all serves to discourage v.h.f. listening by the general public. Part duplication, part splitting of the m.f. and v.h.f. transmitters confuses the public with few broadcasters wanting to risk losing audiences by encouraging them to move away from the m.f. outlets. In a local survey he found 10 per cent of homes with an external v.h.f. aerial, presumably mostly for stereo. Compared with South London this is a very high figure. There are still more old Band I/III television aerials to be seen than aerials for Band II!

Copyright reform delayed

Whether the marketing of R-DAT cassettes and machines will finally get under way in Europe this spring, as the Japanese industry hopes, or whether it will be further delayed by the continuing arguments about the need to incorporate anti-copying devices to protect the CD industry, is only one of the problems that continue to accumulate over the whole field of intellectual property and patent legislation.

A recent unannounced trial in the UK by the Werner video software company of the "Macrovision" anti-copying system for VHS video tapes seems to have done little to inspire confidence in an anti-copying system that can be rendered largely ineffective by relatively simple modification of existing VHS machines and is not designed to prevent copying on Betamax machines.

The trial did not produce significant evidence of any large-scale copying by video libraries. Macrovision, developed by John Ryan, formerly with Ampex, is intended to stop the copying of videos or the programmes on premium cable channels by the addition of phase-modulation to the colour-burst reference signal. This results in fuzzy pictures with spurious or no colours when tapes are copied and then replayed on VHS machines.

Japanese industry continues to resist the appeals of the international recording industry, concerned at the possible impact of R-DAT on the CD digital discs, that an anti-copying chip should be built into all R-DAT machines and different sampling rates, etc. should be used. The recording industry is still hoping to obtain better copyright protection by means of EEC and US legislation. The problem is heightened by the likelihood of blank R-DAT tapes becoming readily obtainable at a time when pre-recorded tapes may be very limited in choice.

The 1986 Government White Paper prepared by the DTI ("Intellectual property and innovation" Cmnd 9712) proposed radical changes which the DTI saw as being necessary to encourage industrial innovation, to keep abreast of the new copying and recording technologies and to simplify and reduce the cost of obtaining patent and design protection. One of its many proposals was to legalize home taping of audio (but not of videos or computer programs) while introducing a compensating 10 per cent levy on blank audio tape cassettes.

However although the White Paper was generally welcomed, the proposed levy ran into a lot of flak from tape manufacturers – as did some of the proposals for restricting to the original manufacturers the supply of special spare parts.

The White Paper has not been followed up by the expected Government Bill. There was no mention of any new copyright legislation in the Queen's speech at the opening of Parliament last autumn. This virtually ensures that no bill based on the DTI proposals will appear before the General Election, if ever, and the whole question could become enmeshed in EEC directives and the extremely complex web of the very different intellectual property legislation in different countries.

Meanwhile further significant advances seem likely to be made during the next decade over the whole field of magnetic recording. Progress in packing density, access times, transfer rates and magneto-optical recording may increasingly come to overwhelm information-storage and recording systems based on optical and photographic techniques. It is foreseen that before very long it will be possible to record as well as play back compact discs by using magneto-optical technology.

In recent years, the US has encouraged more university research and education in magnetic recording with specialist centres at Carnegie Mellon University, Pittsburgh and the University of California at San Diego (UCSD).

Radio Broadcast was written by PAT HAWKER.

Guide to Broadcasting Stations

The 19th edition of GBS is now available at £6.95 or £8.70 by post from bookshops or from Heinemann Newnes, Freepost 10, London W1E 7YZ.

RADIO COMMUNICATIONS

CB, RIS and the Home Office

In November 1981, following several years of public controversy, the first 27/934 MHz CB licences were issued in the UK. The initial response, though more muted than forecast, quickly raised the number of licences to over 450,000, despite continuing protestations that the licences ruled out the use of amplitude modulation (a.m. and s.s.b.) and that the 27 MHz channels did not coincide with those widely used elsewhere. The growth of both illegal and legal CB was reflected in a massive surge in the number of complaints of interference to tv reception made to the old Radio Interference Service, still then operated by British Telecom teams and providing free investigation of interference to radio or television.

The number of CB licences began to fall after the first year and currently are down to 122,920, about one-third of the peak figure. RIS became the DTI's own Radio Investigation Service with a significantly reduced staff and a £21 fee was introduced during 1985. This resulted in a dramatic falling off in interference complaints made to the DTI (from about 1900 to 375 per month). Many viewers have been seeking assistance from the broadcasters, who have neither the resources nor the legal powers/experience/diplomatic approach of the DTI. One result has been to increase personal antagonisms and conflicts between the parties concerned, particularly where the CB operators and radio amateurs are operating in full accordance with the terms of their licences and the problem arising primarily from the lack of 'immunity' of many consumer-electronics receivers and appliances.

The smaller RIS has concentrated its activities primarily on attempting to close down illegal 'pirate' broadcasters, though it has proved more successful at tracing and seizing transmitters than catching and prosecuting people.

According to a recent reply by Lord Lucas, Parliamentary Under-Secretary of the DTI, 83 land-based unlicensed UK broadcasting stations were active during 1986, most of them only intermittently. RIS raided 70 of these on 209 occasions, with 74 prosecutions (only about one prosecution for each three raids). DTI are satisfied that they have adequate resources to keep this problem under control. With Radio Laser back on the air, there are three unauthorized stations broadcasting from two ships off the UK coast, with RIS now proposing to allocate further resources to coping with this problem.

CB is one of the services for which the Home Office is responsible for policy, the DTI for spectrum regulation. It is expected that the UK government will adopt, during 1987, a recommendation (T/R 20.02) by the Conference of European Posts and Telecommunications (CEPT) that there should be a common (harmonized) European allocation between 26.965 and 27.405 MHz for frequency-modulation only. The UK government is continuing to resist pressures from "a few" CB enthusiasts to permit the use of single-sideband, on the grounds that it is more likely to cause interference to other users of the radio spectrum.

The Merriman Committee commented on the need for improved monitoring and policing of the air-waves and it is perhaps unfortunate that in many European countries the "pirates" (CB and unauthorized broadcasting) have shown that persistence often brings the reward of licensing or toleration. Would CB ever have been authorized on 27 MHz in the UK otherwise? Community radio, which has a genuine place in the broadcasting spectrum if finally it comes, will owe its existence to the pirates – just as the origins of Independent Local Radio can be traced to the pirate ships of the 1960s.

The Spanish authorities are planning to spend some £26-million over the next few years in policing the radio spectrum, including establishing main surveillance centres in Madrid, La Coruña, Barcelona and Valencia, 50 smaller monitoring units, 14 mobile units and a satellite signal sampler. The fixed and mobile units will use modern d/f systems to trace illegal transmissions, although it seems unlikely that any great effort will be made to close the several hundred "private" radio broadcasting stations that have existed for many years in Spain.

Mobile safety codes

The inclusion in the new edition of The Highway Code of the recommendation against using handheld microphones or telephone handsets while driving, together with the injunction that "you should only speak into a fixed, neckslung or clipped-on microphone when it would not distract your attention from the road" is clearly putting increased responsibility on the users of mobile radio. What does or does not "distract attention" tends to be a highly subjective judgement, on which the parties to any legal dispute are unlikely to agree.

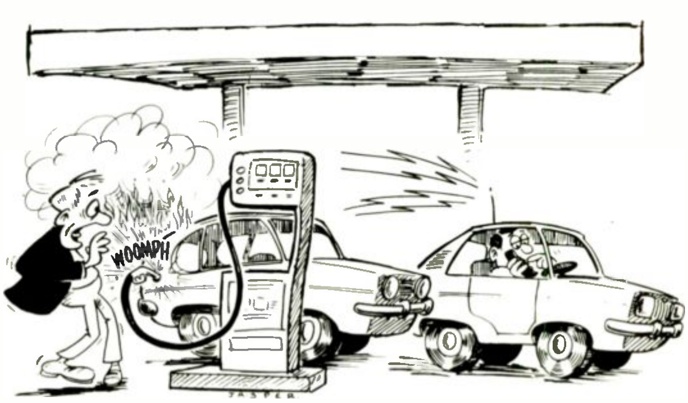
But the new recommendation has served to concentrate minds on the general problem of mobile radio safety. The independent BT Road Safety Committee has recently drawn up a new and stiffer Cellphone Safety Code which is being sent to all existing Cellnet customers and brought to the attention of other cellular radio services. More stress is being placed on the not-always-appreciated need to avoid transmitting while refuelling or while on the forecourt of a petrol-filling station. Unlike conventional mobile radiophones, where the user has direct control over his transmitter, cellular radios are subject to frequent "interrogation" of the mobile unit by the base station to check that the vehicle is still within the same "cell" area. Most cellular radios stay "on" as long as the ignition switch is turned on; the fact that the user is not making a call does not mean that there are no transmissions, since the transmitter automatically replies to the interrogations.

The new Cellnet code includes the recommendation: "Always switch off your Cellphone when at a refuelling point even if you are not refuelling your own car." Whether this practice has been observed fully in the past is open to doubt. Some installations are wired to be switched independently of the ignition.

In papers presented in 1975 at IEE and IERE conferences, a Bradford University team including Dr Peter Excell, G.H. Butcher and D.P. Howson reported that "practical tests" had shown that a potential hazard exists during the fuelling of a vehicle containing an operating transmitter, or parked close to another vehicle containing one. This arises from the possibility of a spark occurring at the most hazardous point, between the fuel nozzle and the tank inlet. They wrote: "Existing injunctions not to operate a transmitter while fuelling a vehicle containing it need to be strengthened: transmitters should not be operated anywhere within fuelling stations. Possibly electro-mechanical interlocks could be applied to advantage here."

It is recognized that sparks are more likely in the case of the higher-power mobile h.f. transmitters as used by a few radio amateurs but this hazard has long been recognized and covered in their safety codes. It is less likely to be known by the large number – now well over 100,000 – of users of cellular radio.

Radio Communications was compiled by PAT HAWKER.



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AC127	0.20	BC207B	0.13	BD236	0.49	BFX29	0.30	HCA16334	0.90
AC128	0.28	BC208B	0.13	BD237	0.40	BFX84	0.26	RCA16335	0.80
AC128K	0.32	BC212	0.09	BD238	0.40	BFX85	0.32	SKE5F	1.45
AC141	0.28	BC212L	0.09	BD242	0.65	BFX86	0.30	TIP29	0.40
AC142K	0.79	BC213	0.09	BD246	0.75	BFX88	0.25	TIP29C	0.42
AC176	0.22	BC213L	0.09	BD376	0.32	BFY50	0.21	TIP30C	0.43
AC176K	0.31	BC214	0.09	BD410	0.65	BFY51	0.21	TIP31C	0.55
AC187	0.25	BC214C	0.09	BD434	0.65	BFY52	0.25	TIP32C	0.42
AC187K	0.28	BC214L	0.09	BD437	0.75	BFY90	0.77	TIP33C	0.95
AC188	0.25	BC237B	0.09	BD438	0.75	BLY48	1.75	TIP34B	0.95
AC188K	0.37	BC238	0.09	BD520	0.65	BRY39	0.45	TIP41A	0.45
ACY17	1.15	BC239	0.12	BD538	0.65	BR100	0.26	TIP41C	0.45
AD149	0.70	BC251A	0.12	BD597	0.95	BR101	0.49	TIP42C	0.47
AD161	0.39	BC252A	0.15	BD589	0.45	BR103	0.55	TIP47	0.65
AD162	0.39	BC258	0.25	BD701	1.25	BRC4443	1.15	TIP120	0.60
AD161/2	0.90	BC258A	0.39	BD702	1.25	BT100A/0	20.85	TIP125	0.65
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AF116	2.95	BC303	0.26	BF119	0.35	BT120	1.65	TIP3055	0.55
AF117	2.95	BC307B	0.09	BF119	0.65	BU105	1.95	TIS91	0.20
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AF125	0.35	BC337	0.10	BF158	0.22	BU126	1.60	2N2219	0.28
AF126	0.32	BC338	0.09	BF160	0.27	BU204	1.55	2N2222	0.29
AF127	0.65	BC347A	0.13	BF167	0.27	BU205	1.30	2N2905	0.40
AF139	0.40	BC461	0.35	BF173	0.22	BU208	1.39	2N3053	0.40
AF150	0.60	BC478	0.20	BF177	0.38	BU208A	1.52	2N3054	0.59
AF178	1.95	BC527	0.20	BF178	0.26	BU208D	1.85	2N3055	0.52
AF239	0.42	BC547	0.10	BF179	0.34	BU3276	1.20	2N3702	0.12
AFZ12	3.75	BC548	0.10	BF180	0.29	BU407	1.24	2N3703	0.12
ASY27	0.85	BC549A	0.10	BF181	0.29	BU500	2.25	2N3704	0.12
AU106	6.95	BC550	0.14	BF182	0.29	BU508A	1.95	2N3705	0.20
AU113	6.95	BC557	0.08	BF183	0.29	BU526	1.90	2N3706	0.12
BC107A	0.11	BC557B	0.80	BF184	0.28	BU80Y	2.25	2N3708	0.12
BC107B	0.11	BC558	0.10	BF185	0.28	BUY69B	1.70	2N3733	9.50
BC108	0.10	BCY33A	1.60	BF194	0.11	MJ3000	1.98	2N3733	2.75
BC108B	0.12	BD115	0.30	BF195	0.11	MJE340	0.40	2N3792	1.35
BC109	0.10	BD124P	0.59	BF196	0.11	MJE520	0.48	2N4427	1.95
BC109B	0.12	BD131	0.42	BF197	0.11	MPSA13	0.29	2N4444	1.15
BC109C	0.12	BD132	0.42	BF198	0.16	MPSA92	0.30	2N5294	0.42
BC114	0.11	BD133	0.40	BF199	0.14	MRF237	4.95	2N5296	0.48
BC116A	0.15	BD135	0.30	BF200	0.40	MRF450A	13.95	2N5298	0.60
BC117	0.19	BD136	0.30	BF241	0.15	MRF453	17.50	2N5485	0.45
BC119	0.24	BD137	0.32	BF245	0.30	MRF454	26.50	2N5496	0.95
BC125	0.25	BD138	0.30	BF257	0.28	MRF455	17.50	2SA715	0.60
BC139	0.20	BD139	0.32	BF258	0.28	MRF475	2.95	2SC495	0.80
BC140	0.31	BD140	0.30	BF259	0.28	MRF477	13.50	2SC496	0.80
BC141	0.25	BD144	1.10	BF271	0.26	MRF838	13.95	2SC1096	0.80
BC142	0.21	BD150C	0.29	BF273	0.18	OC16W	4.50	2SC1106	2.50
BC143	0.24	BD159	0.65	BF336	0.34	OC23	9.50	2SC1172Y	2.20
BC147B	0.12	BD160	1.50	BF337	0.29	OC25	1.50	2SC1173	1.15
BC148A	0.09	BD166	0.95	BF338	0.32	OC26	1.50	2SC1306	1.40
BC148B	0.09	BD179	0.72	BF355	0.37	OC28	5.50	2SC1307	2.95
BC149	0.09	BD181	0.45	BF362	0.38	OC29	4.50	2SC1364	0.50
BC157	0.12	BD182	0.70	BF363	0.65	OC32	5.50	2SC1449	0.80
BC158	0.09	BD183	0.70	BF371	0.25	OC42	1.50	2SC1678	1.25
BC159	0.09	BD201	0.83	BF394	0.19	OC44	1.25	2SC1909	1.25
BC174A	0.09	BD202	0.65	BF422	0.32	OC45	1.00	2SC1945	3.75
BC177	0.15	BD203	0.78	BF457	0.32	OC70	1.00	2SC1954	0.95
BC178	0.15	BD204	0.70	BF458	0.36	OC71	0.75	2SC1957	0.80
BC182	0.10	BD222	0.46	BF459	0.36	OC72	2.50	2SC1969	1.95
BC182LB	0.10	BD223	0.59	BF467	0.68	OC75	1.50	2SC2028	1.15
BC183	0.10	BD225	0.48	BF494	0.45	OC81	1.00	2SC2029	1.95
				BF495	0.45	OC84	1.50	2SC2078	1.45
				BF595	0.23	OC139	12.50	2SC2091	0.85
				BF597	0.25	OC171	4.50	2SC2098	2.95
				BFR39	0.23	OC200	4.50	2SC2166	1.95
				BFR81	0.25	OC201	5.50	2SC2314	0.80
				BFR88	0.30	OC205	10.00	2SC2371	0.36
				BFR90	1.50	R2008B	1.45	2SD234	0.50
				BFR91	1.75	R2010B	1.45	3SK88	0.95

DIODES

AA119	0.80	BY208-800	0.33	IN4001	0.04
BA115	0.13	BY210-800	0.33	IN4003	0.04
BA145	0.16	BY223	0.90	IN4004	0.05
BA148	0.17	BY298-400	0.22	IN4005	0.05
BA154	0.06	BY299-800	0.22	IN4007	0.06
BA156	0.15	BYX10	0.20	IN4148	0.02
BA157	0.30	BYX36-150R	0.20	IN4448	0.10
BAX13	0.04	BYX38-600R	0.60	IN5401	0.12
BAX16	0.12	BYX55-600	0.30	IN5402	0.14
BB105B	0.30	BYX71-600	1.75	IN5403	0.12
BT151	0.79	BZY95C30	0.35	IN5406	0.13
BY126	0.10	CS4B	8.00	IN5407	0.16
BY127	0.11	CS107	16.50	IN5408	0.16
BY133	0.15	OA47	0.15	ITT44	0.04
BY164	0.45	OA90	0.10	ITT923	0.15
BY176	1.20	OA91	0.15	ITT2002	0.20
BY179	0.63	OA95	0.10		
BT182	0.55	OA202	0.20		
BY184	0.35	IN21DR	5.00		
BT199	0.40	IN23B	5.00		
BY206	0.14	IN23C	5.00		
		IN23ER	5.00		
		IN23WE	5.00		

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BZY88 Series	0.10

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ITT CVC30	8.25
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SANYO ORIGINAL VIDEO PARTS

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4-527T-23501	VARIOUS	Motor Assy	9.75
4-527V-51000	5150	Capston Motor	29.95
143-0-4904-00900	FVHP615	Gear Idler Assy.	5.95
143-2-457T-05900	VTC9455	Stopper Reel Base	0.55
143-0-545T-01701	VARIOUS	Pinch Roller Assy.	8.95
143-0-545T-01700	VARIOUS	Pinch Roller Assy.	1.95
143-0-551T-VTC9300		Idler Assy.	0.95
143-0-661T-03800	VARIOUS	Loading Roller	0.95
143-0-662T-01201	VTC5150	Reel Drive Pulley	8.50
143-0-9974-00100	FVHP615	Mod Kit IC BA6304A	1.95

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RANK T20A	6.91
THORN 3000/3500	7.57
THORN 8500	8.00
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GEC 2110 (600/300V)	2.25
ITT CVC20 (200/400V)	1.80
PHILIPS G (600/300V)	2.25
PHILIPS G9 (2200×63V)	1.19
PHILIPS G11 (470/250V)	2.35

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ELC1043/06 MULLARD	8.65
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VA1056S	0.23
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DF96	0.65
DF97	1.00
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DH79	0.56
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DL96	2.50
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ECC801S	3.50
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ECC804	0.60
ECC2000	12.00
ECF80	1.15
ECF82	1.15
ECF86	1.70
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ECF801	0.85
ECF805	2.50
ECF806	10.25
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ECH35	3.50
ECH42	1.50
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ECH83	1.00
ECH84	1.00
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ECL84	0.74
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EF37A	2.50
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EF71	1.50
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EF93	0.95
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EF95	1.95
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M8098	5.50
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M8100	5.50
M8136	7.00
M8137	7.95
M8161	6.50
M8162	5.50
M8163	5.50
M8190	4.50
M8195	6.50
M8196	5.50
M8204	5.50
M8223	4.50
M8224	2.00
M8225	3.95
ME1401	29.50
ME1402	29.50
ME1501	14.00

MH4	3.50
MHL6	4.00
ML4	4.50
MP25	195.00
MS4B	5.50
MU14	3.50
MZ1-100	125.00
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P41	2.50
PABC80	0.75
PC86	0.75
PC88	0.75
PC92	3.50
PC97	1.10
PC800	1.10
PC900	1.25
PCC84	0.40
PCC85	0.55
PCC88	0.70
PCC89	0.70
PCC189	0.70
PCC805	0.70
PCC806	0.80
PCE82	0.80
PCF80	0.65
PCF82	0.60
PCF84	0.65
PCF86	1.20
PCF87	0.40
PCF200	1.80
PCF201	1.80
PCF800	0.40
PCF801	1.35
PCF802	0.60
PCF805	1.25
PCF806	1.00
PCF808	1.25
PCH200	1.50
PCL82	0.85
PCL83	2.50
PCL84	0.75
PCL85	0.80
PCL86	0.85
PCL800	0.80
PCL805	0.90
PE1-100	69.00
PEN25	2.00
PEN40DD	2.50
PEN45	3.00
PEN45DD	3.00
PEN46	2.00
PE06-40N	42.00
PFL200	0.95
PL21	2.50
PL36	1.75
PL38	1.50
PL81	0.72
PL81A	0.72
PL82	0.60
PL83	0.52
PL84	0.78
PL88	1.00
PL95	2.95
PL302	1.00
PL345	12.50
PL500	1.10
PL504	1.15
PL508	1.75
PL509	4.85
PL519	4.95
PL802T	3.50
PL820	2.95
PL5557	29.50
PY32	0.60
PY33	0.50
PY81	0.70
PY82	0.70
PY83	0.70
PY88	0.65
PY500A	1.95
PY800	0.79
PY801	0.79
QB3-300	54.95
QB3-1750	139.50
QB5-3500	595.00
QE03-10	4.95
QE08-200	145.00
QF40	65.00
QP25	1.00
QQE02-5	19.50
QQE03-12	7.95
QQE03-20	35.00
QQE06-40	45.00
QQV02-6	19.50
QQV03-10	5.50
QQV03-10 Mullard	15.00
QQV03-20	25.00
QQV06-40A	27.50
QQV06-40A Mullard	45.00
QQV07-50	63.50
QQZ03-20	42.50
QS75/20	1.50
QS75/40	3.00
QS92/10	5.00
QS95/10	4.85
QS108/45	4.00
QS150/15	6.95
QS150/30	1.15
QS150/45	7.00
QS1200	3.95
QS1202	3.95
QS1203	4.15
QS1205	3.95
QS1206	1.05
QS1207	0.90
QS1208	0.90
QS1209	3.15
QS1210	1.50
QS1211	1.50
QS1212	3.20

QS1213	5.00
QS1215	2.10
QS1218	5.00
QU37	9.50
QV03-12	5.75
QV05-25	2.50
QV06-20	29.50
QV08-100	145.00
QV2-2500	45.00
QY3-125	65.00
QY4-250	70.00
QY4-400	76.00
R10	4.00
R16	12.00
R17	1.50
R18	2.50
R19	2.50
R20	1.20
R1169	55.00
RG1-125	4.95
RG1-240A	14.50
RG3-250A	3.50
RG3-1250A	35.00
RK2K25	62.50
RK-208	12.00
RL16	1.50
RPL16	12.00
RPY13	2.50
RPY43	2.50
RPY82	2.50
RR3-250	15.00
RR3-1250	35.00
RS613	45.00
RS685	54.95
RSS688	52.15
S6F17	5.95
S6F33	28.95
S11E12	38.00
A30/2K	12.00
S104/1K	10.00
S109/1K	15.00
S130	5.59
S130P	5.95
SC1/800	5.00
SC1/1100	6.00
SC1/1200	5.00
SC1/1300	6.00
SC1/200	9.00
SP41	5.00
SU42	4.95
TB2.5/300	85.00
TB2-300	45.00
TB3-2000	395.00
TD1-100A	25.00
TD03-10F	35.00
TD3-12	4.00
TDD4	5.50
TP25	1.50
TSP4	7.00
TT11	1.50
TT21	45.00
TT22	45.00
TT100	69.00
TTR-31MR	65.00
TY2-125A	85.00
TY4-400	85.00
TY8-600W	365.00
TYS2/250	375.00
U18-20	2.75
U19	11.95
U24	2.00
U25	0.90
U26	0.90
U37	9.00
U41	6.95
U50	2.00
U82	3.00
U191	0.70
U192	1.00
U193	0.65
U251	1.00
U801	0.75
UABC80	0.65
UAF42	1.00
UBF80	0.60
UBC41	2.25
UBC81	1.50
UBF89	1.00
UBL21	1.75
UC92	1.20
UCC84	0.70
UCC85	0.60
UCF80	1.00
UCH21	1.20
UCH41	2.50
UCH42	2.50
UCH81	1.00
UCL82	1.75
UCL83	2.50
UF41	1.15
UF42	1.15
UF80	1.75
UF85	1.20
UF89	2.00
UL41	5.50
UL44	3.50
UL84	1.50
UM80	0.85
UU5	3.50
UU7	8.00
UU8	9.00
UY41	3.50
UY85	0.70
V235A/1K	250.00
V238A/1K	295.00
V246A/2K	315.00
V2406/1K	225.00
V241C/1K	195.00
V339	3.50
V453	12.00
VLS631	10.95
VP4B	4.50
VP133	2.00
VR75-30	3.00
VR101	2.00
V105/30	1.50
VR150/30	1.15
VT52	2.50
VU29	4.50
VU39	1.50
W21	4.50
W77	5.00
W729	1.00
W739	1.50
X24	4.50
X66/X65	4.95
X76M	1.95

XC24	1.50
XC25	0.50
XFW47	1.50
XFW50	1.50
XG1-2500	75.00
XG5-500	22.50
XL628FT	7.50
XNP12	2.50
XR1-1600A	49.50
XR1-3200A	79.50
XR1-6400A	149.50
Y502	25.00
Y65	6.95
YD1100	75.00
YJ1060	265.00
YL1020	42.50
YL1060	195.00
YL1070	195.00
YL1071	195.00
YL1290	65.00
Z77	1.20
Z302C	12.00
Z359	9.00
Z505S	15.00
Z520M	4.00
Z521M	8.00
Z700U	3.00
Z749	0.60
Z759	19.85
Z803U	18.95
ZA1004	12.50
ZA1001	1.50
ZM1005	8.00
ZM1020	6.00
ZM1021	8.00
ZM1023	7.95
ZM1041	14.00
ZM1082	9.00
ZM1064	10.00
ZM1177	9.00
ZM1202	55.00
ZM1263	4.00
1B22	10.00
1B27	55.00
1B35A	45.00
1B63A	75.00
1C1	2.50
1C5GT	2.50
1FD1	2.50
1G3GT	2.50
1J3GT	2.50
1K3	2.50
1N2	4.50
1N5GT	2.50
1P28	25.00
1P39	19.50
1R5	0.90
1T4	1.00
1U4	1.75
1U5	1.00
1X2B	1.40
1Z2	8.95
2AS15A	11.50
2B7	1.50
2B22	69.50
2C39A	32.50
2C39BA	39.50
2C40	37.00
2C42	29.50
2C43	60.00
2C51	0.75
2C53	45.00
2CY5	1.50
2D21	1.95
2D21W	2.50
2E22	49.00
2E26	7.95
2J42	93.00
2J55	295.00
2K25	35.00
2K25 Raytheon	75.00
2K26	95.00
2K29	250.00
2K48	140.00
2K56	250.00
2X2A	5.00
3A/107B	12.00
3A/108A	9.00
3A/109B	11.00
3A/110B	12.00
3A/141K	11.50
3A/147J	7.50
3A/167M	10.00
3A2	3.95
3A3A	3.95
3A4	1.10
3A5	4.50
3IL5	0.95
3AT2	3.35
3B2	3.00
3B4	4.95
3B7	4.50
3B24	10.00
3B26	24.00
3B28	15.00
3BZ6	1.50
3C4	1.00
3C23	19.00
3C45	24.00
3CB6	1.50
3CN38A	2.50
3CS6	0.95
3CX3	2.50
3CY5	1.50
3D6	4.50
3D21A	29.50
3E22	49.50
3EH7	1.95
3EJ7	1.95
3V4	1.75
3W4GT	2.50
4B5518	115.00
4-65A	65.00
4-250A	79.50
4-400A	87.50
4-1000A	425.00
4B32	35.00
4BQ7A	1.75
4BZ6	1.95
4C27	25.00
4C28	25.00
4C35	145.00
4CX1000A	425.00
4CX4000A	1100.00

4CX250B	49.00
4CX250B EIMAC	59.50
4D32	125.00
4CX250BN	75.00
4CX250K EIMAC	95.00
4CX125C EIMAC	125.00
4CX350A	95.00
4CX350F	79.50
4XC1500B	398.50
4E27	195.00
4GS7	2.25
4J52	75.00
4JC6A	2.95
4KT6	1.50
4X150A	35.00
5A/102D	9.50
5A152M	9.00
5A163K	10.00
5A170K	6.25
5A-180M	9.00
5A-206K	10.00
5AM8	2.15
5AN8	1.20
5AR4	2.00
5AU4	1.50
5B 110M	10.00
5B-254M	14.50
5B-255M	19.50
5B-256M	15.00
5B-257M	15.00
5B-258M	14.50
5C22	125.00
5CL8A	2.50
5J180E	2950.00
5R4GB	5.50
5R4GY	4.95
5T4	5.95
5U4G	2.95
5U4GB	4.50
5V4G	1.50
5Y3GT	1.95
5Z4GT	1.50
6/30L2	0.70
6A/203K	9.00
6A7	4.95
6A8G	1.50
6AC7	2.00
6AG5	1.50
6AG7	1.95
6AH6	2.50
6AJ4	2.00
6AJ7	2.00
6AK5	1.95
6AK6	2.50
6AL5	0.60
6AM4	3.25
6AM5	6.00
6AM6	1.95
6AN5	4.50
6AN8A	3.50
6AQ5	1.75
6AQ8	0.85
6AR5	5.95
6AR8	3.95
6AS5	1.50
6AS6	2.50
6AS7G	4.50
6AT6	0.75
6AT8	1.75
6AU4	2.00
6AU5GT	4.50
6AU6	0.95
6AV6	0.75
6AW8A	2.50
6AX4GT	1.95
6AY3B	1.95
6AZ8	4.50
6B7	2.80
6B8G	1.50
6B10	1.95
6BA6	0.95
6BA7	4.50
6BA8A	3.50
6BE6	0.95
6BG6G	3.00
6BH6	1.95
6BH8	1.50
6BJ6	1.50
6BK4	4.00
6BK7A	1.95
6BL6	85.00
6BL8	1.15
6BM6	115.00
6BM8	0.58
6BN4	1.65
6BN6	1.65
6BN7	4.50
6BN8	3.95
6BQ5	0.75
6BQ7A	0.72
6BL7GTA	3.95
6BR5	0.70
6BR7	4.95
6BR8	2.15
6BR8A	2.15
6BS7	5.50
6BW4	1.50
6BW6	5.35
6BW7	1.50
6BW8	4.00
6BX6	0.48
6BX7GT	3.50
6BZ6	2.50
6BZ7	2.95
6C4	1.25
6C5	1.95
6C6	2.50
6C8G	1.50
6C11	2.50
6C18	2.50
6CA4	4.95
6CA7	3.50
6CB5	3.95
6CB6	1.95

6CD6GA	4.50
6CF6	1.50
6CG7	2.25
6CH6	6.95
6CL3	3.95
6CL6	3.25
6CL8A	1.50
6CN5	1.60
6CM7	2.95
6CS6	0.75
6CS7	0.95
6CW4	6.50
6D6	2.50
6DC6	2.35
6DJ8	0.95
6DK6	1.50
6DQ5	5.95
6DQ6B	2.50
6DT6A	1.50
6DW4	2.15
6E5	3.95
6EA4	4.95
6EA7	2.50
6EA8	2.50
6EB8	1.75
6EM5	2.50
6EM7	2.50
6EU7	1.95
6EU8	1.75
6EV7	2.95
6EW6	2.95
6EW7	4.50
6F1	2.00
6F5	4.95
6F6	2.50
6F6G	2.00
6F7	5.50
6F12	1.50
6F13	3.00
6F14	1.00
6F17	2.75
6F21	2.50
6F23	0.60
6F24	1.25
6F25	1.25
6F28	1.25
6F32	1.25
6F33	17.00
6FG5	1.95
6FQ7	2.95
6G6G	5.50
6GE5	3.95
6GH8A	0.80
6GK5	1.50
6GK6	1.95
6GM6	2.65
6GS7	2.15
6GV7	2.50
6GW6	2.50
6GY5	3.95
6H1	9.50
6H3N	2.50
6H6	1.95
6H6GT	1.95
6HF5	5.50
6HF8	2.50
6HS6	4.95
6J4	2.15
6J4WA	3.15
6J5	2.50
6J6	2.00
6J7	4.15
6JB6A	4.50
6JE6C	6.50
6JU8	2.50
6JS6C	6.50
6J7G	4.15
6K7G	2.00
6K8G	3.00
6KD6	6.50
6KM8	2.50
6KT8	2.95
6L1	2.50
6L5	3.15
6L19	3.95
6L6GC	2.95
6L6GC(GE)	5.75
6L6GT	1.95
6LD20	1.15
6LF6	7.50
6L6GAY SYLVANIA	5.50
6LJ8	2.50
6LQ6	6.50
6Q7GT	1.20
6R7G	3.15
6S4A	1.50
6SA7GT	1.35
6SC7	1.50
6SG7	2.50
6SH7	1.35
6SJ7GT	1.20
6SK7	1.35
6SK7GT	1.35
6SL7GT	0.85
6SN7GT	1.35
6SQ7	1.35
6SS7	1.95
6U4GT	1.75
6U6WA	3.50
6U8	1.15
6U8A	1.50

6V6G	1.25
6V6GT	1.50
6VGG	1.00
6Y6G	3.95
6X2N	1.00
6x4	1.50
6x5GT	1.00
6x5GTY	1.00
6x8B	2.25
7A6	4.50
7A7	2.00
7AD7	1.75
7AU7	1.50
7B6	3.50
7B7	2.50
7C5	3.50
7C6	2.50
7E7	2.50
7H7	3.50
7J7	5.50
7Y4	2.50
8B8	2.50
8B10	2.50
8BQ5	1.95
8FQ7	1.95
10D2	1.25
10DE7	2.50
10EW7	2.95
10F1	0.75
10GK6	1.95
10P14	2.50
10P18	0.78
10LD12	0.65
11E2R	45.00
11E3	55.00
11R3	5.50
12A6	3.95
12AD6	1.50
12AH7GT	4.95
12AL5	1.00
12AT6	1.25
12AT7	1.15
12AT7WA	2.50
12AU6	1.50
12AU7	0.65
12AV6	1.95
12AV7	2.50
12AX7	0.65
12AX7S	7.95
12AX7WA	2.50
12AY7	3.95
12AZ7A	1.95
12B4A	4.50
12BA6	1.95
12BE6	1.95
12BH7A	2.50
12BL6	1.75
12BY7A	2.75
12C8	2.50
12CA5	1.95
12CXE	1.20
12DQ6B	3.50
12DW4A	3.50
12E1	19.50
12E14	38.00
12GN7	3.95
12HG7	4.50
12HG7A	4.50
12J5GT	3.95
12J7GT	3.50
12JZ8	2.95
12K5	1.95
12K7GT	1.50
12K8	1.95
12SA7GT	1.95
12SG7	4.75
12SH7	1.95
12SK7	1.95
12SJ7	1.50
12SQ7GT	1.95
12SN7GT	1.85
12X4	1.95
12SY7	4.50
13D3	3.20
13D7	3.20
13D9	3.20
13DE7	2.50
13DR7	2.95
13E1	145.00
13EM7	3.50
16GY5	2.95
17BE3	2.50
17DW4A	2.95
17EW8	0.95
17JZ8	4.50
18D3	6.00
18GB5	3.50
19AC5	3.50
19AU4GT	2.50
19G6	9.00
19G3	17.00
19H4	35.00
19H4R	25.00
19H5	33.50
19Q6	9.00
20A2	10.50
20D1	0.70
20LF6	7.95
20L1	0.95
20P1	0.55
20P3	0.60
20P4	1.95
20P5	1.15

21JZ6	4.95
21LU8	3.75
24B1	39.50
25DQ6B	2.95
25L6GT	1.75
25BQ6	1.75
29C1	19.50
29KQ6	6.50
30C17	0.40
30C18	1.48
3F5	0.95
30FL1	1.00
30FL2	1.35
30FL12	0.95
30FL13	1.10
30FL14	1.25
30L1	0.45
30L15	0.60
30L17	0.60
30P4MR	1.00
30P12	1.00
30P18	0.60
30P19	1.00
30PL1	2.50
30PL13	0.60
30PL14	1.75
31JS6C	5.50
33A/158M	19.50
35A5	4.50
35L6GT	2.00
35Z3	1.85
38HE7	4.50
40KD6	5.50
42	6.95
47	6.00
50A5	1.50
50C5	0.95
50CD6G	1.15
50EH5	1.50
50JY6	2.95
52KU	2.00
53CG	15.00
61SPT	4.50
75B1	3.50
75C1	2.50
80	4.50
83	8.50
84	3.00
85A1	6.50
85A2	2.50
90AV	15.00
90C1	3.50
90CG	13.50
90CV	12.50
91AG	9.00
92AG	19.50
92AV	15.00
95A1	6.50
100E1	10.00
108C1	1.50
150B2	6.50
150C2	2.50
150C4	2.15
155UG	25.00
185BT	1.50
211	33.50
274A	15.00
307	5.00
328A	15.00
388A	17.50
425A5	8.00
431U	4.50
572B	55.00
705A	8.00
708A	8.00
724A	275.00
726A	75.00
803	14.95
805	59.00
807	2.50
810	85.00
811A	15.00
812A	35.00
813	27.50
813 Philips	35.00
829B	14.50
833A	95.00
866A	6.50
872A	20.00
873	60.00
884	5.50
930	9.95
931A	13.95
954	1.00
955	1.00
958A	1.00
1299A	0.60
1619	2.50
1625	3.00
1626	3.00
2050W	6.95
2050	5.50
2051	5.50
3534	4.00

404A	10.95
927	15.00
1927	25.00
4687A	9.50
4212E	250.00
4313C	4.00
4328D	9.00
5636	5.50
5642	9.50
5651	2.50
5654	1.95
5663	1.95
5670	3.25
5672	4.50
5675	28.00
5678	7.50
5687	4.50
5692	3.50
5696	4.50
5704	3.50
5718	6.15
5725	2.50
5726	2.50
5727	2.50
5749	2.50
5750	1.85
5751	2.95
5763	5.75
5814A	3.25
5823	9.50
5829WA	6.50
5840	3.50
5842	11.00
5847	10.95
5879	5.00
5886	13.95
5894	39.50
5899	4.50
5963	1.75
5065	2.25
6005	1.85
6012	16.00
6021	3.65
6057	3.75
6058	3.95
6059	3.75
6060	2.25
6062	4.50
6063	2.00
6064	3.25
6067	7.00
6072	4.20
6080	8.50
6080WA	9.50
6132	10.50
6136	2.50
6146B	9.50
6155	65.00
6156	65.00
6157	2.50
6158	3.20
6201	6.45
6205	6.95
6211	2.50
6267	4.50
6350	3.50
6360	4.50
6386	14.50
6463	7.50
6545	8.50
6550A GE	10.95
6550 RCA	15.00
6688	6.50
6870	11.50
6887	9.50
68838	9.95
6973	5.95
7025	2.50
7027A	4.50
7032	2.00
7059	2.50
7167	3.95
7189	3.50
7193	7.50
7199	7.50
7247	4.95
7360	13.50
7462	15.00
7475	5.00
7486	125.00
7527	85.00
7551	8.50
7558	9.45
7586	15.00
7587	29.50
7791A	5.95
7609	47.00
7733	5.50
7788	29.50
7815	72.95
7868	4.95
8012	15.00
8950	7.50
18042	10.50
18045	10.00
18046	11.50

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FEEDBACK

Airmac

One of our readers, who was associated with the firm Airmec (not Airmac) telephoned to tell us that the receiver taken to Poland by Mr Bar (February letters) was probably made by that company, which was a subsidiary of Radio and Television Trust. They exported sets under the Airmec name, but used the name Philco, under licence from America, for export. The Airmec name is no longer used.

Our informant still possesses a 1947-vintage Airmec receiver, which works well, having needed only a replacement electrolytic in 40 years of service. – Ed.

Police radio

The article by Jack Davies (January 1987 issue), brought back a flood of memories as I was one of the ETE/Mullard/Philips team that installed and commissioned the synchronous f.m. system for the Lancashire police.

The system was based on the Philips IGO (impulse governed oscillator) concept used for frequency and audio locking of a.m. broadcast transmitters operating on the same frequency. The design and development of the system started in 1947 when Philips Electrical was approached by the late Inspector Frank Gee who had read a paper describing the Philips IGO work. Philips Transmission Equipment Ltd., in Balham did the initial study for the Lancashire police. The development work was handled by a small group of engineers led by the late Christopher Bailey working in a makeshift laboratory in a disused laundry in Wandsworth. Frank Gee and Eric Jones, then the commercial manager of the Mullard/Philips communications activities, were the driving force behind the project. Many of the team in Wandsworth and Lancashire were licenced amateurs.

Jack has a good memory as, apart from one or two minor details, his description of the system is correct. The original two-station arrangement at Billinge and Barnacre was a crude lash-up to prove the system. A preset variable delay was included to equalise the different path lengths between the wire-linked base station and the radio-linked slave transmitter. After these intitial tests a more substantial set of prototypes was produced for installation in the Force HQ, Hutton. This was also a single-frequency system and was designed to work with up to six remote slave transmitters. Initially only four slaves were used, as it was found that they provided full coverage of the county.

The updated master unit used a more sophisticated variable-lock system to provide the necessary audio delays and the frequency off-set facility mentioned by Jack. It was never intended that those prototypes would have an extended life, and development work continued both in Lancashire and at Wandsworth to provide multi-channel operation and many other facilities that were likely to be required for future expansion of the system.

From the experience gained with the Lancashire units, Gee and Bailey produced a comprehensive specification for a set of production equipment to replace the prototypes. In 1950 Mullard had formed a new company Mullard Equipment Ltd, (later MEL) which merged with ETE. A Mobile Radio Division of MEL was established at the same time under Christopher Bailey and took over the responsibility for the Lancashire units. In early 1953 contracts for the replacement production system were being negotiated between Lancashire and Mullard when, for policy reasons, Mullard decided to discontinue v.h.f. mobile radio activities. As reported, the Lancashire Police Wireless Department continued to use and simplify the system to provide greater reliability and ease of servicing before it was finally closed down in 1968.

R.L. Glaisher (G6LX)
Croydon

Planck and the fine structure

It is unfortunate that the deep relationship that is 'thought' to exist between Planck's constant, h and the so called atomic fine structure constant, α as was suggested by Ove Tedenstig (*EWW* Feb. 1987) is not really new. Already this relationship is common knowledge and has been well established since the early development days of quantum physics. Most general text books on the subject show that α is given by

$$\alpha = \frac{2\pi e^2}{ch} \qquad (1)$$

However, the classical rest radius of the electron r_e is derived from the following:

$$\frac{e^2}{r_e} = m_e c^2 \qquad (2)$$

where e is the charge of the electron and m_e is its rest mass. Therefore, substituting for e^2 in (1) and re-arranging results in

$$h = 2\pi m_e r_e c(a-1)$$

This leads us nowhere new except, perhaps, to that of complicating furthermore the subject.

M. Zaman Akil
Regent's Park
London

Insanity

Mr W. Scott really ought to straighten out his wife for talking about the insanity of engineers (Feedback, January, 1987).

All these standards are inflicted on us by desk-pilots with a lack of imagination and arrogance that I associate with civil servants, despite Bernard Jones having taken me to task for calling them such (November, 1986).

The most recent of the mains wiring codes is so baffling and silly that it has earned a send-up in *Punch* (30th July, 1986, p.29).

Shortly after the end of the war, a committee of intelligent men (obviously engineers) sat at Whitley and worked out a colour code for circuit wiring in RNSS equipment. In 1951, when a scientific assistant, I was told to clear out a lot of files and saw the word "secret", which naturally persuaded me to look into them. I found the Whitley code and have used it ever since in everything I have built, also putting tiny numbers beside every wire in my diagrams to indicate its colour in accordance with the resistor colour code. No one smote me with the Official Secrets Act, even after I sent the code to *WW* (May, 1960, p.256).

Yellow, Signal; Red, Steady positive potential; Orange, signal at a positive potential; Blue, steady negative potential; Green, signal at a negative potential; Black, earth; Brown, signal at earth potential; White, pure a.c. (any frequency); Mauve, anything needing distinguishing from the above.

Although one colour somehow got lost in transmission (grey) the meaning of it could be deduced from the other nine. This was the only code I have ever seen that was able to make the transition from valves to transistor circuitry unaltered.

It may not have been the original intention, but from this code comes naturally the only three colours for wiring a mains plug that will offer protection to persons handicapped by all known types of colour-blindness:

white	live
grey	neutral
black	earth

A colour code for mains wiring that can be safely used under the light of sodium lamps calls for a level of intelligence that I fear may prevent it from ever becoming an officially ratified standard.

John C. Rudge
Harlington
Middlesex

Hands-on Engineers

Regarding 'Hands-on Engineers', by R.E. Young, there cannot be many engineers who will disagree with his thesis that "engineers should have had lengthy shop-floor experience with working plant and equipment". But what about the corollary that they should continue to have that experience no matter what level or sharpness of speciality they attain? Maybe, like military reservists, they should be called up for their annual refreshment.

The element of snobbery should not be overlooked, either. Could anything be more absurb than, for example, the sight of an Experimental Officer walking alongside the quite lightly-loaded trolley of instruments being pushed by a Shopman (new-style 'labourer'). And what about the Technician's (new-style 'craftsmen') mate – possibly also styled Shopman – who is condemned by fortuitous cultural and economic circumstances to be forever a fetcher and car-

FEEDBACK

rier? And then there is the pathetic reluctance of 'qualified' engineers to seek help from their supposed juniors, because that would be demeaning; or to pay adequate attention to their suggestions, of which the most damaging variation is the 'not-invented-here' syndrome.

Service in a warship in wartime is the place to experience the results and the sometimes fatal consequences of these attitudes and practices: doubtless other Services could claim similar suitability. And not only wartime, for I recall vividly the pre-war loss of the new submarine HMS THETIS with most of its crew and some of its builders, *within Liverpool docks*, because a test-cock on a torpedo-tube inner door was blocked with paint; and because the Davis escape apparatus would not work unless the ship was on an even keel.

I recall, too, my own weaknesses arising from excessive 'chalk-and-talk' learning – partly, it must be conceded, from wartime shortages of time and equipment – and from my unscientific jumping to conclusions without experimental verification of them. For example: having absolutely no hands-on experience of the use and care of lead-acid (or *any*) batteries, I used to keep a gyro-compass alarm battery trickle-charged by the ingenious device of a torch bulb connected between the charging terminal and the battery, when the alarm system was in use at sea. I could tell that the battery was fully charged by the colours of the positive and negative plates in the glass battery case. However, when the alarm system was called for when a gyro-compass broke down, the battery would not sound the heavy-current alarm bell though, fortunately, it was able to light a red warning lamp on the bridge of the main escort vessel on the Russian convoy. But (and I am not sure of the relevance of this to my argument) nobody recognized it as an alarm! I was called from my hammock to "get this damned red light switched off": it was irritating the Officer-of-the-Watch! In direct contradiction to Murphy's Law, it was the spare compass that had broken down.

It was 20 years later that I learned that lead-acid batteries cannot be continuously trickle-charged, or regularly topped-up after only slight use, but must be occasionally discharged fully if they are to retain their capacity. It seemed that the battery manufacturer learned this at the same time as I did, for his engineers had approved my charging arrangements. *Their* alarm sounded when a large number of expensive teak-encased automobile batteries were returned under guarantee within only a few months. It was another 15 years or so before research had perfected lead-acid portable batteries that could be continuously trickle-charged.

Very likely the relatively 'junior' engineering grades who normally looked after the ship's Low Power System batteries would have made a better job than I did of 'my' alarm batteries. My point is that I thought I *knew* about them because I had been *taught* about them. You have to *learn* through your finger ends and through the consequences of your mistakes and incorrect assumptions – which necessarily entails lots of opportunities to make mistakes.

Finally, in supporting R.E. Young's plea that a "managing engineer's" career demands that at least the classical seven years should be spent under apprenticeship conditions", I believe that Sir George Stapledon was right to urge the value of *everyone* doing an apprenticeship in some form of craft. Apart from its value in inculcating a real feel for material and process, it would, I believe, reduce the appalling trend towards full-time consumerism that is making most of us little different from the unfortunate geese who are forcibly stuffed to make paté de foie gras.

Ronald Gill
Allestree
Derby

Relativity

Although I haven't read W.A. Scott Murray's relativity article in your December issue, I have followed the resulting correspondence with some interest.

There is a fundamental error in everybody's thinking here, as to why the Earth is designed as an oblate spheroid. As every schoolboy knows, the Earth is this shape due to the constant pressure applied by the wing nuts situated at each polar cap. A quick glance at any model of the Earth on our readers desks will confirm this fact.

R. Thomas
Dorking
Surrey

The main thrust of Dr Murray's interesting article "If you want to tell the time ..." (*E&WW*, Dec. 1986) hinges on the statement in the last sentence in the box. However he does not tell us why we must "not identify" the two terms with each other. Nor is there any reason why we should at first sight, since although STR is recognised to be a special case of GTR, so that any STR effect must necessarily be a GTR effect as well, the opposite is by no means always true. We may have one of these "one-way" cases here.

It seems hardly necessary to follow in detail how Einstein reaches his conclusion of a rate-change of $\frac{1}{2}v^2/c^2$ seconds per second in his 1905 paper. He uses the well-known device of treating a curved path as a succession of instantaneous linear paths in order to apply a linear equation to a curved case. We should now consider the situation from the viewpoint of the accelerated, GTR case.

The moving clock is continuously accelerated towards the fixed clock, with an acceleration of ω^2r. GTR tells us that a clock under acceleration has its rate altered by a factor which equals its "acceleration potential" divided by c^2. In this case, the acceleration potential of the moving clock relative to the fixed one will be seen to be:

$$\text{Potential} = \int_0^R \omega^2 r.dr = \tfrac{1}{2}\omega^2R^2$$

(since when R = 0, P = 0 and the constant of integration therefore = 0). We now have:

$$\text{Rate change} = \tfrac{1}{2}\omega^2R^2/c^2 = \tfrac{1}{2}v^2/c^2$$

where $v = wR$.

We have to conclude that far from "not identifying" the two terms with each other, we cannot avoid it. They are the same term, merely derived by different routes. In my opinion, Dr Murray's argument therefore fails.

In passing, I think that this also finally disposes of the "Dingle Question". Viewed from the GTR standpoint, one clock is under acceleration and the other is not, so there was never any symmetry in the situation, and hence no question.

On a quite different tack, I am most grateful to Prof. Waldron for his very authoritative overview of the present 'state of play' on the second postulate (Feedback, December, 1986). It seems that I can go on breathing for a little while yet, hoping for an explanation of split spectra to gallop to the rescue, because in my simple-minded fashion I have always had the idea that, since it appears to describe precisely the characteristics light possesses in the aether, its disproof would not only scupper the theory of relativity, but blow a nasty hole in the only other theory I know about as well. Of course, I will still have to come to some sort of terms with the 'resonance' theory Dr Aspden espouses (Feedback, Nov. 1986). In order to get the arithmetic right, I find that his c' (>c) has got to be the speed relative to the aether. This means that we have an entirely new aether to deal with, capable of supporting an infinite number of different light-speeds. I confess that my mind boggles madly when I try to define its characteristics. It mucks up relativity – and everything else – with a vengeance!

Alan Watson
Pollença
Mallorca

Your correspondent Lee Coe (January 1987) seems not to be aware of the relativistic Doppler effect, the theory of which may be found in any undergraduate physics textbook.

According to the relativistic model, the Doppler effect arises from the Lorentz contraction of the space and time coordinates, and not from a change in wave propagation velocity as is assumed in the classical model.

The classical and relativistic results differ by the Lorentz factor

$$\sqrt{1 - v^2/c^2}$$

and for ordinary speeds the results are virtually identical.

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New Malden
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Scientific interface for the Amstrad PCW

The Amstrad PCW8256/8512 is marketed as a low-cost word-processor, but it can also make an excellent computer for the laboratory.

BRIAN J. FROST

Although marketed for small business applications, Amstrad's PCW machines are supplied with powerful CP/M and Basic software, a large internal memory (256K or more) and the ability to handle graphics on screen and printer.

This design exploits the features of the 8256 to provide a simple, general-purpose interface that can be used to generate, record, analyse and plot complex waveforms or voltages without the need to purchase extra peripherals. It offers both analogue and digital input and output and uses modular circuitry which can perform as a complex function generator, waveform recorder, pattern simulator, or general purpose measuring system for software measurement or control of analogue or digital real-world parameters.

Its facilities also allow the investigation of such techniques as digital signal processing, network analysis, speech and music synthesis, and can help in the teaching of electronic theory.

The unit was first designed to allow simple programmable measurement and waveform generation for applications in the d.c. to upper audio-frequency range: for example, battery discharge curves, speech and music waveform synthesis and capture or monitoring and storage of one-off events that otherwise are not suitable for an oscilloscope.

However, it became apparent that significant power came from the inclusion of analogue output as well as input, thus permitting waveforms to be replayed, edited or created directly from software.

With the ability to use over 85% of the processor memory for data storage (excluding the large memory disc within the computer), the unit has been used for

- digitizing or synthesizing music and speech
- waveform capture
- measuring voltages
- waveform storage, plotting and manipulation
- replay from waveform library to oscilloscope, chart recorder etc.
- controlling or monitoring t.t.l. logic
- measuring network transient response.

A block diagram of the scientific interface is shown in Fig.1. The processor bus available at the rear of the computer is buffered and decoded to communicate with five separate modules: two analogue to digital con-

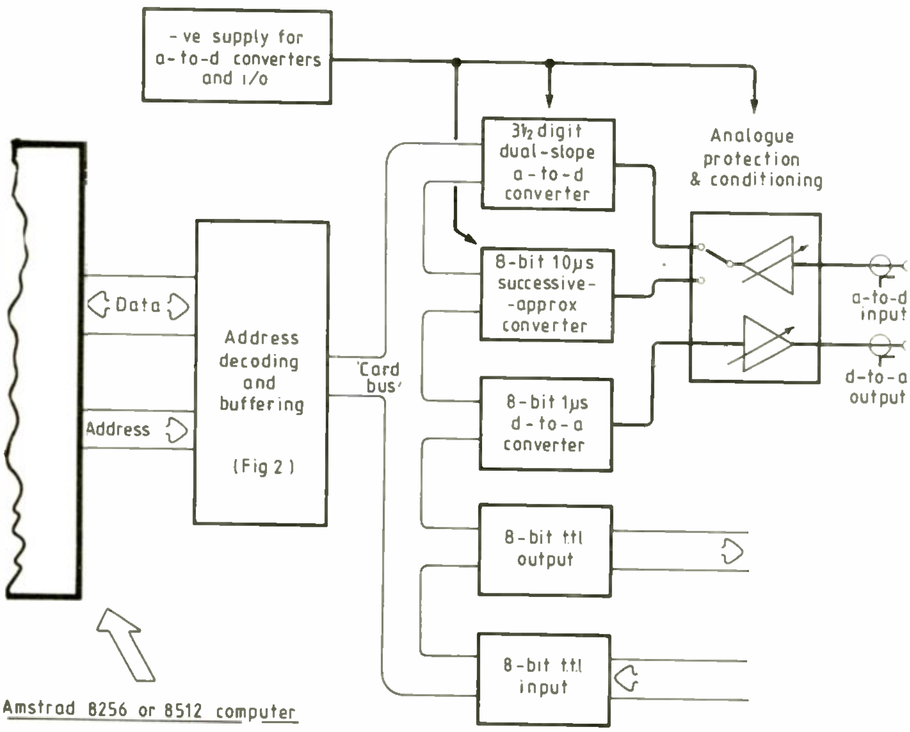
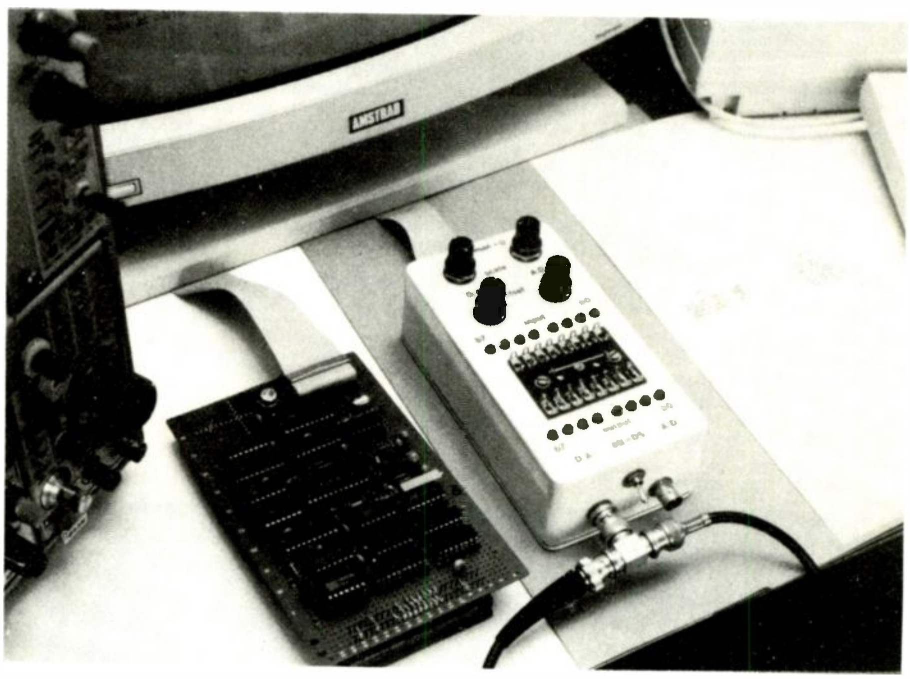


Fig.1. System block diagram. For versatility, the interface is modular in design.



verters, one digital to analogue converter and a simple digital input and output. Circuitry between these functions and the outside world provides conditioning and protection against damage, an important point that has often been considered trivial in other designs.

To keep the design as simple as possible, software control has been adopted for all data transfers. For example, waveform generation is performed simply by outputting data bytes via the eight-bit d-to-a converter. Such data can be created by Basic programs, derived from user-written functions that generate sine, square, triangle or even 'funny' shapes, or supplied by replay of previously recorded data captured by the a-to-d converter and stored in the disc waveform library. The interface's versatility results from the large memory available.

Although they provide greater speed, more hardware-intensive techniques such as d.m.a. were not considered here since the aim was not primarily to exceed the upper audio band but rather to provide circuitry that would interface easily to existing languages, besides being simple and flexible in construction and use.

ANALOGUE I/O DEVICES

Despite certain performance restrictions imposed by the software approach, the choice of devices used for the analogue i/o is still fundamental to the design and so it is worth identifying the trade-offs available.

It became clear that for analogue input no single a-to-d converter would allow measurement to be made at high-speed, with good resolution and at reasonable cost. It is a point of interest that there is no other semiconductor sector where the trade-off between performance and cost is more marked than in analogue data converters.

Despite continuous improvement in value for money, popular converters are still of two main types: successive approximation and integrating. Each has advantages and disadvantages. A successive approximation converter is fast (often less than 50μs conversion time) and is readily available from 8 to 12 bit resolution. In contrast, an integrating is much slower (often less than 25 conversions per second) but easily provides greater precision with the equivalent of 12 to 16 bits resolution. Integrating converters also have a certain inherent immunity to noise and mains pick-up and in many cases offer auto-zeroing and dual-polarity logic.

To offer good precision and yet high-speed measurement, a low-cost device of each type has been included in the design, with switching so that the final choice can be decided by the application. The devices selected are a high-speed eight-bit successive approximation converter sampling at up to 100k samples per second, and a low-cost 3½-digit b.c.d. dual-slope integrating converter that provides 0.05% resolution as well as dual-polarity, auto-zero and noise rejection, at a speed of around 15 conversions per second.

Choosing the digital to analogue converter is rather easier since an eight-bit device allows good waveform resolution and a speed of operation limited only by software. Despite this software speed limitation, sine

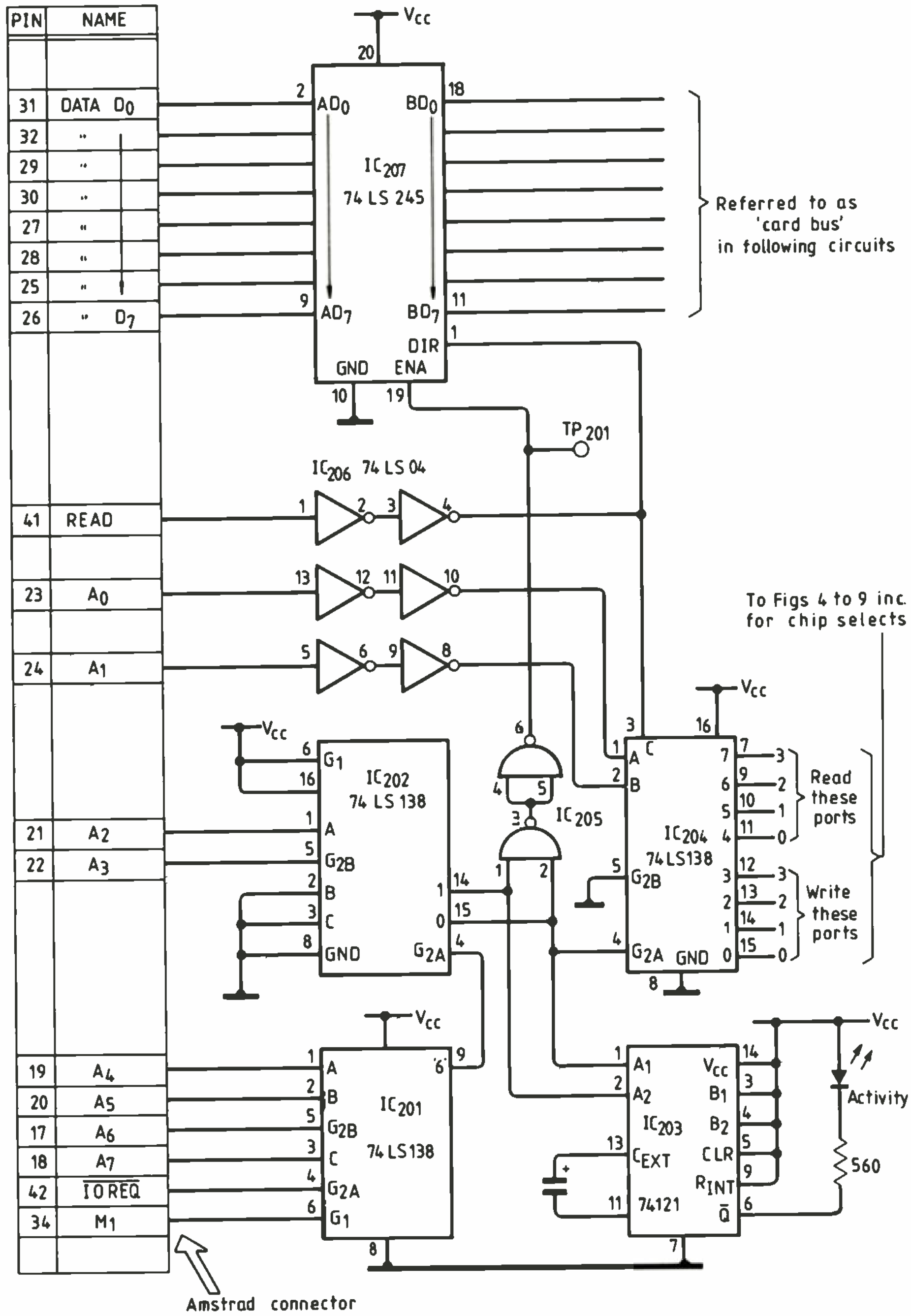


Fig.2. Address decoding and buffering module plugs into the Amstrad bus connector.

waves well into the kilohertz region can be generated. High-frequency waveforms are easily cleaned up using simple RC filtering since the sampling harmonics do not appear until around 30kHz.

To be continued.

Brian Frost, C.Eng., M.I.E.E. graduated from Bangor University in 1974 with a degree in electronic engineering. Until recently he was in charge of the design of automatic test and manufacturing equipment at STC; now he is with Deltest Systems working on advanced analogue specific a.t.e.

His spare-time interests include writing and an involvement with Remap, a UK-wide network of engineering working voluntarily to make special aids for the disabled. In this field he is working on radio communication aids for the deaf. He is also a licensed radio amateur, G6UTN.

COMPONENTS

The interface is available fully assembled and tested at £139, or in the following kit stages:
Kit A: printed circuit board with connector for address decoding circuitry of Fig.2, £16.50.
Kit B: address decoding circuitry of Fig.2, including p.c.b, connector, and all components fully assembled and tested, £31.50.
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Alcatel and ITT converge on IT

ADRIAN J. MORANT

January 1 saw the start of a new era with the establishment of a new telecommunications company, Alcatel NV. This new alignment will be instrumental in placing greater stress on information technology and the convergence of telecommunications and computing. A joint venture consisting of the telecommunications activities of the ITT Corporation worldwide and all of Alcatel of France and Cables de Lyon activities under the management of the Compagnie Générale d'Electricité (CGE), the company is active in 110 countries, with annual sales of $12 billion and some 150 000 employees. CGE group controls 55.6% of the company and ITT owns 37%.

At the same time as bringing together these resources the new company will make existing and prospective customers (including PTTs and thus, effectively, governments) re-examine their procurement policies and is therefore a realignment of the industry. This is especially so in public switching, where a country rarely has more than two or three suppliers, and so this can be seen as another step in the rationalization in the market-place. In other areas it could well bring the benefits of economies of scale.

In the short to medium term, the outcome will probably be less than the sum of the individual parts. This is due to the difficulty of merging two companies which, because of their very size, overlap in a number of product areas. Thus, an amount of rationalization will be required – some of which will no doubt be traumatic. Even before this occurs, it will already have changed the centre of gravity of the telecommunications industry.

With sales forecast to reach $12 billion this year, the new organization becomes the world's second largest telecommunications supplier with a broad spread of activities including public switching, business systems, cables and a variety of consumer and industrial products. It claims to be the world's largest international supplier of public network equipment and to have market leadership in digital switching and transmission equipment, including advanced fibre optic systems. However, while in the fullness of time Alcatel will have a higher profile, many people in the UK will not even recognise the name even though many more will know ITT.

ITT has occupied an important place in the UK for many years. Probably most widely known in the High Street are the tv sets bearing its name and STC (once Standard Telephones & Cables) was one of its UK subsidiaries. Even though it no longer has control, it still holds 24% of STC's shares.

Last year Alcatel and ITT had total sales in public telecommunications of around $5 billion and, in digital public switching together they have 37 million lines either installed or on order in 76 countries. The new company will develop and market both the Alcatel E10 and ITT's System 12. Alcatel is a pioneer of digital switching, having supplied the world's first digital public telephone exchange, which was commissioned in France in 1970. Since then, with 765 E10 exchanges in service, over half of the French network is already digital while the whole of the country can benefit from the 64k-bit/s switched bearer service to transmit data and image. Fully compliant with the latest CCITT standards, the system will allow for smooth migration from PSTN to ISDN.

ITT entered the business much later. Nevertheless, almost two million equivalent lines of System 12 have been handed over to PTT customers in 14 countries while the total order book has now reached 14 million equivalent lines for 21 countries over the next 10 years.

Today five subsidiaries of the new company (SEL in West Germany, BTM in Belgium, FACE in Italy, Standard Electra in Spain and STK of Norway) are principally involved in production and development of System 12 under the central co-ordination of a public switching headquarters based in Brussels. These companies are involved in technology transfer to other manufacturing subsidiaries of the new company, in direct export to world markets and in joint ventures and licence agreements for local production in countries which include China, Turkey and Yugoslavia.

It has been announced that development will continue on enhanced features for System 12 (which in recent times has involved R&D expenditure in excess of $100M per annum) to meet PTT requirements for ISDN-related services. However, System 12 deliveries have been running late and the view has been frequently voiced that the design is flawed. While ITT could not deny that there were delays, it, and now Alcatel, assure everyone that these problems are things of the past.

In West Germany, the Deutsche Bundespost has started Europe's first large-scale ISDN field trial. This trial includes a System 12 exchange in Stuttgart to which 400 full-ISDN subscribers will be connected. In Belgium, the PTT is the first one in Europe to introduce CCITT No.7 common channel signalling links between exchanges for handling both signalling and call charging information. This feature is being implemented on System 12s throughout the country. Other systems include a combined exchange in Denmark handling traffic equivalent to a 40 000 line local exchange and a group of exchanges in Norway, equipped for 70 000 lines, which interconnect local and toll exchanges with remote subscriber units. It does appear, therefore, that System 12 is getting over its early problems.

In radio links Alcatel is Europe's largest and the world's second supplier with over 100 000km of equipment already in service. In submarine cable links, it holds 25% of the world market outside the USA. This amounts to some 31 000 nautical miles of submerged cable containing 3 400 repeaters.

In addition to conventional copper cable it has a new generation of digital optical fibre systems. These activities stem from Cables de Lyon together with the fibre optic activities of ITT in the USA. This is possibly one of the reasons that STC has been excluded from the joint venture, even though ITT owns a large proportion of its shares. After all, STC's expertise in submarine cables – including optical – is in direct competition.

In terms of subscriber services, Alcatel switches are central to the French videotex service. The growth of this network, which now serves over three million subscribers, is in part due to the French government's electronic telephone directory project. This ensured that there was a large installed base that would attract information providers.

Similarly in mobile communications, the group manufactures both u.h.f. and v.h.f. network equipment and mobile units and has joint agreements with different European manufacturers to develop a 900MHz digital cellular radiotelephone system which it hopes will be adopted as the future European system.

In business systems the new company will have sales of around $3.2 billion (£2.5G). As well as producing over 10 million telephone instruments, Alcatel has its existing range of p.a.b.xs and telephone key systems while ITT brings its Office 2000 system. This latter is broken into three basic elements essential to a user's information management system: telecommunications (orientated towards private systems); data communications (host/computer orientated systems) and computing where ITT has a family of small business computers. It encompasses a complete range of hardware and software ranging from telephone handsets and peripherals like facsimile machines up to powerful super-minis that link to mainframe computers.

Altogether, this is enough to make a very powerful group with enormous resources. However, success in many of its areas of operation is not only determined by technical and direct commercial considerations – politics and even national aspirations are involved. The broad spread of product mix in telecommunications and IT will provide many opportunities but only time will tell.

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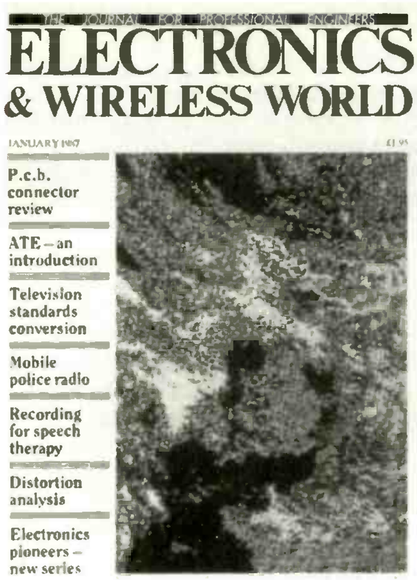

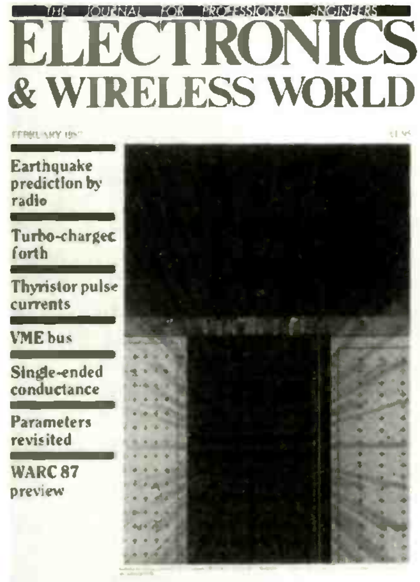

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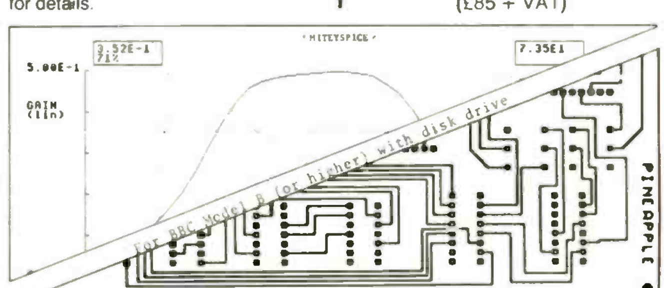

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Quality assurance

"Quality can't be put in at the end: you've got to build it in from the beginning," seems to be the conventional wisdom behind Quality Assurance (QA). New government standards may be encouraging this attitude, but if there's a "revolution" taking place in the QA world, its happening slowly.

"A cultural change is taking place in QA, and it's not before time," according to Mike Perry from the British Standards Institute, "the next five years should be very exciting." Perry says the move to higher quality is coming from the top downwards. The new corporate philosophy, according to Perry, is 'Total Quality Management' (TMQ). TMQ, an American phrase with its roots firmly in Japanese management practice, calls for productivity to go hand-in-hand with quality. The idea is to involve all members of the workforce to keep the customer satisfied at every level. In some Japanese plants, for example, production line workers have been able to send components back to the previous work station when they are not satisfied with the quality of the piece.

The British government is seen to be promoting TMQ with the introduction three years ago of BSI 5750. Made up of three parts, BSI 5750 introduces the art of statistical process control, so that any flaws can readily be identified and put right. The idea behind BSI 5750 is for major companies – such as British Aerospace (BAe) and British Telecom (BT) – to put pressure on their sub-contractors to conform to quality standards. Quality becomes the responsibility of the sub-contractor. The government is therefore using the purchasing power of these giant corporations to bring smaller companies into the quality line.

Parallel with the commercial developments have come a new set of military procedures. The new NATO AQAP standards replace the old 0251 MoD standards. Again, the responsibility for maintaining standards lies with the sub-contractors. When certified by MoD inspectors, the company is then visited around four times a year to make sure things are up to scratch, according to an MoD spokesman. The MoD also has a verification workshop where more detailed inspection work can be undertaken.

So what sort of people are being taken on in the QA business? The general standard seems to be an HND followed by three to five years of experience. The favoured age range seems to be 24-38 but, as with all these guidelines, they're only approximate. The average pay package for a suitably qualified and experienced engineer is around £12,000.

Steve Ollerton from Data Engineering Recruitment said that, while they prefer two to three years experience, a shortage of good QA engineers means they'll take somebody with 12 months under their belt – so long as the experience is directly related.

QA is big business at BAe's Stevenage plant, with a staff of 850 out of a total workforce of some 6 500. These people cover all aspects of the spectrum from technicians to engineers. These include calibration engineers using proprietary test equipment. BAe recently passed through its AQAPS procedures with "flying colours" according to personnel manager Richard Aubigne. Aubigne says AQAPS covers all areas of the plant including quality planning. "AQAPS takes the skill away from people," said Aubigne. "You can't do things your own way and that's no bad thing as you can't miss anything out this way." BAe currently has a vacancy list for 20/30 QA people – right across the board. Officially, for engineers BAe requires an HNC with six years of experience. However, with such good training facilities, the company is willing to take people on with the right qualifications and then train them up themselves.

Aubigne said calibration engineers seem to be the hardest to come by "Some take months to recruit – others take a couple of years," he said. With such a specialized area and modest salary, Aubigne said BAe is finding recruiting the right engineers very difficult indeed.

David Hunt from Interlord – a Wimbledon-based recruitment company – said there's a large demand for QA engineers, not just in this country but in Northern Europe as a whole. Hunt maintains the demand for British QA engineers persists because of their high reputation for getting the job done. Providing the engineer is fluent in that country's language, a well qualified person is widely sought after. Hunt added that the change to BSI 5750 and AQAPs standards has led to more work for the QA engineer. "As companies carry on picking up new standards there's an increased requirement for quality personnel," he said. There seems to be a shortage of experienced people in all engineering fields. QA engineers are in especially short demand, according to Hunt, because of their loyalty to one particular company. Hunt puts this down to QA being regarded as a highly desirable and interesting occupation.

At Plessey Semiconductors, QA personnel come from the general graduate training programme which takes on 25 to 40 people each year. Vacancies are then filled as they appear. A small proportion of engineers cross over from electrical engineering. A Plessey spokeswoman said it isn't any more difficult to find QA's than any other type of engineer – but that's hard enough!

Mark Wright from the Independent Broadcasting Authority agreed with Hunt insomuch as he has a very low turnover of Quality Control staff. The IBA employs Quality engineers to monitor the technical quality and broadcasting standards of local stations. They also make sure broadcasting equipment is up to specifications. Wright said the IBA looks for degree-educated people with two to three years experience. When it does have vacancies it can't fill internally the IBA advertises through the trade press.

While degrees are preferred by some large companies, it seems most QA engineers take the HNC/HND route. According to Graham Smith from the Southampton Institute of Higher Education, the courses are very "hands on" practical courses, with the theory to back it up. At HND level the students, most of them on day release from electronics employers, have 6/7 assignments to complete. Smith said these assignments are very sophisticated and a lot of emphasis is placed on presentation with people being groomed to become QA managers. After finishing the HND, some students go on to take the Engineering Council Part Two exams, which on completion give chartered engineer status. Smith said these exams require six passes which can take up to three years part-time study to complete.

Southampton also runs courses for those people who work in QA on a day-to-day basis at the technican level. This is a City and Guilds 743 course, teaching Quality Control techniques to mature people who are often trying to be upgraded to inspector level. With the introduction of the new standards there is increased company demand for training. To meet this demand Southampton is running courses specifically designed for each company, either in-house or at the company's premises.

BSI 5750 will eventually affect all manufacturing companies. Many larger ones, such as BT, have already come into line and are applying pressure on their subcontractors to do the same.

Mike Perry said the job of the QA engineer is bound to change quite dramatically. Previously a works engineer given the quality hat, as well as many others, the QA manager is adopting an ever more important role. The QA manager needs to be able to gain the respect of all departments within the organization as quality becomes an all-pervading issue. The QA manager also needs to be able to bend the ear of the chief executive officer, who alone can authorize the required levels of expenditure.

QA engineers are therefore going to have to be of senior management status. Pay scales seem slowly to reflect demand for highly skilled personnel. With a large number of companies seeking to adopt the BSI 5750 standards the demand is set to increase. However, it seems unlikely most companies will be able to offer the salaries currently on offer to some QA consultants. According to Perry, figures of £35 000 are not unheard of. As I said, a revolution may be taking place but it's certainly happening slowly.

Workfile is written by Stephen Horn, Employment Editor, Electronic Weekly.

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