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The circuit board described in this article is not, strictly speaking, indispensable for a fully operative indoor unit. But then, the optional add-on circuits are relatively simple to build on a single PCB and may provide you with a number of quite useful extensions.

Circuit description
The circuit diagram of the optional extension board is shown in Fig. 18. The various functions it offers are best discussed by starting from the three possible positions of the front panel mode switch, S1a-b.

1. **TUNE**: S1a-b is set to position 1, as shown in the circuit diagram. Oscillator IC3 is disabled by the low level at its RESSET input, pin 4. Electronic switch ES1 is closed, while ES2 is opened, so that the DC-coupled video signal, CVBS (see Part 2) is routed to TV modulator IC5. The operation of this versatile RF chopper will be reverted to.

The RF board tuning voltage, Vtune, is taken from the output of summing opamp A3, which is driven with the tuning control voltage (terminal T, controls P1-P3), and the output voltage of AFC amplifier A3.

If AFC switch S3 is opened (AFC off), ES1 and ES2 are off and on, respectively, which means that the voltage at the + input of A3 is a fixed level determined with P4. Vtune will, therefore, track the voltage at point T, just as if there were no amplifier of any type in function.

Switching on S3, however, causes Boc, rather than the voltage at the wiper of P5, to be fed to the + input of A3. This creates a feedback loop in the tuning voltage circuit. It will be recalled that Boc is the smoothed direct voltage component of the baseband video signal. Tracing its origin will reveal that Boc is the proportional equivalent of the PLL-generated tuning voltage across varactor D1; i.e., it can provide information about the instantaneous centre frequency of the PLL subcarrier (see Part 3).

Assuming the AFC function to be switched on, and assuming that the selected oscillator, LO1 or LO2, starts to deviate from its set frequency—which may well happen owing to thermal effects—the PLL will consequently alter the voltage across D1—and hence Boc—to match its VCO frequency with that of the incoming carrier at about 610 MHz. The AFC circuit next responds to the assumed fluctuation of Boc by correcting Vtune such that the oscillator remains at the set frequency, i.e., Boc remains constant.

The practical limitations of the proposed AFC circuit mainly concern the response speed of the loop, and the AFC hold range. The AFC circuit should be insensitive to the demodulated video component, which, of course, is also the PLL action to an FM input signal. This function is taken care of by Cs (see...
Fig. 18. Circuit diagram of the optional extension board in the IDU

Part 2), as well as C41. Feedback resistor Rs4 defines the AFC hold range, i.e. the span of Vtune that ensures a constant Bdc voltage. The stated value of this resistor fixes the AFC hold range, i.e. the span of Vtune that ensures a constant Bdc voltage. The stated value of this resistor fixes the amplification of A4 at about 3 KRw + RnVBu, which will ensure sufficient AFC action in most practical cases.

1. SCAN Sdown is set to position 2, ES4 is closed, and IC1 oscillates at about 10 Hz. The triangular wave at pins 2, 4, & 6 is amplified to about 30 Vpp by means of A1, which consequently causes the relevant oscillator, IO1, or IO2, to produce a swept output frequency over its entire mixer injection band. The purpose of the SCAN facility is to facilitate the initial dish positioning procedure. As soon as the dish "sees" the satellite, there will be a marked change on the TV or monitor screen from stable noise to a rather unsteady flicker, caused by the receiver sweeping across the incoming transponder signals. Also, the S-meter will show some deflection and hence can be used to find the initial aerial position.

2. TEST REMODULATOR Si is set to position 3. ES4 is opened, so that the video test signal is passed to TV modulator IC4.

The remodulator test facility enables ready tuning of the TV set to the modulator output frequency, thereby slightly alleviating the possible difficulty in setting up a satellite reception system for the first time.

LNB theft alarm (IC4, TA4).
The relevant circuit section is so simple as to obviate the need for a detailed description. With three jumpers installed as shown by the dashed lines, LED De and buzzer Bz will warn of attempts to steal the costly LNB. The jumper block and the potential-free relay contacts should enable a straightforward connection of the LNB theft alarm to many types of existing alarm system. Table 3 shows some of the possible alarm configurations plus associated jumper positions.

<table>
<thead>
<tr>
<th>Alarm configuration</th>
<th>Jumpers/signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED and buzzer only</td>
<td>abcdefghijklmn</td>
</tr>
<tr>
<td>to external alarm</td>
<td>a</td>
</tr>
<tr>
<td>IDU alarm disabled</td>
<td>a</td>
</tr>
<tr>
<td>external 20 mA loop (OR function)</td>
<td>a</td>
</tr>
<tr>
<td>IDU alarm drives</td>
<td>a</td>
</tr>
</tbody>
</table>

Table 3

The relevant circuit section is...
Remodulator (ICs).

The Type TDA5660 from Siemens is an all-in-one TV modulator chip which can be configured for a wide variety of TV standards. In this design, it provides a double-sideband, AM vision, FM sound, TV signal at 48 MHz, which is roughly channel 2 (48.25 MHz, Band I). Operation on channel 3 or 4 is also possible by simply using an appropriate crystal in the X position. The circuit may also be modified to output a UHF TV signal (470-790 MHz), but this is rather more complicated than exchanging the crystal, and is, therefore, only recommended for experienced RF constructors. The matter will be reverted to in the section on construction.

The audio input signal to the TV modulator chip is passed through a pre-emphasis network, R1-C1 (r = 90 μs). The modulator chip provides wide-band FM modulation at the audio sub-carrier frequency of 6.0 MHz, as set with R5. The VHF output signal is available at symmetrical outputs pins 13 and 15. A double-pi-filter, C19-C22 and C23-C26, precedes the 300Ω-to-75Ω balun L20, forming the RF signal at C18. Trimmer C26 is used to set the modulator output filter for optimum balance. The dashed lines around the remodulator circuit denote metal screens.
which serve the preclude stray
radiation.

Construction
If you have made it so far in
building the IDU, you are not
likely to encounter serious dif-
ficulties in getting the present
extension board up and run-
ing.
Fig. 19 shows how PC board
Type 66032.3 is to be com-
pleted. Only three points re-
quire special attention, namely
making Lw and Lw, and fitting
the extension board on top of
the vision sound PSU board de-
scribed in Part 3 of this series.
In order to avoid unnecessarily
repeating the suggestions for
making one's own inductors, it
is recommended to re-read the
passage on preparing Lw; this
can be found in "Elktor India,
December 1988.
With reference to Fig 20 and
Table 4, oscillator coil Lw is
made as follows (note that the
white ABS former as part of the
Type 771S inductor assembly is
divided into two equally long
sections by means of a small
rim):
1. Starting from f, and obser-
vining the indicated winding di-
rection, close-wind 11 turns in
upward direction onto the
lower section of the former
body, doing so neatly fill this
section. Connect to b (not to e).
2. Starting from e', and once
more observing the correct
winding direction, close-wind 4
turns upward onto the upper
section of the former; the first
turn should rest against the rim.
Connect to a.
3. Check for any short-circuits
between the windings, and
verify correct continuity at the
pins.
4. If you have a GDO, check
whether the inductor can be
tuned to about 50 MHz with a
1pF capacitor temporarily fitted
across f-b.
5. Mount the former plus
screening can onto the PCB.
Adjust the yellow-tipped core
unit to its top level with the hole
in the screening can.
As to Lw, the construction of
this balun (balanced-to-unbal-
ced transformer) is evident from
the six-step instruction shown
in Fig 21. Almost any type of
small, two-hole former can be
used for at least 100 MHz.
No ferrite core is needed for
100 MHz.
After making the balun and
fitting it onto the board, it is time
to check whether this is cor-
rectly populated. There should
be six wire links in all, and the
jumpers in the PBS alarm cir-
cuit should be fitted as re-
quired. Positions C1 and C3
are vacant as yet. Make sure
that all ceramic capacitors in
the remodulator section are
mounted with the shortest pos-
sible lead length. The crystal
case must not be grounded.
For any metal screen around
the remodulator circuit, and the
lengthwise fitted screen across
IC-1, is governed by 9 soldering
pens. A single strip of 12 mm
wide thin brass sheet or tin
plate is readily cut and bent to
size. Remember to drill two
small (• 3 mm) holes in the
screen to enable feeding
through the shielded wire to
the audio input, and, if re-
quired, the 3 mm coax cable
from the RF output to K1 on the
enclosure rear panel.
The completed extension
board is mounted on top of the
rear side of the vision sound
PSU board, i.e. as close as pos-
sible to the enclosure rear panel.
Remodulator output socket K1
can be fitted at a suitable lo-
cation in the rear panel, while
being connected directly to the
relevant pin on the PC board,
i.e. without a length of coax
cable. Note, however, that this
mounting method requires a
suitably sized hole in the
previously mentioned
screen, allowing for the passing
of the socket.

Table 4. Home wound inductors

<table>
<thead>
<tr>
<th>Inductor</th>
<th>SWG</th>
<th>turns</th>
<th>remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lw, Lw</td>
<td>30</td>
<td>11</td>
<td>Closewound on Neodid dia. 4 mm former Type 771S, see Fig 20.</td>
</tr>
<tr>
<td>Lw</td>
<td>30</td>
<td>8</td>
<td>RF transformer; see Fig 21</td>
</tr>
<tr>
<td>Lw*</td>
<td>24</td>
<td>3</td>
<td>Space windings to obtain overall length of 5 mm, internal dia = 3 mm.</td>
</tr>
<tr>
<td>Lw, Lw*</td>
<td>24</td>
<td>5</td>
<td>Space windings to obtain overall length of 6 mm, internal dia = 3 mm.</td>
</tr>
</tbody>
</table>

* Only required for UHF-band operation of remodulator.
The lowest possible mounting height of the present board above the vision-sound PSU board is determined mainly by the height of the fuseholder on the later PCB. Sufficient stability of the "sandwich" construction is ensured by using two conventional 15 20 mm long PCB spacers in the two rear positions.

It goes without saying that the overall height of the two-board unit should enable the IDU to be closed properly. Also, the vision-sound PSU board should be fully operative and correctly aligned, since many of its adjustment controls are no longer accessible with the extension board fitted on top.

The wiring of the boards should be fairly straightforward, requiring no further remarks other than that the audio, Bcc and Vdown connections should be made in conventional shielded microphone cable, while the CVBS-1 connection is made in +3 mm coax in all cases, ground the cable shield at the lower board only.

Finally, the external loop connection can be made with whatever type of socket or terminal strip is thought most convenient; a 3- or 5-way DIN socket is satisfactory.

Setting up

Before detailing a suggested setting up procedure for the present board, it must be made expressly clear that attempting to use the completed extension PCB along with as yet unoperational RF and vision-sound PSU boards needlessly complicates getting the IDU to function correctly. Therefore always build up the receiver as detailed in Part 2, and familiarize yourself with the various adjustment points and their typical response, before adding the present board.

1. Set 5a to TUNE, and switch off the AFC (5b). Turn Pr (course tuning) to check whether Vdown varies from about ±30 V. Tune to a satellite programme and check the presence of composite video at pin 10 of IC1. Do the same for the audio at pin 1.

Measure Bcc, note the value, and adjust Pa for an identical voltage at its wiper. Switch on the AFC and check its hold range by turning Pr; reception should remain unaltered over a certain portion of the tuning control travel, then suddenly be lost.

2. Set 5a to SCAN, and switch off the AFC. Use a scope to check measuring points 2 and 10. Vdown should be an undistorted triangular wave, i.e. it should have clearly defined points of inflection, and no clipped tops or appreciable offset. If necessary, R42 and R65 may be redimensioned to achieve the correct wave form and amplitude respectively.

Set Pa to the centre of its travel and observe the monitor screen to see the effect of the SCAN mode when a satellite is received. You may want to experiment a little with the value of C56 to obtain the best noticeable effect on the screen. Try to remember what it looks like!

3. Set 5a to TEST REMOD, and connect a TV set to 1. Tune the TV to channel 2. Adjust the core in L10 until the test signal—a white vertical bar two durs to the left of the screen—can be seen with good definition. Adjust Ps for optimum synchronization, or use a frequency meter to check measuring point 18 for the presence of the stated rectangular wave (see Fig. 18). Fine-tune the TV set to the test signal, and switch the IDU on and off a few times to verify whether the 48 MHz oscillator starts correctly, or if necessary, set 5a to TUNE and observe the transmitted signal on the TV. It may be necessary to re-do the setting of Ps and L10, as well as the TV tuning, for optimum picture quality.

Turn up the volume control on the TV and peak L1 for best sound reproduction. A suitable ceramic capacitor (10-100pF) may be fitted in the C4s position, in case L1 cannot be tuned low enough.

Finally, tune the TV set to a lower UHF band harmonic of the remodulator, and adjust C56 for maximum signal strength. Unfortunately, the presence of harmonics cannot be nulled out altogether, given the relatively low frequency of operation of IC4. Depending on the degree of crystal activity, it may be worthwhile to fit a damping resistor (100-10K) across pins f and h of L10.

Run a quick check on the operation of the A.T.P. by connecting the two-board cable to K. Please note that the alarm circuit is fed from the unswitched +12 V supply. Therefore the +12V terminal on the PCB should be wired to the buzzer as well as the appropriate connection of Sa (see Part 2).

Finally, if the setting of Sa fails to give a satisfactory compromise between the operation of the SCAN function and that of the internal test pattern generator, try fitting a number of small capacitors in the C56 position.

Remodulator on UHF

The circuit diagram of Fig. 22 shows how to modify the on-board TDA5660-based TV modulator for operation in the UHF TV band (470-790 MHz). As this modification is not supported by the PCB layout, altering the circuit is recommended for experienced RF construction only.

Preset 5a is used to set the desired output frequency, which must be well removed from the PLL VCO frequency to avoid carrier interference. Therefore do not tune IC1 to the generally used modulator channel 35.

The small ceramic NPO capacitors can be fitted in a three-dimensional construction, along with oscillator inducer L10, which can be spaced or compressed slightly to set the initial output frequency. The B5 capacitors are, of course, fitted direct across the relevant IC pins at the PCB track side.

The modulator output filter must also be altered as shown to allow for the higher frequency. Use a suitably sized bead for L10, and wind the turns through each hole, rather than three as in the VHF circuit. The data for L10, L9 and L4 can be found in Table 4.

Aerial positioning unit

The circuit diagram of Fig. 23a and the photograph of Fig. 23b show a simple, yet indispensable accessory unit for the IDU. It is a hand-held remote meter circuit which is connected to the IDU over a length of 6- or 7-way cable, enabling the user to monitor the S-meter indication while lining up the aerial for optimum reception. It should be noted that the circuit diagram and practical realization are but suggestions; other configurations, as well as more sophisticated controls are perfectly feasible, and constructors should have little difficulty in tailoring the aerial

Fig. 22. Modified circuit for the remodulator, if this is to operate in the UHF band.
Test set up to examine the performance of the BFG66 prestige line in the IDU. Display indications, left to right: frequency (MHz), associated gain (dB); noise figure (dB). Courtesy of SSB Electronics, Iselheim, Federal Germany.

Threshold extension

The following is a necessary brief examination of a number of experiments with the PLL demodulator, IC2, on the RF board. As these experiments are not supported by the PCB layout, their being carried out is only recommended for experienced RF constructors. Also, since the objective of the proposed modifications is to further lower the PLL noise threshold so as to improve upon a D/A converter with relatively low C/N ratio (8-10 dB), there is no point in altering the PLL circuit if your specific outdoor unit ensures a C/N output of more than about 12 dB.

When the C/N ratio at the input of the PLL demodulator approaches the noise threshold, the received picture is more or less impaired owing to noise spikes occurring mainly in the saturated colour areas. This effect is mainly due to insufficient open loop gain of the PLL at the chroma subcarrier, 4.433 MHz (PAL system).

Incorporating a chrominance filter in the secondary PLL loop may improve reception to some extent, but it should be noted that the effect depends on the transponder deviation and bandwidth. For instance, the signal from Teleclub Switzerland could be slightly improved by peaking the chroma filter whilst observing the few remaining sparkles in the ochre rectangle at the lower right of the test chart. Correct tuning of the series filter will enable the sharp white-to-black transitions in the chart to appear with a clearly improved definition. The practical circuit of the chroma filter extension is shown in Fig. 24a.

It will be recalled that C21 and C22 define the secondary loop response and hence the operation of the PLL at a specific transponder deviation. It is important to realize that, at present, there is no single standard for the peak-to-peak deviation of transponders, nor even if these are part of one and the same satellite. Research carried out by the EBU and the CCIR has provided evidence for the proposition that, given a specific C/N ratio, S/N rises with increasing deviation. It is, therefore, arguable that future satellites will hold transponders with larger output bandwidth, after all, a number of the present generation of TV satellites were originally designed to operate in data communication networks.

Fig. 23. Circuit diagram (23a) and practical outlook (23b) of the aerial positioning unit.
Fig. 24 Experiments in obtaining a possibly low noise threshold for various levels of transponder deviation.

Fig. 25. Band curve of an incorrectly aligned (25a) and a correctly aligned (25b) IF chain on the IUD RF board.

RF board measurements

The IF amplifier chain on the RF board was studied with respect to its frequency vs amplitude characteristic. Use was made of a 0-1800 MHz spectrum analyzer plus associated sweep unit.

Fig. 25a shows the curve of a wrongly adjusted IF chain; one of the four band filter trimmers has obviously been set at too low a frequency, causing a marked peak outside the required pass band. While adjusting the band filters to obtain a satisfactory filter response, it was found possible to locate the pass band anywhere in the 450-850 MHz band, while the bandwidth was never less than about 35 MHz. Therefore, constructors not in possession of an RF sweep generator or other sophisticated equipment to measure the IF bandwidth need not worry too much about the overall pass band of the RF board. As long as all trimmers can be tuned for a noise output, the initial alignment is satisfactory.

Finally, interested constructors are advised that Plessey have recently introduced the Type SL1455 quadrature FM TV demodulator, which is said to achieve a noise threshold of about 7.5 dB, i.e. it is some 1 dB better than the SL1451 configured for optimum operation given a specific deviation.

Next time

Next month's concluding article in this series will tackle a wide variety of questions raised in connection with satellite TV reception. So should any aspect of the present subject matter still puzzle you, see whether it is among the subjects qualified for closer examination in Part 4.
The Future Belongs to the Photon

Electronics has been the main engine of innovation since the invention of the transistor 40 years ago. Most of tomorrow’s interesting technologies will work by manipulating light, not electricity.

The electronics revolution is young. The electron was identified less than a century ago and the microchip, on which today’s information-technology industry utterly depends, has been around for fewer than 20 years. The successes crammed into these two hectic decades have created the impression that electronics is a technology capable of limitless improvement.

It is not. Electronics will give way to a superior technology based not on electricity but on light. Physicists did not realize until early in this century that light came in the separate packets they now call photons. But science has made startling progress in manipulation photons. A photonics revolution is already in the making.

The first shot of the electronics revolution was the transistor. Photonics’ first shot was the invention, in 1960, of the laser. Until then, those trying to do tricks with light had to make do with a jumble of disorderly wavelengths. Lasers create a source of light with a uniform wavelength and with each wave moving in step with its companions. This is a tool of immense power. Lasers can—or so President Reagan hopes—destroy ballistic missiles thousands of miles away. They can cut metal in factories and repair blood vessels in human eyes. Hospitals use laser beams guided through optical fibres to shatter people’s kidney stones. A French inventor has replaced the strings of a harp with laser beams. Like transistors, lasers have shrunk: they can now be generated by a chip the size of a grain of sugar. This is paving the way for a wholesale switch from electronics to photonics.

Why is the switch worth making? Because photons travel faster than electrons; because they have no mass; because (unlike electrons, which interfere with each other) photons can be made to pass through each other unperturbed; because light behaves both as a particle and as an electromagnetic wave—which means that optical devices could be based on much the same operating principles as those already used in electronics.

Moreover, electronics is discovering its limits. One is the speed at which electrons travel through semiconductor materials. So long as electrons remain the information carriers of computers, this sets an absolute limit on the speed—and hence power—of computing. Electronics has not reached that limit yet, but it is drawing close enough to worry engineers. The customary way to make computers cheaper and faster is to squeeze electronic components closer together. The number that can be fitted on a single chip has grown from about a dozen 20 years ago to 2m today. But miniaturization, too, is bumping against limits. Engineers are running out of ways to pack chips ever smaller paths along which electrons can run. And when components get too close, the chips are plagued by “cross talk”—the leakage of charges from one component to another.

If computers are to work faster still, a new approach is needed. The best bet is “parallel processing”—the notion that computers ought to be able to perform a lot of operations simultaneously, instead of channeling all their calculations through a bottleneck central processing unit. Here, too, the case for a photonic solution is compelling. Sending several electric currents through one chip at the same time makes cross-talk and disaster. Not so with beams of light: a chip could process several at once without their interfering with each other.

Still sceptical? Consider how rapidly light has nudged electronics out of two pillars of information technology: telecommunications and the storage of information.

In communications, telephone companies are tearing out their copper cables as quickly as they can afford to and replacing them with ethereal optical fibres made of glass. Light is a better messenger than electricity. It wastes less heat and is immune to electromagnetic interference. Better still is light’s enormous bandwidth. Because it spans so many frequencies, light can squeeze in far more information than electricity can.

The quality of the optical fibres themselves has improved dramatically. In early (circa 1970s) fibres, light ran in a disorganized zigzag through a relatively large core within the fibre. The resulting collisions with the fibre’s cladding absorbed much of the light, requiring frequent repeaters to refresh the signals. In 1977, experimental fibres transmitted up to 140 megabits of data a second, and needed a repeater every six miles or so. Today, one experimental fibre network installed in Britain carries telephone traffic at 12,000 megabits a second, with 30 miles between repeaters.

The first transatlantic fibres will be carrying data and telephone conversations between Europe and America in 1988. Yet the technology is on the threshold of another luminous leap.

This will not come from changes in the fibre itself, but from the devices used to send and receive the optical signals. The first step is to combine in a single device all the paraphernalia that optical fibres require—lasers to send signals, detectors for receiving them, and a rag-bag of lenses, mirrors and electronic controls.
The second step is to transmit light beams "coherently"—i.e., in tightly-defined wavelengths—into a receiver that can be tuned to select the required wavelengths and sort out the separate streams of data. In principle, coherent transmission enables a single fibre to carry 10,000 telephone conversations or 10,000 digital television channels at once.

The optical assault on data storage—that other pillar of information technology—has been as impressive. Music lovers were in the van with their compact discs. The music is turned into digital signals, burned on the disc as a series of minute pits and then decoded for playback by a low-power laser. Audio discs like these are only the first big success of a technology restlessly seeking new applications and markets. Optical discs are beginning to replace magnetic ones as a way to store computer archives. Because they are tough, the discs can be stored inside specially-constructed jukeboxes. One 4.7-inch disc can store about 550m bytes of data—the equivalent of 1800 floppy discs or about 250,000 printed pages. Which means a jukebox can store the archives of an entire government department.

Optical discs suffer from one drawback easing them or writing new information on them is difficult. This has impeded their marriage with computers, but has also prompted an imaginative hunt for applications in which data must be stored permanently without alteration.

Discs sold under a standard format known as compact disc read only memory (CD-ROM) are enabling data-base companies to sell archival information to subscribers who pay by post instead of expensively by telephone. Grolier, an American publisher, has put its Academic American Encyclopaedia (30,000 articles, 10,000 pages) on one tenth of one disc, which it sells for less than $20.

A new generation of discs—called WORMs (write-once-read many times) is halfway there. These are sold blank so the end user can store whatever data he likes on them, although the information, once stored, is there to stay. But the technology for a fully-erasable disc will probably be perfected by the end of the decade. Two ideas for making them are already showing particular promise.

One is based on a magneto-optical process. The disc's recording layer is an alloy of terbium, iron and cobalt. To store information, a laser heats up a tiny spot on this layer, creating a vertical magnetic field. The information is read by another laser whenever it encounters a magnetized spot. The light's plane of polarization is rotated. The information can be erased by heating the spot.

The other approach is chemical. Here, a laser is used to switch the structure of a tellurium alloy back and forth between amorphous and crystalline phases, which reflect light differently.

Impressive as they are, the progress made by optical discs and fibres do not amount to a revolution. Photonics will not become fully of age until it equals, and then surpasses, the central triumph of the electronics revolution: the computer.

At the heart of the computer sits the transistor. A transistor, remember, is a switch, a device that can flip backwards and forwards between two states. Computers are chains of switches. They treat sequences of ones and zeros as digits (in binary counting) or to denote "true or false" (in which case chains of switches are used as the building blocks of algebraic logic). The challenge for photonics is to invent a device that does for light what the transistor does for electrons.

Into the heart of the computer

It has virtually happened. At AT&T's Bell Laboratories and Britain's Heriot-Watt University in Edinburgh, small and primitive circuits of the kind that could one day grow into computers are already running on light. The switches they use—known variously as bistable optical devices (BODs) or transphasors—are essentially optical transistors. Light emerges from them as a strong beam (on) or a weak one (off). Put a bunch of transphasors together, shine laser beams through them, and you have the basic ingredients of an optical computer.

To understand how a transphasor works, think of it as a partially-reflecting mirror facing each other. If a beam of light is shone through them some of it gets trapped, bouncing backwards and forwards between the mirrored surfaces (see diagram on next page). As these waves cross each other, they can either interfere with and weaken the beam or align with it and reinforce it. This phenomenon is the basis of a simple instrument—used to measure wavelengths—-invented by two French scientists, Charles Fabry and Alfred Perot, in 1896.

The Fabry-Perot interferometer emits a strong beam or a weak beam depending on whether the waves are being reinforced inside the cavity. On its own, however, it is not a switch: a useful switch needs to be obviously on or obviously off. Common sense says that a gradual change in the intensity of the beam shining in will produce a gradual change in the beam getting out. Not the abrupt change that is needed. In ordinary circumstances, common sense would be right. In the case of the transphasor, it is not.

To make the Fabry-Perot interferometer into a switch, physicists hit on the idea of making it with a phenomenon known as optical bistability, first observed at Bell Laboratories in 1976. The secret is in the cavity between the mirrors, and if this were filled with an ordinary medium—air, say, or most solids—the intensity of the beam passing out of the mirror would, indeed, change in proportion to changes in the intensity of the beam shining in. Transphasors, however, use a family of materials (such as indium antimonide and zinc selenide) that are "non-linear". If a laser beam shines into these materials, a slight change in its intensity can trigger the wave-reinforcement and make the beam coming out of the transphasor suddenly brighter—and make it stay that way until the trigger is released.

Bell Labs and Heriot-Watt have made different sorts of transphasors, but they both work. Heriot-Watt's are entirely optical: the laser beams are shone into bistable plates made of zinc selenide. Bell Labs is trying a hybrid approach. Its devices, made of gallium arsenide, use electro-optical interference within the cavity to trigger the reinforcement effect. In an optical computer, these devices would be the "chips" and the "wires" would consist of laser beams.

To make a computer, it is not enough to be able to turn just one switch on or off. Computers are complex arrays of switches, each of which feeds signals into the next. So optical switches must be "CASCADEABLE"—the beams of light emerging from one transphasor must be able to flip the next, and so on. They must also be able to receive and send several signals at the
To speed this procedure, engineers are creating optoelectronic chips. To do so, they have had to conquer a disadvantage of the photon—its inability to carry an electrical charge. Packing signals off the end of an optical fibre demands some way to sort out waves of light and send them to different destinations. Electrons can be shunted by the application of an electric field; chargeless photons are impervious to such methods.

The answer has been to channel the light through "waveguides" etched into chips made of materials with unusual optical properties. These materials change their ability to conduct light when an electric field is applied to them. Using lithium niobate, engineers have been able to make a wide range of optoelectronic modulators, switches and other devices.

But there is another reason for wanting to bring the photon and the electron together: parallel processing. Britain's Plessey has developed a BOD in which the bistability comes from inserting a photochromic material—one whose chemical form changes when exposed to different wavelengths of light—into the cavity. Plessey believes the device could be used for parallel processing. The idea is to squeeze an array of BODs on a single two-dimensional plate. Each then becomes an independent switching centre that can be addressed simultaneously by an incoming laser beam (see diagram below).

This approach comes into its own in applications such as image-processing, in which the value of thousands of picture elements (pixels) must be individually calculated to build up a whole picture. Plessey aims to get around this data-processing bottleneck by using light to process all the pixels at once. The optical switches are not yet as fast as electronic ones, but that hardly matters when they work simultaneously. Plessey reckons that with its photochromic BOD, a device the size of a fingernail could process 4m pixels in one ten-thousandth of a second.

Photonics has come a long way in the quarter century since the arrival of the laser. But entirely new ideas for manipulating and exploiting light are still popping up. These range from the mundane (mechanical and biological sensors based on optical fibres) to the frankly quixotic (travelling to the stars by giving spacecraft sails that catch photons). Physicists have begun to use laser beams to trap individual atoms so they can be observed in detail. Engineers envisage massive computer memories with data encoded within the light waves of a hologram.

Why this sudden flowering? In the 1970s, physics made a wealth of discoveries about the ways in which light interacted with matter. These discoveries are now finding applications. The properties of non-linear materials—which made the transphaser possible—are one example, but there are others. In some circumstances, light travelling through a material sets up internal sound waves that contour themselves like a deformable mirror, sending the light backwards out of the substance on the path along which it entered. In 1973, Dr Boris Zeidovich and colleagues at the PNI Lebedev Physical Institute in Moscow used this property to make something called a phase-conjugate mirror.

This is no ordinary mirror: it can take an image that has been distorted and then straighten out the jumbled-up waves to reconstruct the original image. Like so many technologies, the mirror was treated as a laboratory curiosity at first. It is now being pressed into service by astronomers to take the twinkle out of stars, and by star-wars generals to shoot laser beams through the turbulent atmosphere. The mirrors can also be used to project three-dimensional images through optical fibres and to stick tiny components on microchips. One way or another, light looks like the wave of the future.
UNIVERSAL CONTROL FOR STEPPER MOTORS

With good quality stepper motors widely available at reasonable cost, this flexible, computer-driven, control board will make it rather hard to hold on to the belief that stepper motors are the exclusive realm of industrial electronics. If you are suspicious about "universal", just glance at the specifications Table below; if you are into industrial electronics, well...

Stepper motors: some problems

The following is a necessarily brief discussion of the main difficulties to be overcome when using stepper motors.

Limited speed range: the stator windings constitute an inductive load, which limits the commutation speed of the coil current. Also, the revolving permanent magnet rotor causes an inductive voltage which further worsens the commutation. These effects limit the maximum attainable step rate (also: pull-out rate), but can be overcome by utilising current drive control.

Resonance: the undamped character of a stepper motor operating at a relatively low step rate causes its movement to be rather halting. The upper oscilloscope trace in Fig. 1 shows the considerable overshoot after each step. Should the step frequency equal that of the underdamped oscillations, resonance inevitably occurs, causing a powerful, jerky movement of the spindle. Mechanical damping devices have been developed to ensure a smoother spindle movement, but these permanent loads typically cause the already low efficiency of the stepper motor to fall below the acceptable level.

The lower oscilloscope trace shown in Fig. 1 provides evidence for the proposition that micro-step operation can provide a marked improvement in linear spindle movement.

Stepper motors come in an astounding variety of types and sizes, and they are frequently spotted items in electronic surplus stores and on hobby venues. Sheer curiosity has prompted many a home constructor to purchase one at a fraction of its original price. However the number of wires coming from the device, and the fact that it is often found far more difficult to get going than a simple servo motor, more often than not causes the perplexed owner to carefully put his price possession in the junkbox, together with other "possibly useful" materials.

In Stepping Motors, Elektor India, May 1985, the general methods were examined for the driving of stepper motors. Also that article provides a useful discussion of stepper motor terminology, used further on in this article.

The main specifications of the proposed control board are summarized in the shaded Table on this page. The board is readily tailored to suit the user's requirement, but it should be made quite clear at the outset that each of the following sections to be read closely to be able to decide on the most favourable circuit configuration for a specific application. A detailed discussion of each of the technical features is, therefore, indispensable to a good understanding of the operation of this fully user-configurable interface board between computer and, for instance, robot limbs, a pantograph, or a plotter.

<table>
<thead>
<tr>
<th>Technical specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive capacity for motor types</td>
</tr>
<tr>
<td>one 4 phase bipolar type</td>
</tr>
<tr>
<td>two 2 phase bipolar type</td>
</tr>
<tr>
<td>one 6 phase unipolar type</td>
</tr>
<tr>
<td>two 4 phase unipolar type</td>
</tr>
<tr>
<td>Max output current</td>
</tr>
<tr>
<td>L293E fitted 1 A phase</td>
</tr>
<tr>
<td>L296 fitted 2 A phase</td>
</tr>
<tr>
<td>Software controlled polarity and 32 step current flow definition</td>
</tr>
<tr>
<td>Driver type</td>
</tr>
<tr>
<td>Switch mode current sources</td>
</tr>
<tr>
<td>Digital I/O</td>
</tr>
<tr>
<td>8-bit data input and 2-bit handshaking to Centronics standard</td>
</tr>
<tr>
<td>Supply</td>
</tr>
<tr>
<td>10...35 V with L293E fitted.</td>
</tr>
<tr>
<td>10...45 V with L296 fitted.</td>
</tr>
<tr>
<td>Regulation not required.</td>
</tr>
</tbody>
</table>
thus enabling the direct transfer of motor power via a set of gears.

Low efficiency, an energized stepper motor dissipates an amount of energy in the resistive load formed by its stator windings. When the spindle is held stationary, this resistance is the sole current limiting factor; also the stall torque is often needlessly high. Current drive systems may enhance the dynamic characteristic of the stepper motor to some degree, but linearly controlled current sources, unfortunately, exhibit a very low efficiency.

The present design is based on the use of high efficiency, switch mode current sources, thereby going round the problems associated with the previously mentioned systems. Also, the proposed current driver has the advantage of being uncritical of its input supply voltage; extensive regulation and smoothing circuits are, therefore, not required—an important fact in view of the possibility high currents involved in operating the stepper motor. As the current through the windings is fully programmable, the user can arrange for the overall dissipation of the stalled motor to be significantly reduced.

Limited resolution stepper motors are classified according to the number of steps per spindle revolution. Using the microstep mode, this specification becomes less important, and a specific type of motor can, therefore, be tailored far better to the task it is to perform.

Block diagram
After these preliminary considerations, it is time to have a look at the block diagram of the stepper motor control board—see Fig. 2. This design is in essence a quad bipolar power driver. Each driver consists of a bridge circuit and can supply both negative and positive output current from a single supply. Starting at the input side, it is seen that each driver comprises a latch and a D/A converter to enable programming the level and the polarity of the current fed to each individual stator in the stepper motor.

The switch mode current sources are essentially voltage-controlled pulsewidth modulators (PWMs), driven with the difference between the objective and the actual measured current. These two values are obtained from the D/A converter and a DC current sense amplifier, respectively. The four driving PWMs are synchronized via a common 40 kHz oscillator signal, which ensures a favourable switching frequency—the switch losses are still acceptable and the signal is audiable—as well as the absence of beat signals.

At the top of the block diagram, there are some more circuit functions common to the four drivers. An address decoder uses the two MS (most significant) bits to discriminate between...
Circuit diagram of the universal control for stepper motors. The choice between the L293E and L298 motor driver is left to the user.
between the control data sent to each of the four driver circuits: Provision has been made to use handshaking with the computer for optimum reliability of the data transfer to the board. A reference voltage source makes it possible to use D/A converters without an internal reference circuit. Finally, a 5 V supply powers all logic circuits on the board.

Depending on the application you have in mind for the stepper motor control board, this need not incorporate all of the previously introduced circuits. For instance, the relatively expensive D/A converters may be omitted if you do not envisage using the micro-step facility, but would still want to be able to program semi-step operation. The proposed board makes it possible to drive a four-stator system, even with two separate two-stator motors. It is possible to operate one motor in the micro-step mode, while the other one is controlled in the standard way, i.e. by means of a "stepped down" driver circuit. The user is offered a choice of two possible types of driver IC, which can be fitted as required by the expected output current. As you can see, our use of the word "universal" in the title of the present article is fully justified.

Circuit description

It is not very difficult to spot the various functional blocks in the circuit diagram, Fig. 3. As to the aforementioned common circuits on the board, ICs 3 is the 5 V regulator. ICs 40 kHz oscillator. ICs the one-of-four driver decoder, and zener diodes D17 and D18 may be used to provide DACs ICs-IC6 with a highly stable 2.5 V reference. On receipt of a computer-generated STB or STB strobe pulse, ICs decodes D15 and D16 in turn and enables the corresponding sextuple latch, ICs. IC3, to clock the 6-bit value which determines the output current level supplied by the driver (D6, D7) as well as the polarity (D5). Therefore, only five bits of the six or eight-bit DACs are used to translate the latch output into a voltage between 0 and 2.5 V in 32 increments (2). Each of the DAC output voltages is used to drive the inverting (+) input of opamps A7, A8, A9 and A10. How

determinate in turn are capable of determining the output current level. This design is necessary to study Fig. 4. From a functional point of view, the Types L288 and L298 from SGS Ats are largely identical; these devices merely differ in respect of the maximum available output current. The L288 is twice as powerful as the L2995 and is, therefore, housed in a Multimate-15 SIL enclosure, rather than a 20-pin DIL package as is the L293E. Each IC holds two independently controllable bridge circuits plus associated logic drive. Since these ICs are to be driven with logic voltages only, there would seem to be no way of controlling the bridge currents with a linear regulating system. However, in each driver the emitters of the lower bridge transistors are brought out to pins, enabling the connection of an external current sense resistor which provides a voltage drop proportional to the output current. (Fig. 5 further illustrates this principle, which forms the basis of the negative feedback controlled switch-mode current driver.

PWMs and current drive

In order to make clear the operation of the switch-mode current driver circuits in this design, it is necessary to study Fig. 4. From a functional point of view, the Types L288 and L298 from SGS Ats are largely identical; these devices merely differ in respect of the maximum available output current. The L288 is twice as powerful as the L2995 and is, therefore, housed in a Multimate-15 SIL enclosure, rather than a 20-pin DIL package as is the L293E. Each IC holds two independently controllable bridge circuits plus associated logic drive. Since these ICs are to be driven with logic voltages only, there would seem to be no way of controlling the bridge currents with a linear regulating system. However, in each driver the emitters of the lower bridge transistors are brought out to pins, enabling the connection of an external current sense resistor which provides a voltage drop proportional to the output current. (Fig. 5 further illustrates this principle, which forms the basis of the negative feedback controlled switch-mode current driver.

Any duty cycle of the current drive system starts with IC1 generating a 1 μs negative reset pulse for all four monostable multivibrators MMV1-MMV4. Taking MMV1 and the upper section of IC1 as an example, the reset pulse causes C1 to be discharged to the zener voltage of D14. Simultaneously, MMV2 is triggered, and provides an output pulse determined with network R10-C12, as well as the DC level applied to the control voltage input, pin 3. This level is internally compared with the voltage across C15 and hence determines the length of the output period. Since the comparator internal to the Type 556 MMV is incapable of linear operation with input control voltages below 1.5 V, D14 leaves sufficient residual charge in C14 for the MMV to produce sufficiently short output periods. From this it is seen that the MMVs in the circuit essentially function as voltage-controlled pulselength modulators, enabling the power output stages contained in IC1 and IC2 for the duration of their output periods.

Fig. 4. Internal organization of the SGS stepper motor drivers L293E and L298.
Therefore, current sense resistor $R_s$ carries the stator current and hence produces a proportional voltage drop, which is averaged in network $C_vR_s$ and raised in amplifier $A_1$.

Opamp $A_2$ compares the measured current ($-\text{input}$) with the object current ($+\text{input}$), and corrects its output voltage to MMVs until these two values equal. Simple as this may seem at a first glance, there is, however, a snag in the measuring of the stator current. As long as the bridge is enabled, stator current $I_s$ flows through $R_{sense}$, and its voltage drop is simply $I_sR_{sense}$ volts—see Fig. 5, line a. The disabling of the bridge immediately breaks the current through $R_{sense}$, but not that through the stator winding, whose inductance causes it to supply a lagging current, which is driven into the supply via free-wheeling diodes—see Fig. 5, dashed line b. In essence, the self-inductance of the stator winding has a smoothing effect upon the stator current. Therefore, the average value of $U_{sense}$ is not a direct measure for the stator current, since it does not comprise the free-wheeling current. With most types of stepper motors, the period $L/R$ of the stator winding is long as compared to that supplied by the PWM drivers ($T=1/40 \text{kHz} = 25 \mu s$). In practice, the variation in free-wheeling current in between driver pulses hardly causes any ripple, and the error incurred by only measuring the current through the sense resistor is, therefore caused by the duty factor variation. In general, a relatively small duty factor variation suffices to give a considerable stator current span. As soon as the duty factor rises above some 50%, and the free-wheeling period starts to overlap the bridge on-time, the lines remain relatively quasi-linear. The required duty cycle giving maximum stator current is a function of the ohmic resistance of the stator winding and the supply voltage level. The higher that voltage, or the lower that resistance, the stronger the tendency to large variations in $I_s$ around a 50% duty factor.

The foregoing considerations can not lead to the conclusion that the output signal of $A_1$ need not be exactly proportional to the stator current.

![Fig 5 Current flow during the bridge on period (a) and during the bridge off period (b, free-wheeling operation).](image)

Fortunately, the overall linearity is still acceptable, and occasional deviations can be compensated by suitable software.

Returning to the circuit diagram, Fig. 3, the remainder of the circuit functions are quite conventional designs. Timer IC1 provides the negative-going 40 kHz synchronisation signal for the R and T inputs of the MMVs. In the absence of a common sync signal, the input supply would be corrupted by a good many inductive voltage peaks, which would readily lead to the MMVs being triggered in error and the entire circuit operation being upset in consequence.

Network $R_1$-$D_1$ prevents 5 V regulator IC3 from being damaged by too high an input voltage. As the maximum input voltage for IC3 is 35 V, the use of the Type L298 stepper motor driver ($V_{max} = 45 \text{ Vpeak}$) necessitates firing the voltage limiting network. But even with the L298E fitted in the circuit, it is still a good idea to use $R_1$ and $D_1$, as they also afford protection against inductive voltage peaks on the unregulated supply rail. The use of the 2.5 V reference diodes $D_{1'}$ and $D_{1''}$ is not obligatory, and their use will be reverted to in the section on construction.

The logic sections of the circuit are composed of CMOS ICs. This means that the logic drive to the board must be capable of supplying CMOS-compatible signals. Should you want to drive the board with TTL signals from a Centronics port, the said CMOS ICs must be replaced by the suggested HCMOS versions.

**Construction**

Before embarking on the construction of the present board,
The type and the number of stepper motors must be considered in order to be able to decide on the most favourable as well as the most economical realization of the circuit. To begin with, there are the L293E and the L298 to choose between. The latter should be used with currents in excess of 1 A per phase. Two L298s can be bolted onto a common heatsink together with regulator IC1. As all conductive surfaces of these ICs are at ground potential, there is no need for insulating washers and the like. Relatively low output currents can be handled by the more economic Type L293E, which can be fitted in the IC1 and IC2 positions on the PCB. In most cases, the copper surface soldered to pins 5, 6, 15 and 16 of these chips provides sufficient cooling, while IC1 is best fitted with an insulated, standard U-shaped vane radiator. Should you decide to use a L29B8 for two stator windings, and a L293E for the other two, do not forget to limit the input voltage in accordance with the maximum specification of the latter. Depending on the type of output driver fitted, dimension R1 as per Table 1.

As already stated, the stepper motor current is fully programmable, but in order to attain optimum resolution in the microstep mode, the maximum value of I1 must be defined by means of selecting appropriate resistors in the R1 and R2 as well as in the R3...Rn positions —consult Table 2. As for IC4 and IC3, then fit a wire link in the holes provided for the two outer pins of the regulator As to the D/A converters, there are a number of types to choose from. In principle, the Type ZN436E gives satisfactory performance for most applications. Note, however, that it comes without an internal reference, so that D1 (D0) must be fitted, and R1 must be an IC2 type, while R3 must be omitted —consult Table 3. Jumpers c and d are not used, and jumpers e is fitted to pass the reference voltage to the REF IN pins of IC3, and IC1. The Type ZN426 x (the suffix indicates the
number of bits 6, 7, or 8) is also usable but is expected to be somewhat more expensive, as it holds an internal reference circuit, which can be used by fitting jumper c or d, depending on the position of the DAC on the board, and using a 390Ω resistor in the R6 or R7 position, whichever is appropriate. Should you want to do without the micro-step facility altogether, mount two 10k resistors as shown in Fig. 7. Completing the stepper motor control board is very straightforward indeed when using ready-made, through-plated PCB Type 37003 (see Fig. 5) available from our Readers Services. When using the L293E driver chip, solder it straight onto the board to effect sufficient cooling by the large copper surfaces at the track side of the PCB.

Connections
In general, the connection of bipolar stepper motors is fairly simple. A two-phase motor requires to be driven with one half of the control board circuit. The actual connection of the stator windings is largely unimportant. Reversing the polarity of one stator winding or interchanging both windings simply causes the motor to run in reverse. A bipolar four-phase motor requires to be driven by the whole of the control board. When using such a motor, observe the correct phase relationship between the stator windings, else the spindle will merely oscillate between two positions, rather, than revolve. Basically, unipolar motors can be connected in three ways, as shown in Fig. 8. The first method, shown in Fig. 8a, requires passing less than normal current through the series connected windings to preclude overheating and/or saturation effects in the stator. Also, the increased stator inductance causes a considerably lower pull-in rate. The second method involves creating a centre-tapped winding—see Fig. 8b. In principle, this arrangement always results in one half of the winding being short-circuited to the positive supply rail. As compared with the above method, there is the advantage of the lower overall inductance, but the short-circuited half-winding gives rise to an increased motor dissipation, owing to the inevitably high induced current, which is only advantageous in that it ensures good damping characteristics and hence a relatively smooth spindle movement. The last alternative is shown in Fig. 8c. This method of connecting a unipolar motor is based upon the use of the individual windings as if these were of the bipolar type. In case the two windings of a stator are not connected internal to the motor, anti-parallel connection is preferable. A normal, parallel connection immediately results in the magnetic fields counteracting, causing the spindle to remain stalled.

Provision has been made on the PCB to fit a 64-way, a & c row bus connector, K4. Its connections are left vacant to enable users to configure the bus wiring as required. At the other side of the board is K5, a 20-way angled plug which is used for the Centronics signals. Depending on the setup of the computer system in which the present board is to be incorporated, wires may have to be cut from K3 to K4 or K5 may be used for mechanical support. Those users intending to make a stand-alone peripheral device of the stepper motor control may want to cut off the PCB section provided for K5 altogether.

The power supply
As already stated, the present board is rather unusual in its input supply voltage. Extensive regulation and smoothing of the 12.35 (15) V input rail is not recommended in view of the overall system efficiency. When designing the power supply in question, merely observe that the ripple voltage does not exceed 10 to 15% of the output voltage.

It must be reiterated that the maximum permissible peak input voltage for the board depends on the type of badge driver IC fitted; for the L293E, Vmax = 45 Vpeak. For the L293E, Vmax = 45 Vpeak. In practice, it is recommended to keep the input voltage a few volts below these values to allow for the induced peaks caused by the free wheeling current. A second factor to be considered in the establishing of the supply voltage is the ohmic resistance of the stator windings in the stepper motor. As a rule of thumb, the supply voltage for the board must be at least two times the typical operating voltage of the motor operated with voltage drive. In principle, therefore, the most commonly available 5 V stepper...Fig. 8. Basic methods for the connection of unipolar motors.
motors should work all right with a board supply of 10-12 V, but a higher supply is preferable for improved current drive characteristics and hence a higher pull-in rate. The total current consumption of the system goes mainly on account of the stepper motor(s). Due account should be taken of the fact that the total current drain may amount to 8 A when using the board to drive 4 off 2 A stator windings. Obviously, the mains supply should be designed to reliably cater for possibly high current peaks, and the same goes for the supply wiring. Also observe the 2 times 4 contacts on K1, reserved for the connection of the input supply, keep the total current drain in mind and, if necessary, use soldering pins to avoid overloading the relatively thin connecting posts in K1.

### Driving stepper motors

As the stepper motor control board is essentially only a peripheral device, the computer—or more precisely the software—determines the movements of the stepper motor spindle. The key to the driving of the motor(s) is the 8-bit control word sent to the board via the computer's parallel output port. Fig. 9 shows the bit assignment for that control word. The two MS bits—Da and Ds—are used to address one of four stator drive circuits. Bit Ds provides the polarisation control, while Da-Ds determine the stator current in 32 (2^5) increments. Note that some Centronics output ports are open-collector types, requiring the data input lines and the STB line to be pulled high to +5 V with 470 kΩ resistors. Quite essential to the operation of the stepper motor is the stator current timing sequence. Fig. 10a shows the timing for full step operation, in which the stator current is arranged to reverse with every step. SEM step operation is illustrated in Fig. 10b; during the reversal of the stator current, this is held at nought. This basic method is further exploited in the quarter-step mode shown in Fig. 10c; while extrapolation of this principle leads to the stator current being reversed linear with time, as shown in Fig. 10d. In practice, however, the linear extrapolation is slightly problematic since the sub-steps at the current crossover point are inevitably larger than those during the start and the end of the commutation cycle. Moreover, the available torque will vary considerably during the sub-steps, as the total stator current is not constant. During the current reversal, a permanent load fitted to the spindle will cause the rotor to deviate more from the object position than during moments of maximum current, resulting in irregularity of the substep size. This effect is generally found to be rather more manifest with dual-stator motors than with four-stator types. Up to and including quarter-step operation, dual-stator motors have an adequate performance, but four-stator types are clearly to be preferred for all applications mentioned so far. The reason for this is the more constant average stator current of the latter motors. In conclusion, dual-stator motors are best operated with a constant total stator current, as shown in Fig. 10e. The commutation characteristic required for equal step size is mainly determined by the specific type of motor to hand, and some trial and error programming may be required to obtain optimum performance.

### Sending bits to the board

The simplest method of driving the stepper motor is probably the writing of a array which holds all data for a full commutation cycle. Such a cycle essentially involves once reversing the current, and reversing it again to return to the original polarity. In a four-stator motor, this corresponds to 8 full steps. A programmed pointer is used to send the data words to the board, and can be read, incremented or decremented to control the direction of the spindle rotation. To get the motor to run as required, the pointer is programmed to address the individual array entries in a closed loop. Table 5a is a data dump of an array to control a four-stator motor according to the timing diagram of Fig. 10d. Note especially the toggling of the

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**Table 4. Handshake configurations**

<table>
<thead>
<tr>
<th>port type</th>
<th>computer to board</th>
<th>board to computer</th>
<th>wire link or jumper</th>
<th>notes</th>
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<tbody>
<tr>
<td>Centronics</td>
<td>STB</td>
<td>ACK/BUSY</td>
<td>b (1); (2)</td>
<td></td>
</tr>
<tr>
<td>250 P10 (input mode)</td>
<td>READY</td>
<td>STROBE</td>
<td>a</td>
<td></td>
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<tr>
<td>6522 VIA.</td>
<td>DATA READY</td>
<td>DATA TAKEN</td>
<td>DATA TAKEN</td>
<td>(b)</td>
</tr>
</tbody>
</table>

(1) Pull up resistors may be required on board; see text.
(2) Use of ACK or BUSY is system dependent.
(3) Depending on the PCR register contents.
- pull mode; DATA TAKEN line not required
- handshake mode: DATA TAKEN forces interrupt, service routine outputs next byte after required delay.
Unfortunately, the fairly large number of sub-steps often makes it impossible for the motor to attain its maximum speed. In this context, there is no doubt about the advantage of machine language subroutines over BASIC programs. Should the need arise to have the motor run at a relatively high speed, it is possible to program for more than one step at a time. At high switching frequencies, the stator inductance limits the current to such an extent that accurate current drive and hence micro-stepping, is unattainable anyhow. However, this is of little consequence, since the motor will nonetheless run smoothly with the step rate well in excess of the resonance frequency. Micro-stepping is, therefore, primarily of use either for relatively low motor speeds, or for accurate spindle positioning.

When skipping array entries to realize sufficient motor speed, care should be taken to finish with the last byte of the relevant stator phase. Large steps should, therefore, always comprise sub-steps which are powers of two (2, 4, 8, 16 or 32 steps at a time).

Table 5a.

<table>
<thead>
<tr>
<th>M</th>
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</tr>
</thead>
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<td>00</td>
<td>3F 3D</td>
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<td>1B 19</td>
<td>02</td>
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<td>17 15</td>
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<td>13 11</td>
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<td>2F 2D</td>
</tr>
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<td>0F 0D</td>
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<td>2B 2A</td>
</tr>
<tr>
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<td>08 08</td>
<td>0A</td>
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</tr>
<tr>
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<td>07 05</td>
<td>0C</td>
<td>27 25</td>
</tr>
<tr>
<td>0E</td>
<td>03 01</td>
<td>0E</td>
<td>23 21</td>
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<td>21 23</td>
<td>10</td>
<td>01 03</td>
</tr>
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<td>18</td>
<td>11 13</td>
</tr>
<tr>
<td>1A</td>
<td>35 37</td>
<td>1A</td>
<td>15 17</td>
</tr>
<tr>
<td>1C</td>
<td>39 3B</td>
<td>1C</td>
<td>19 1B</td>
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<tr>
<td>1E</td>
<td>3D 3F</td>
<td>1E</td>
<td>1D 1F</td>
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Table 5b.

<table>
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<td>82</td>
<td>00 7B</td>
<td>82</td>
<td>10 AR</td>
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**Note:** The table represents hexadecimal data for one commutation cycle. Table 5a is for a four-stator motor operating as per Fig. 10d, Table 5b for a two-stator type operating as per Fig. 10e.
Digital circuits only respond to discrete values of input voltage and produce discrete values of output voltage. Usually, these circuits operate between two discrete voltage levels, i.e., high and low (logic) levels. It is therefore clear that before such a circuit can operate the analogue signals have to be converted into digital (= binary) signals.

Some fundamentals

Fig 1 shows the basic setup of a digital processing circuit. The incoming analogue signals at X are digitized, in an analogue-to-digital (A-D) converter, processed in a (digital) signal processor, and then reconverted into analogue signals in a D-A circuit.

The A-D converter produces a stream of binary values by quantization. In this method, the incoming waveform is divided into a finite number of subranges each of which is represented by an assigned binary value within the subrange. In a compact disc player, a 16-bit A-D converter is perfectly adequate, while in video circuits 8-bit converters are satisfactory.

Since the signal processor operates by computation, it can handle only a finite number of pulses in unit time. It is the task of the A-D converter to ensure that the input capacity of the processor is not exceeded, and thus in turn determines the sampling rate.

Sampling is a technique in which only some portions of the (analogue) input are used to produce the set of binary values to represent the information contained in the whole signal. To ensure that the output values represent the input signal without significant loss of information, Nyquist’s Sampling Theorem states that the rate of sampling of a periodic quantity must be at least twice the frequency of the input signal. A-D converters in CD players therefore produce about 45,000 sixteen-bit values for each second of music. The signal processor in these players need therefore be only moderately fast, as they have some 32 μs between consecutive computations. A video signal processor must be much faster, as this has to carry out more than 10 million computations per second.

Requirements and applications

The setup of Fig 1 can perform all the functions of an analogue circuit, and more. It is far superior to a complex combination of resistances and opamps in summing, subtracting, multiplying, and raising to a power.

For example, the volume setting in an analogue circuit involves the signal being attenuated by resistance(s), being distorted in transistors, being subjected to hum from the main transformer and finally being output by a scratchy volume control wiper. In a digital circuit, it is merely divided by a variable divider or multiplied by a variable factor. Filtering in a digital circuit is also simplicity itself, the basic operations of multiplication and addition enable virtually any kind of filter to be realized. Of course, the filter designer must be thoroughly familiar with filter theory, and Fourier and Laplace transforms. Apart from that, the filter can be adjusted, altered, and varied with the aid of software.

For instance, in a digital television receiver, the tuner is connected to the various output stages by digital circuits. These circuits filter (compute) from the video signal the sound and chrominance subcarriers, extract the quadrature components from these and demodulate them; cut off any noise pulses; eliminate any conversion errors and picture interference (within limits); arrange the volume of sound, stereo balance, tone, colour saturation, brightness, and optimum contrast. These circuits are currently contained in special VLSI chips.

As yet, there is no (pure) amplifier for CD players with direct digital input. But progress is rapid...

Signal processors

As already mentioned, virtually all requirements are met by the basic operations of multiplication and addition. Also, it was shown that the signal processor does not have all that much time left for each computation. Signal processors have, therefore, microprocessors with typical instruction codes; they are relatively small but, none the less, quite fast.

Some sequences such as: “fetch value 1; fetch value 2; multiply values 1 and 2; add value 1 to the result; load the accumulator at the position of value 1 and increase the address counter,” as a rule have only one operational code. Moreover, while an instruction is being processed, the next instruction and the next two values are retracted from the memory (pipelining). This means that such an instruction takes three clock pulses from start to finish. With a 10 MHz clock, a 16-bit multiplication and addition lasts only 300 ns.

Even faster are signal processors that use the Harvard instead of the von Neumann architecture. In the latter, data and instructions are stored in a common memory, whereas in the former separate memories are used (see Fig 2). In Harvard-type processors, instructions and data (in some even two sets of 16-bit data) are fetched from the memory simultaneously. This means that two to three times as many operations can be carried out per second as compared with a von Neumann device.

The software for the required function is first computed and loaded into a normal computer, with which the run of the processing cycle is simulated before the PROM of the signal processor is loaded.

To conclude, and especially for
those readers who want to design a digital filter and are not too familiar with Fourier or filter theory, a sample design for a personal computer.

Basically, there are two types of filter: recursive and non-recursive. Figure 3 shows an example of the simplest type of recursive filter, where the output signal is available for further use in a successive cycle. This type of filter can be used for high- or low-pass purposes. Non-recursive filters are formed by inserting the input signal(s) into two or more successive filter sections as shown in Fig. 4. Each section must, of course, have a secondary memory. This type of filter is suitable for use as a transverse or comb filter.

A low-pass filter is easily computed from the following mathematical relation

$$ y(t) = ax(t) + by(t-1) $$

where $y(t)$ is the output signal resulting from an input signal $x$ at time $t$; $y(t-1)$ is the output signal one computing cycle before $y(t)$.

The following example program was written in GFA BASIC for the Atari ST. If the GFA interpreter is not available, the Run Only Version can be copied (free of charge) at any Atari dealer. It can, however, be modified for use with other types of computer relatively easily, particularly if Pascal is used.
This article deals with a remarkable combination of versatile hardware and ingeniously written, learn-as-you-program, software. The BBC Buggy is a computer-controlled little robot with some quite astounding capabilities.

Although this series of articles is primarily intended to discuss commercially available software packages for the BBC micro, it was deemed worthwhile to introduce the BBC Buggy and its associated control programs to the many owners of a BBC home micro.

Available from Economics’ Education Division, the Buggy is in essence a small vehicle, composed of Fischer-Technik parts, and controlled over a length of flat ribbon cable connected to the standard peripheral port on the BBC machine.

The principle of a steerable turtle, known from interactive programming languages such as LOGO, has been put into practice in the case of the Buggy, as it is a tangible vehicle rather than any kind of graphics figure moving about on the screen and programmed to make drawings by means of a set of user-definable commands. In principle the Buggy is therefore but a tool in learning about structured programming. However, the fact that it is a precisely engineered vehicle offers possibilities not currently available with simulation-based (joystick & screen) systems.
The Buggy hardware

It would be beyond the scope of this article to give a detailed description of the Buggy's construction; the accompanying photographs should give readers a good impression of what the vehicle looks like.

Two powerful stepper motors, controlled via a top-mounted interface board, ensure a high degree of positional accuracy at a remarkably low programming effort. The Buggy can carry a pencil to leave a trace as it completes its task route; the main-driven wheels and the rear-mounted ball bearing enable the Buggy to revolve around its own axis, leaving only a dot on the electromagnet operated pencil as the wheels revolve in opposite directions.

 Provision has been made for the incorporation of a large number of optional hardware add-ons, such as a grab arm, a bar-code reader (BCR), and a front-mounted light-dependent resistor (LDR), which can be used to track down light sources. The fully equipped Buggy is an agile, semi-intelligent creature that can find and remember its own way through almost any 'landscape': no matter how many purposefully created obstructions it encounters while seeking its way to the finish.

The grab arm is a stunning example of the combined power of the Buggy hardware and software; the control program, through a digitizer, monitors the current consumption of the grab arm motors, and thus prevents lifted objects from being crushed. Actually, the Buggy was tested by having it lift, carry, and put down an egg without making a mess of it.

The optional BCR enables the Buggy to travel over a track consisting of one metre or so of bars which may represent, for instance, the notes of a piece of (computer) music; the BCR system is comparable to that used for the digital reading of note data printed on many shopping items. However, since the Buggy travels at a highly accurate speed, no synchronization bars are required in the coded pattern. A few try-outs showed quite conclusively, however, that the Buggy can be relied on to supply 100% faultless BCR data to the computer. It is also possible to have the Buggy read its route directions from pieces of BCR strip located at a few places in the landscape.

The Buggy software

Whatever the performance of the Buggy's hardware, the vehicle would be but a clumsy toy without the supporting software Economatics. In our view, this vehicle deserves credit for the production of software that is, in a word, unbeatable even by experienced machine language programmers. The BBC BASIC Interpreter is exploited to the full, and the same goes for the graphics features of the machine. The Buggy command set comprises 10 simple to program instructions, while the user is free to add his own for specific purposes. PEDIT can be loaded from disk to support the use of the software-controlled pencil; again, the degree of accuracy achieved with the Buggy's propulsion system is astounding with some skill in programming, writing one's name on a sheet of paper is feasible.

The programs supplied by Economatics are user-friendly and readily extendable for specific purposes. Most instructions relating to the Buggy's movements can be defined in the necessary number of incremental steps; e.g. 128 steps FORWARD, TURN 3° LEFT, SPEED=70%, etc. Economatics supply a copiously detailed instruction manual with the Buggy; a large number of highly instructional programming examples are given, as well as a step-by-step construction method for the fully fledged version of the project.

Applications

As already noted, the main interest for the BBC Buggy lies in the educational field. The fact that a tangible vehicle can be seen to move about with apparent intelligence is highly stimulating to further exploration of programming methods. The Buggy therefore comes in when screen-based turtles fail to arouse further interest in writing structured programs leading up to sophisticated applications in the field of robotics and its associated science, cybernetics.

The so-called Buggy Park is an outstanding example of the resourcefulness of Economatics in devising a bench-mark for other remote-controlled vehicles: in essence, the park is a rectangular space bordered by a "wall"; the instruction manual gives full details of the suggested construction, as well as of the way the exact size of the park is entered in the relevant control program. SUNSEEK can be run to show the Buggy's ability to track down a small light source located anywhere in the park: neither the placing of the bulb, nor the raising of obstructions during the performance will keep the Buggy from finding and remembering its way to the light. On arrival there, a triumphant cry is produced.

Sceptical onlookers can be invited to a game of MAN VS BUGGY, which effectively demonstrates the skill of the latter in finding a particular location within an area relying on limited sensors (LDR, touch-sensitive bumpers) only.

Conclusions

The BBC Buggy is a most instructive extension of the BBC computer: its hardware and software operate in a purposeful manner, ensuring both optimum processing of instructions and ease of extension by the user. The BBC Buggy comes as a Fischer-Technik Kit, together with the associated software and instruction manual, and requires no special tools for assembling. More information on the BBC Buggy and its hardware and software options are available from Economatics Education Division, 4 Orgeave Road, Handsworth, Sheffield S13 9JQ.

Buggy: £129.98; PEN Kit £19.85; Grab Arm £79.00.
Good control with high power

**precision power supply**

Any item of test equipment is useful but only one is absolutely necessary and that is some form of power supply. These normally provide a voltage output of up to 25 or 30 volts at about 1 amp which is fine for most purposes. However, this current level can be rather limiting when testing computers, audio amplifiers and other high power equipment. It is essential too that some form of protection such as current limiting is included in the circuit design. The precision power supply here is capable of providing up to 3 amps at 36 V and incorporates both current limiting and short circuit protection. Meters are included to enable current and voltage output levels to be monitored.

Although the last two points are not strictly necessary, their inclusion makes the power supply more versatile and easier to use. The precision power supply here follows the standards set by commercial equipment and includes all of the above features. It has a variable output voltage range of 0 to 35 V and continuously variable current limiting up to 3 amps. The performance is on a par with fairly expensive commercial power supplies but approaches the stabilisation problems with a rather novel circuit design.

**The principles**

The vast majority of power supplies use either 'series' or 'pass' regulation. This means that the stabilising power transistors are connected (effectively) in series or in parallel to the load. In common with most designs the circuit here utilises series pass regulation. The originality in the circuit design is the method used for stabilisation. The block diagram in figure 1 illustrates the principle of a conventional series regulator. The active element of the cir-
circuit is opamp A and its output is the source of the load current, that is, in series with the load RL. The non-inverting input of the opamp is held at a reference voltage, Uref. The inverting input of the opamp is at a voltage level that is a proportion of the input voltage—derived by potentiometer P. Under these conditions the output of the opamp will become stable at the point where the voltage difference between the two inputs is zero. That is, the opamp will maintain a condition where the reference voltage and that at the wiper of potentiometer P are equal. It will be obvious that the output voltage will therefore be dependent on the position of P. With the potentiometer in mid-position the output will be double the reference voltage. The disadvantages of this system are that the stability factor is dependent on the setting of potentiometer P, the output can never be lower than the reference voltage and the operation of P will not be linear. Two of these points may not be so significant in some cases but an output minimum that is restricted to the reference voltage will be embarrassing to say the least!

The block diagram of figure 1b provides another solution. In this case, the opamp is used as a unity gain amplifier and P becomes a voltage divider connected across the reference voltage. The output of the opamp will now be proportional to the voltage level at the wiper of P.

In this configuration the output range will be between 0 and the reference voltage. This sounds better but it is still far from ideal. The opamp will now require a negative voltage supply rail, an added disadvantage.

The reference voltage must be at least as high as the maximum required output, not an ideal situation! Finally, the stability factor is still a question of potentiometer P.

Figure 1c goes a long way towards removing the problems by replacing the reference voltage, as far as the opamp is concerned, with a reference current. The output voltage is now determined by the current passing through P. The advantage is that the circuit is no longer dependent on the reference voltage level.

We now arrive at figure 1d which, in principle, is very similar to 1c. The reference current in this case is derived from the output voltage via a series resistor R. The idea is not entirely new but the method used here is a little unorthodox.

As previously mentioned, a current source is achieved by placing a resistor in series with a reference voltage derived from the output. However, for this to happen in practice, the value of potentiometer P has to be much lower than R. The opamp still tries to balance out the difference between the voltage levels at its inputs but now the output voltage will be equal to the level on its non-inverting input.

The series resistor is effectively placed between the two inputs of the opamp. However, due to the high impedance of the inputs, theoretically at least, no current can enter the opamp. In effect then, the current derived from the reference source follows the path shown as a dotted line in the block diagram. Since \( U_1 = U_2 \) (the opamp ensures this) the current level remains constant, totally independent of P and the load. The current level is equal to \( U_{\text{ref}} \). The opamp will balance out the voltage across P and, in doing so, the reference current is compensated for any change in load. The result of all this is that the circuit conforms to what we are looking for, a constant reference current (even at 0 V) using a reference voltage source and a resistor.

The precision power supply

The major difference between the block diagram of the precision power supply in figure 2 and that of figure 1d is the fact that two opamps and a series pass power transistor are included. The current source \( U_{\text{ref}} \) and R and the potentiometer P1 are very similar.

The second opamp A2 is responsible for output current limiting. The voltage across the emitter resistor \( R_e \) of transistor T is proportional to the output load current. A proportion of the reference voltage is derived by the setting of P2 and this is compared to the voltage across \( R_e \) by opamp A2. When the voltage across \( R_e \) becomes higher than that set by P2, the opamp reduces the base drive current to T until the difference is reduced to zero. The LED at the output of A2 functions as a current limiter.

The circuit diagram

So much for the theory, now for its practical application. The circuit of the power supply, shown in figure 3, has two independent power supplies (if that makes sense!). The power for the output stage is provided by transformer Tr2 which, of necessity, will be rather a hefty beast. Transformer Tr1 provides power for the reference source and the opamps.

The reference source is derived with the aid of the inevitable 723 (the worlds longest living chip!). The components

![Figure 1. The drawings here, in conjunction with the text, illustrate the advantages of why the use of a constant current reference source is preferable to a reference voltage.](image-url)
around this IC were chosen to provide a reference voltage of 7.15 V. This appears at the junction of R1/R5, R15/R16 and R9. For ease of understanding it should be noted that R4/R5 represents R and IC2 corresponds to A1 in the theoretical diagram of figure 2.

The reference voltage eventually arrives at the non-inverting input of IC2 (pin 3) while the inverting input is connected to the zero rail via R6. Diodes D2 and D3 are included to protect the inputs of the opamp against surge voltages. The output of IC2 controls the power output stage, consisting of transistors T3, T4 and T5, by providing the base drive current for transistor T2.

A word about transistors T3...T5. These are connected in parallel and their outputs are combined via emitter resistors to provide the power supply output via R21. This resistor is the practical counterpart of R in figure 2. The use of three 2N3055's in this configuration provide an economical power stage that can handle up to 3 amps comfortably.

The voltage across R21 is compared in IC3 with a voltage level determined by the setting of P2. This latter is derived from the reference source via R15/R16. The output of IC3, like that of IC2, is fed (via D5) to the base of T2. When the output current is higher than that set by P2, the output current is reduced by IC3 until the two levels are matched. Transistor T1 and its surrounding components cause the LED D7 to light when current limitation is in effect.

Two meters are included to allow direct monitoring of both voltage and current levels at the output. Each meter is provided with a series potentiometer, P3 and P4, to allow for fine calibration. These can be replaced with fixed resistors if desired once their values have been found.

Capacitor C3 in the reference voltage circuit (IC1) serves two functions. It reduces any noise produced by the internal zener of the 723 and it also provides a 'slow start' for the reference voltage supply. This means that when the power supply is first switched on, the opamps are giving time to 'settle down' before being asked to do any work, a sort of early coffee break! If this slow start was not designed in it could possibly allow the maximum voltage level to appear at the output, albeit very briefly, but still potentially damaging.

The diodes D1 to D8 in various parts of the circuit are included to guard against the possibility of accidental connection of an external voltage to the output terminals of the power supply when it is switched off. For instance, this could quite easily occur when working with a circuit that has a built in battery back-up.

Components R7 and C6 increase the reaction time of the circuit when changing output voltage levels while capacitors C7 and C8 eliminate the possibility of oscillation in the opamps. For stable operation of the circuit a minimum
Figure 3. The circuit diagram of the precision power supply. Resistors R4/R5 correspond to R in figure 2. IC2 to A1, IC3 to A2 and R21 to R4. Of the two transformers, Tr1 provides the supply for the reference current source while Tr2 supplies the power for the output stage.
Figure 5. The track pattern and component layout for the printed circuit board used for the precision power supply.
output load resistance is necessary. This is taken care of by R22.

It will be noted that there appear to be more output terminals than the usual power supply needs. The two extra outputs, +V_s and -V_s, are in fact inputs. These so-called 'sense' inputs are used to allow for voltage drop compensation when working with long connecting cables between the power supply and its load. Figure 4 illustrates how the inputs are used. Two extra wires are connected as shown between the load and the sense inputs. The result of this is that the supply voltage level is now effectively measured at the load and not at the output terminals of the power supply. This enables the circuit to compensate for any voltage drop resulting from the resistance in the main supply cables. It should be noted that if the total resistance of the two main supply cables is 1 Ω, at the current level of 1 A the voltage drop will be 1 V. In normal use,
shorting links can be placed between +U and +Us, and -U and -Us.

**Construction**

The maximum output current of the circuits as shown here is 3 A at 35 V but in principle different current ratings are possible. It must be remembered that any change in this direction must be accompanied by a change in the ratings of both C9 and C10. The limiting factor is the maximum collector/emitter voltage capability of transistors T2...T5. This is 60 V for the 2N3055. The other deciding factor will of course be the current rating of the transformer for the power output stage. The maximum output of the power supply is a factor 1/\sqrt{2} of the current supplied by the transformer which explains why a 4 A transformer is required to achieve an output of 3 A.

The three power transistors in parallel are used because each 2N3055 cannot dissipate more than 50 W. The consideration is that when the output voltage is at 0 V the maximum dissipation required is the maximum level of the rectified voltage multiplied by the maximum current. For an output of 1 A at 35 V only one 2N3055 would be sufficient. One more power transistor can be added without any modification to the circuit providing that the correct value for the emitter resistor is calculated. A 2°C/W heatsink is needed for each power transistor or a 1°C/W for each pair. Capacitor C12 is mounted directly onto the output terminals as shown in figure 6.

Do not mount the resistors R4 and R16 initially as their value will depend on the maximum output voltage and current. For this reason it will not be possible to mount the printed circuit board into the case until test and calibration is completed. Set P1 to maximum, switch on and connect a multimeter to the output of the circuit. By trial and error find the actual value of H4 which gives the maximum required output voltage. This can be done by connecting different resistors in parallel to R5. When the correct value has been found it can be soldered in place on the board. Repeat the exercise with P2 and R16 (in parallel with R15) until the maximum current level is found.

The remaining calibration is that of the meters by adjustment of P3 and P4. It is possible to build the power supply using only one meter. In this case a 2 pole 2 way switch connected to points x, y and z is required to switch between volts and amps.
The printed-circuit board (No. 88083-Fig. 5) needs to be completed with perhaps more care and attention than usual for two reasons. Firstly, the clock in the RAM and the A-D-converter operates at a fairly high frequency, so that neat soldering is a must. Secondly, the attenuator section should be constructed and screened neatly, since this determines to a large degree the overall accuracy of the circuit.

Fig. 6 shows the component layout of the PCB since the board is double-sided with through-plated holes (see also p. 83 of last month's issue). It is advisable to check all such holes with a multimeter before any work is done; if the through-plating of a hole is not sound, it is a difficult job to locate this after the board has been completed. Readers not familiar with this type of board should note that soldering needs only to be carried out at the underside of the board. It is best to begin with the mounting of the IC sockets. After these have been soldered in place, mount the resistors, capacitors, preset potentiometers, and trimmers. Take care with the trimmers, because these often have no value printed on them. Finally, fit the 16 MHz crystal. The completed board is shown in the photograph in Fig. 6.

Next, a screen should be made for the attenuator section. This is cut from 0.5 mm thick tin foil, about 15 mm wide and 400 mm long. This strip is folded as shown in the photograph in Fig. 7 to fit around the attenuator section. The foil is soldered in a few places to pins that have been inserted in appropriate islands on the board. Once the attenuator has
been preset, the top of this section should also be closed with a suitable lid of tin foil. The screen ensures that the input circuit is rendered insensitive to noise.

The board can then be fitted in a suitable enclosure as shown in the photograph at the head of this article. Apart from this board, the enclosure will also house a simple mains supply. This supply, which delivers ±5 V, is constructed on the PCB shown in Fig 9: its circuit is given in Fig 8.

The front of the enclosure should be fitted with two BNC sockets: one for the measuring input and the other for the external trigger input. The rear panel should be provided with an exit for the ribbon cable to the computer and an inlet for the mains cable.
Connecting the computer

The drive unit is connected to most computers via a suitable adapter to enable the data communication between the two units to be controlled. An exception is the BBC Micro, because the program for this computer makes use of the printer port and the user port. The latter serves as the B port and the former as the A port, the READY signal from the drive unit is fed to the ACK input. The connection diagram for this set-up is given in Fig. 10.

The C64 and Electron computers are connected to the drive unit via a PIA (peripheral interface adapter) Type 6821. The connections to this are shown in Fig. 11. It is conveniently
constructed on the small PC board shown in Fig. 12. The board can be inserted direct into the C64, when it is to be used with the Electron, the connector part may be cut off. The Electron is connected to the PIA as shown in Fig. 13. in this case, an address decoding signal has to be generated with the aid of two additional gates as shown. The PIA is at address FC8. Finally, the Electron is connected to the drive unit with the aid of a free connector and a length of ribbon cable. Note that the cable between the drive unit and the PIA should be kept as short as is practicable.

Connection between the drive unit and MSX computers needs a somewhat more extensive I/O board, which is planned to be published in a future issue.

Setting up

In the setting up of the drive unit, an oscilloscope is needed. First connect the drive unit to the computer as detailed above, and switch on both units.

Next, if either the BBC or the Electron is used, write the test program given in Table 1 or 2 respectively into the computer; if the C64 or an MSX unit is used, a couple of POKEs is all that is required.

Connect the input of the drive unit to ground, and adjust F until the output voltage at the output of op amp A, (pin 6) is 0.00 V.

Next, inject a 1 kHz square-wave signal into the drive unit, and set the input sensitivity (lines V-V) to 0.000 V. Adjust trimmers C3s and C5s to obtain a true square-wave signal at the output (pin 6) of A.

Set the input sensitivity (lines V-V) to 0.001 and adjust C6s to regain a proper square wave at pin 6 of A. Repeat this procedure with sensitivities of 0.010, 0.100 and 0.1000 when C9s, C13s and C14s are respectively adjusted.

At all times, adapt the level of the square-wave input but take care to avoid overloading the circuit (the level at pin 6 of A should not exceed 5 V).

Redo all the adjustments mentioned to make sure that all settings are correct.

With the aid of a voltage divider (made from 1% resistors, e.g. 22 Ω and 2kΩ, or 82 Ω and 10kΩ) derive a voltage of 40.0 mV from the power supply, and apply this to the junction Rs+Rm.

Set the signal on lines OFs-OFs to
Software

First, the PIA (if used) is initialized. Make the RESET line low, which results in all the PIA registers to be set to nought. The adapter occupies four addresses I/O to 1/O+3 incl. (see Fig. 14). Two of the locations have consecutive registers and are selected by making bit b2 in the associated control register 1 (data register) or 0 (data direction register).

Select DDRA as shown above and write FF in this register all A ports are then set as outputs. Then write 65 in CRA which results in input CA reacting to a leading edge, as well as data register DRA being selected. It is then possible to write into this register, for instance, 18 which pulls the PB line high.

The B ports are arranged as outputs by making control register B logic low, and writing FF in DDRB. They are set as inputs by making bit b4 in CRB 0, and writing a 0 into 1/O+4 and 4 into 1/O+3.

Arrange the A and B ports as outputs; disable the interrupts; and set the interrupt flag (bit 7 of data register A) to a leading edge at CA.

A timing diagram of all important control signals is given in Fig. 15; this gives a good idea how communication between drive unit and computer takes place.

All PA lines are made 0, after which the data for setting the interface can be written into the latches via the PB.

Table 1.

| 10 MODED | 20 dra = 6FCB1.ddra - 6FCB1.cra - 6FCB2.drb - 6FCB2.crb - 6FC01.drb - 6FC01.crb - 6FC01.cra - 6FCB0.ddra - 6FCB0.cra |
| 30 OFF = 0 | 40 OFF = 0 |
| 50 OFF = 0 | 60 OFF = 0 |
| 70 OFF = 0 | 80 OFF = 0 |
| 90 OFF = 0 | 100 OFF = 0 |
| 110 IFTRIG = 2 THEN dra = 630 |
| 120 IFTRIG = 2 THEN dra = 630 |
| 130 IFTRIG = 2 THEN dra = 630 |
| 140 IFTRIG = 2 THEN dra = 630 |
| 150 IFTRIG = 2 THEN dra = 630 |
| 160 IFTRIG = 2 THEN dra = 630 |
| 170 IFTRIG = 2 THEN dra = 630 |
| 180 IFTRIG = 2 THEN dra = 630 |
| 190 IFTRIG = 2 THEN dra = 630 |
| 200 END |

Table 2.

| 10 MODED | 20 drb = 6FCB0.ddra - 6FCB0.cra - 6FCB1.cra - 6FCB2.drb - 6FCB2.crb - 6FCB0.ddra - 6FCB0.cra |
| 30 OFF = 0 | 40 OFF = 0 |
| 50 OFF = 0 | 60 OFF = 0 |
| 70 OFF = 0 | 80 OFF = 0 |
| 90 OFF = 0 | 100 OFF = 0 |
| 110 IFTRIG = 2 THEN dra = 630 |
| 120 IFTRIG = 2 THEN dra = 630 |
| 130 IFTRIG = 2 THEN dra = 630 |
| 140 IFTRIG = 2 THEN dra = 630 |
| 150 IFTRIG = 2 THEN dra = 630 |
| 160 IFTRIG = 2 THEN dra = 630 |
| 170 IFTRIG = 2 THEN dra = 630 |
| 180 IFTRIG = 2 THEN dra = 630 |
| 190 IFTRIG = 2 THEN dra = 630 |
| 200 END |
Fig. 13. This shows how the Electron is coupled to the PIA. The two ICs for the additional address decoding are not provided for on the PIA board.

Fig. 14. The registers of the PIA.

<table>
<thead>
<tr>
<th>I/O</th>
<th>DRA: Data register A</th>
<th>DOR: Data direction register A</th>
</tr>
</thead>
<tbody>
<tr>
<td>I/O + 1</td>
<td>CRA: Control register A</td>
<td></td>
</tr>
<tr>
<td>I/O + 2</td>
<td>DRA: Data register B</td>
<td>DOR: Data direction register B</td>
</tr>
<tr>
<td>I/O + 3</td>
<td>CRB: Control register B</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 15. Flow diagram of the program that produces the picture on the screen, effects the control via the keyboard, carries out the necessary computations, and communicates with the PIA.

Fig. 16. Start

1. Initialize PIA
2. Write and process parameters
3. Adapt picture information
4. Everything written?
   - No
   - Yes
     - Wait 256 clock pulses
     - Enable trigger
     - Oscilloscope: Ready?
       - No
       - Yes
         - Read page 1
         - Read page 2
         - Search trigger point & process data
         - Plot picture
ports. These data relate to the time base; the offset; the trigger level; leading- or trailing-edge triggering; selection of input sensitivity; and selection of AC or DC inputs. Note that PAo to PA9 incl. are used here as clock signals. See also under Control signals in Part 1. Tables 3-8 show the correlation between data and selected settings.

The PB ports are then set as inputs; PA0 is made logic 0; and PA9 is briefly made logic 1. This results in the offset data in the DA converter being read.

Next, make the PA line high, which creates a waiting period of at least 256 times the selected time base. This ensures that the first memory page no longer contains old data. Make the PA line (INH) logic high, which results in the digitized input signal being compared with the set trigger level. As soon as these levels are equal, the highest data bit in the RAMs is set 1 (which makes it possible later to determine exactly where triggering took place); the RAM counter is reset; writing is discontinued; and the circuit pulls the READY line (CA1) high to indicate to the computer that the two RAM pages are full. The computer then makes lines PAo and PA9 logic low, which results in the READY line being pulled low. The computer can then read the RAMs.

First, however, the PA line is briefly made 1 to reset the RAM counter to nought, so that the first memory location can be read immediately. After this, CPU1 pulses on PAo enable the data of successive addresses to be read at each leading CPUL edge.

After the first memory page (256 bytes) has been read, make PA9 (INH) high: this serves as the eighth address bit for the memory. Subsequently, the second page of 256 bits is read in a similar manner. All data can be stored or processed immediately, depending upon the available memory.

Finally, new data may be written (with the PB lines arranged as inputs). A pulse on the PA line will cause the offset data in the DA converter to be clocked. Making the PA line high will cause the PA line to start again with writing into the first memory page. After an interval of not less than 256 time base clock pulses, the trigger may be enabled again.

As stated in Part 1, complete programs for the Acorn Electron, the BBC Micro, the Commodore 64, and MSX machines are supplied with printed-circuit board 86083.

To enable owners of other makes of computer to compile their own program, a flow diagram of the program is given in Fig. 16. The quality of the screen image will depend largely on the resolution of the computer.

First of all, the location on the first memory page where the trigger bit (D7) went high must be determined. The next location is the first for a complete picture, from which the whole page may be read. The second page can be started at the first location, since all data there are in correct sequence.
Why should anyone construct an ohmmeter, when every multimeter has several resistance ranges? True, the multimeter has many ranges for resistance measurement, but the higher end of the resistance scale reads the values very poorly. Due to the nonlinear scale, the values at the higher end are very closely spaced while the values at the lower end are widely spread.

In case of the linear scale ohmmeter, the divisions are equispaced over the entire scale. This advantage is due to the small I.C. OpAmp used in the measuring circuit.

The Circuit

A simplified schematic diagram of the linear scale ohmmeter is shown in figure 2. The actual circuit is shown in figure 3, which looks much more complex than it really is. First let us concentrate on the circuit shown in figure 2. The main component of the circuit is the OpAmp IC1. IC1 contains a multistage differential amplifier circuit. A differential amplifier amplifies the voltage difference between its two inputs. The voltage on the non-inverting input (+) increases the output voltage, whereas a voltage on the inverting input (-) reduces the output voltage. The gain of such amplifiers is a few hundred thousands. Gain of one hundred thousand means that a difference of 10 microvolts at the inputs gives rise to 1 Volt at the output.

A voltage divider made of Rx and R is connected across the output and the voltage at the interconnection of Rx and R is fed back to the amplifier at its inverting input. This is known as negative feedback. This has an effect on the circuit which makes the voltage on the inverting input practically equal to that on the non-inverting input. To understand exactly what happens, let us...
consider a hypothetical experiment. Assume that the voltage on the non-inverting input rises from 5.6 to 6.6 V, i.e., 1 V. The output voltage will try to increase by 100000 V. The voltage on the inverting input will also simultaneously try to rise depending on the ratio of Rx and R. This in turn will try to bring down the output voltage. The result of this will be that the voltage on the inverting input will also rise to almost the same voltage which is on the non-inverting input.

In case of the linear scale ohmmeter circuit, the input voltage on the non-inverting input remains constant at 5.6 V. The voltage across R is thus fixed at 5.6 V as we have already seen in the above experiment. This means that the output voltage at the output of the amplifier depends entirely on the value of Rx. The relation between these values can be calculated as follows:

Voltage on R = 5.6 V
Voltage on Rx = Uout

\[ U_{out} = \frac{R + Rx}{R} \times 5.6 \text{ V} \]

Which clearly shows that Uout is directly proportional to Rx if the constant value of 5.6 V is taken care of during calibration with Rx = 0. To take care of this, the meter is placed on the non-inverting input of the actual circuit, so that the voltage of 5.6 V does not play any part in the measurement. The zener diode produces the stable input voltage which is supplied to R5. The output voltage is measured through the combination R6 - P1 - M1. The diode D2 protects the meter M1 from very high voltages, which can occur when the ohmmeter is connected without a test resistance.

The R6 - P1 - M1 combination can be replaced by a multimeter in the 1 V or 2.5 V range. The measuring range of the ohmmeter is selected through switch S2. Resistances R1 to R4 substitute the resistor R from our simplified circuit of figure 1. The four ranges are described in table 1.

<table>
<thead>
<tr>
<th>Switch Setting of S2</th>
<th>Full Scale Deflection Resistance Value</th>
<th>Measuring Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1MΩ</td>
<td>10μA</td>
</tr>
<tr>
<td>2</td>
<td>100kΩ</td>
<td>100μA</td>
</tr>
<tr>
<td>3</td>
<td>10kΩ</td>
<td>0.1mA</td>
</tr>
<tr>
<td>4</td>
<td>1kΩ</td>
<td>1mA</td>
</tr>
</tbody>
</table>

The Power Supply for the linear scale ohmmeter is formed by two 9V batteries. The current consumption is around 10 mA and the battery life is very long.

You must have already noticed by now that the circuit functions on the basis of a constant current source. As the voltage on R (or R1/R2/R3/R4) always remains constant at 5.6 V, the current through R = Rx combination also remains constant. Thus the voltage across Rx is always given by the following relation:

\[ V_{Rx} = \frac{5.6 \text{ V}}{R} \times Rx \]

As the value of \( \frac{5.6 \text{ V}}{R} \) is constant, \( V_{Rx} \) is always proportional to \( Rx \).

Construction

As usual, the mechanical work involved in construction is much more compared to the job of soldering the electronic components together on the PCB. The mechanical work can be simplified by using a plastic enclosure, which is easier to handle than metal enclosures. Suitable holes must be drilled in the lid for sockets, switches S1, S2 and the meter M1. A large cutout of 50 mm diameter must be carefully made for the meter body.
A standard Selex PCB can accommodate all the circuit components. Layout and wiring is quite simple and is shown in figure 4. Details of IC1 and diodes D1, D2 must be properly observed.

Three different Op Amps have been specified in the component list for IC1. These are all pin compatible. The commonly used Op Amp 741 will not work in this circuit. The resistances used must be of very close tolerances, typically 2.5% or less, for R1 to R4. This ensures that the scale is uniformly divided.

The construction details are shown in figure 5. The Selex PCB is fixed on the bottom of the enclosure and the batteries are clamped using an aluminium clamp.

After wiring and assembly, the potentiometer P1 is adjusted such that the meter shows full scale deflection for a 1KΩ resistance in Range 4 (0 to 1K). The test resistance of 1K used here must be as accurate as possible.

Table 1 shows the setting of switch S2 and the range covered by the setting. Also indicated is the current through the test resistance for each range. The scale of our prototype is suitable for range 2 (0-100K). For other ranges, the reading must be multiplied by 10 (Range 1), 0.1 (Range 3) or 0.01 (Range 4).

Component List
R1 5.6MΩ, 2.5%
R2 56KΩ, 2.5%
R3 56KΩ, 2.5%
R4 5.6KΩ, 2.5%
R5 2KΩ
R6 50KΩ
P1 5KΩ Trimpot
C1 10μF/25V (Electrolytic)
D1 - 5.6V Zener 400mA
D2 - 1N4148
IC1 - 3140/310 D81/1F0 366
S1 - Push Button Switch
S2 - Four Position Rotary Switch
M1 - 100uA moving coil meter

Other Parts
1 Calibration resistance 1KΩ, 2.5%
1 Selex PCB
1 8 pin IC Socket
2 Banana Sockets
2 9V Batteries
2 Battery Connectors
Suitable enclosure, wires etc.
The Cackling Generator

Functional description

The audio frequency noise signal generated by the third oscillator can be adjusted by the potentiometer P1 to set the desired sound level.

To achieve a near natural cackling quality, four short and then a long cackling noise with rising sound level must be generated. This is achieved by the connection of first two oscillator via a RC network consisting of R4, R8, R10, C3, C4 and D2, D3, D4.

The sound of cackle can be modified by changing C7 by trial and error, to suit your own test.

The voltage on R4 can be greater or less than that on R10 and to take care of this fact, a combination of D2, D3, C3, C4 is used to function as a bipolar capacitor.

When voltage on R4 is more positive than that on R10 D2 blocks and C3 is

If one listens to the cackle of a hen, laying of eggs looks like big work! This interesting sound can be generated by a simple circuit. The circuit described here can also be combined with kitchen timers. Egg timers can also be used as a stand alone noise generator to produce interesting results. It can also be used to cause of puzzled faces and hearty laughs, especially when it is beautiful packed as shown in the photograph given above.

The Circuit

The circuit is shown in figure 1, and mainly consists of three oscillators and one amplifier. Each of the oscillators is constructed with two inverting buffers and a few resistors and capacitors. All six inverting buffers are part of one IC (4049).

The first oscillator (using N1 & N2) provides a rectangular signal. The signal is not quite rectangular due to the presence of C1. The actual waveform is shown in figure 2a. This signal has two jobs to do: it determines the length of the cackling cycle and it also determines the gap between two cackling cycles.

The second oscillator (using N3 & N4) provides the envelopes for the four different cackling sounds which are spread over the full cackling cycle. The length of each envelope is different as can be seen in figure 2b.

The third oscillator (using N5 & N6) generates the audio frequency noise signal which is enveloped by the second oscillator to produce the bursts of cackling noises.
charged. When R10 has more positive voltage than that on R4, D3 blocks and C4 is charged. D4 prevents the voltage on R8 from becoming negative.

The audio signal finally arrives at T1 where it is amplified and fed to the loudspeaker. Observe the shape of the transistor T1 in the circuit diagram.

Construction

This circuit has many components to be accommodated and requires a double size SELEX PCB. The layout is shown in figure 4. The electrolytic capacitors require the maximum PCB space. While soldering their polarity must be correctly observed. The current consumption is between 5 to 15 mA, and a small 9V battery pack is adequate to supply this current.

If one wants to combine this circuit with a kitchen timer, the relay contacts of the timer switch can be suitably connected into this circuit so that the cackling noise starts when the set time has lapsed.

If you want to pack this circuit nicely in shape of a hen as shown in the photograph (5), it should be assembled on two small SELEX PCBs, and interconnections should be made with wires. The loudspeakers and battery can be fitted as shown in the photograph. Potentiometer P1 can be fitted in front as shown, so that sound level can be conveniently adjusted.

Component List

| R1, R2, R14, 220kΩ | R3, R6, R10, 1MΩ |
| R4, 220kΩ | R11, R12, 820kΩ |
| R13, 10kΩ | R18, 220Ω |
| P1, 100kΩ, Trimpot | C1, 15μF, Metalised Polyester |
| C2, C6, 1μF, Metalised Polyester |
| C3, C4, 470μF, 6V |
| C5, 150μF |
| C7, 1μF |
| C8, 22μF |
| C9, 10μF, 10V |
| C10, 220μF, 10V |
| D4, D5, D6, 1N4148 |
| D4, 811 |
| T1, RC6178 |
| I1, 4049 |

Other Parts

- S1: ON-OFF Switch
- 1 loudspeaker: 8Ω, 200 mW
- 1 large or 2 small SELEX PCBs
- 9V miniature battery

Figure 2

The waveforms generated by oscillators 1, 2, and 3 shown in a, b, and c.

Figure 3

Components mounted on a double size SELEX PCB. The electrolytic capacitors take lot of PCB space.

Figure 4

Schematic layout while assembling the circuit, ensure to have correct polarity for electrolytic capacitors, diodes and the IC.

Figure 5

A suggested packaging for the cackling generator.
Electrical Power characterises the use or supply of electricity. In the abbreviated form it is represented by the letter P and the units for measuring electrical power are Watts (W). The higher the power of a drilling machine, the higher is the torque generated by it. The higher the Wattage of a bulb, the brighter is its glow. A water heater with 3000 W rating gives more heat than a 1000 W heater. The higher the power of a stereo amplifier, the louder is the music.

However, all the previous examples are not identical in case of the drilling machine, it draws the specified power from mains supply when it is drilling a hole in a hard material. The power consumption is much less when it is in the idling state. This is not true in case of the bulb or the water heater, because they draw the specified power from mains as soon as they are switched on. Also, the example of the amplifier is still different. The power drawn by the amplifier can be controlled externally by the setting of the volume control knob, between a minimum and maximum amount. The specified power of the amplifier generally refers to the maximum power. The useful power is much less than the power drawn from mains. When the amplifier draws 30 W from the mains, it does not supply 30 W to the loudspeakers. Even the bulb with 100 W rating does not convert all the 100 W of power into light, most of it is lost as heat and only a part of it is given as light.

There can be two meanings to the power specification of any electrical appliance. It can be the actual power drawn by the appliance from mains or it can be the maximum power the appliance is capable of drawing from the mains supply. Another distinction can be made when electrical power can be measured up by the appliance. It can be the one we use. In case of the bulb we know that when we take a 100 W bulb from mains, only a few watts are given out as light and the remaining power is converted into heat. So, if we are specifying the power that is given out, we cannot call it a bulb. It is also true in case of the stereo amplifier, we must distinguish between the power drawn by the amplifier and the power given out to the loudspeakers. It generally takes up twice as much as it gives out. Thus an amplifier which is capable of drawing 30 W from mains will not deliver more than about 15 W to the loudspeakers.

Power is never lost, it is converted from one form into another, when we talk of power loss, what we really mean is that some part of the power is not put to any use. It is converted to a useless form of energy, as in case of the bulb where most of the power is converted into heat. However, if for any reason, we were using a 100 W bulb to heat something, then we would say that most of the 100 W of power is converted to useful heat and some part is lost as light. It all depends on which form of energy the appliance is expected to deliver.

The stereo amplifier draws electrical power at 50 Hz from the mains. It gives out electrical power at the audio frequencies to the loudspeaker. The loudspeaker in turn takes up the electrical power from amplifier and converts a part of it into sound energy. Some of it being converted to heat inside the voice coil of the loudspeaker. Though it is not lost, it is useless.
Described here is the construction of a simple electronic switch which is electrically isolated from the mains. Electrically isolated means that there is no electrically conductive connection between the switch and the mains supply lines. Also the mains voltage has no effect on the switching mechanism.

In most of the cases a switch in the electrical circuit is directly placed in the power line. This is the simplest way to connect and disconnect an appliance from the mains supply. However, the disadvantage of such type of switching is that the full supply voltage is always present on one terminal of the switch. This may not always be acceptable, especially in case of switching to be activated by sensitive circuits like computers. In such cases one can also use a driver transistor and a relay, but the relay contacts can create problems when they get worn out. Even during normal operation, the closing and opening of relay contacts can produce electrical disturbances which may in turn affect the actuating circuits of the computer.

The better way is to use an electronic switch similar to the one described here. Even though the practical circuit of an electronic switch used for controlling mains loads from a computer is not as simple as this, the principle remains same. What is described here is a simple battery operated version.

The circuit still ensures full electrical isolation from mains voltage.

The Circuit

The circuit of the electronic switch is shown in Figure 1. The heart of the circuit is the "Opto-Coupler" which is nothing but a combination of a small lamp bulb and an LDR. The lamp L1 and the LDR are enclosed in a light proof enclosure and properly sealed. The light proof enclosure can be constructed from black card paper or a small piece of black plastic tube.

The construction can be different, as long as the LDR is illuminated by the lamp L1 and no other external light source. The LDR is a Light Dependent Resistor, which changes its resistance value depending on the amount of light falling on it. The Lamp and LDR should be placed inside the tube in such a way that there is about 1 or 2 cm distance between the lamp and the light sensitive surface of the LDR.

The function of the circuit is very simple. When switch S1 is closed, the lamp L1 glows. Due to the light falling on the LDR, its resistance falls to a very low value (approximately 100 to 500Ω). This low resistance connection between the mains line and trigger pin of the Triac, through the R2, R3, C1 combination now triggers the triac during every half cycle of mains voltage. The load is thus placed directly on the mains line through the triac.

When switch S1 is open, the lamp does not glow, the resistance of LDR rises to a few megaohms and there is no path for the trigger current to flow. The triac is off and there is no connection between the mains line and the load R3, C1 form the protective.

Photograph

The circuit becomes perpetual through the use of a plastic enclosure and properly installed mains socket/plug pair. Three different possibilities of control are achieved through the three banana sockets and switch S1.

Figure 1

The circuit of the Electronic Switch. The terminals A1 and A2 of the triac should not be exchanged. A2 must be on the load side.
The Control Unit.

a) 16 Bit microprocessor (INTEL 8086)
b) Present on card memory of 16K (EPROM) and 8K (RAM)
c) Provides communication between MARS and user with appropriate displays on monitor
d) Easily expandable to control large number of MARS systems simultaneously.
e) Speed control by simple command from user
f) Uses a + 12 -12 and -5 volt for motor and control care

g) User has three modes of operation to choose
1) TEST mode
2) MANUAL mode
3) TEACH mode

The Mechanical Unit

An omnidirectional ground transporting robot on four wheels are powered by a pair of stepper motors. Each of these motors are capable of independent motion thus very easily MARS can turn about any point.
The ARM unit is capable of handling loads of upto 500gm held at the gripper. High degree of accuracy and low mechanical power input is achieved by the use of gears. ARM unit has 90 degree freedom of movement up and down making it capable of lifting objects from the floor level.
The BASE unit has 360 degree freedom of movement.
The very cost effective design of gripper achieves a high degree of compliance to suit any application. Driven by high speed DC motors this gripper makes ‘hold’ and ‘release’ action almost instantaneous.

Construction

As always, all the rules for construction of a circuit which connects to the mains, must be observed strictly. The circuit can be constructed on a piece of Wire Strip, as shown in Figure 2. It can be inserted inside a suitable plastic enclosure. Standard plug socket combinations can be used for mains inlet and outlet. Three banana sockets can be installed on the plastic case and connected to points 1, 2 and 3 shown in the circuit diagram of figure 1.

This gives us three alternatives for switching on the load:
1. Directly by switching S1 on
2. Through an external switch or relay contact connected across sockets 1 and 2
3. By applying an external voltage of 4.5 to 6V across sockets 2 and 3

Triac TIC 206M, or equivalent, can handle loads upto 200W. Triac TIC 226M or equivalent can handle loads upto 300 W

An important point to remember here is that the lamp takes a little time to extinguish when disconnected from battery, and this will introduce a short delay between turning off switch S1 and switching off the load from the mains.

This circuit will not be suitable for applications which require emergency disconnection of load from the mains.

The photograph below show the robot performing its operation.

BHAVI SAKLECHA
18, Palm Grove Road, Austin Town, Bangalore 560 047

The Control Unit.

The Control Unit.

Meet...

An Electronic Engineering student at MSRIT Bangalore has developed a Robot. The cost of this project, which consists of the control unit and mechanical unit is approx Rs 3000/-. The low cost of the project apart this is quite an achievement for a Student.

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FLEXICELLS TO BEAT BATTERY WEIGHT

by Dr Alan Hooper, Materials Developments Division, Harwell

Engineers designing electrical and electronics equipment, from electric traction vehicles to portable radios for domestic or military use, have always been frustrated by the weight and size of batteries that have to be carried. Now under development at Britain's largest laboratories, in collaboration with other scientists in the UK and in Denmark, all-solid-state rechargeable lithium batteries bring pollution-free driving a great deal nearer and may trigger many new and exciting ideas for battery-powered equipment.

Battery-powered electric vehicles (EVs) are already in use in many countries. One example, in the UK, is the humble milk-delivery wagon, or 'milk float'. It is successful because to do its job it needs to work over only a short range and a low speed is acceptable in built-up areas, where it has the added advantage over the internal combustion engine of not causing pollution. It is efficient and convenient for continual stop-start operation and a commercial fleet of such vehicles is easy to maintain.

On the other hand, its restricted performance causes considerable frustration to motorists who meet it on the open road, for it cannot travel at the speed of the rest of the traffic. Across the Atlantic, the golf-cart would hardly be welcomed on the freeway. So the view of the general public is that electric vehicles have a poor performance but are acceptable for specialist duties.

It is the source of power, the battery which lies at the heart of the problem. To put it simply, traction batteries are too heavy and too large for the amount of energy they store or the power they can provide. A large fraction of the energy stored in a typical traction battery is needed just to propel the battery itself.

Aqueous electrolytes
For practical purposes, the present choice of batteries for EV traction is between two systems, each employing an aqueous electrolyte, which is either lead-acid or nickel-iron. This situation has remained essentially unchanged since the beginning of the 20th century despite many attempts, especially over the last 25 years, to develop new systems. Over that period, stimulus by the appearance of potential rivals has led to significant improvements in the performance of existing systems and of vehicles with good short-range traffic-compatible capabilities. Most of the vehicles now available are urban delivery vans but one of the latest is a version of the popular Peugeot 205 car, powered by a nickel-iron battery. There are certain practical drawbacks specific to individual systems, but the main, general problem is still that of limited range. EVs are still, in general, economically uncompetitive with their internal combustion engine counterparts.

The performance offered by the enormous energy density of petroleum, with more than 10,000 Wh/kg (watt hours per kilogram) compared with 20-40 Wh/kg for lead-acid traction batteries and a high-rate recharge capability (two minutes at the pump in contrast to a battery charge of several hours), will never be matched by that of any battery system, in spite of an on-board energy conversion efficiency that is five times better. However, if a battery were available with high energy density (100 to 200 Wh/kg) it would significantly affect the practical value of EVs in a wide variety of applications from wheelchairs and bicycles to commuter cars, taxis and delivery vehicles.

Not only would longer ranges and greater load-carrying capabilities be realised, but the improvements in gravimetric energy density would open up considerable scope for innovative engineering in vehicle design, using lighter and cheaper materials. It is this, rather than cheaper batteries, which would lead to a cost-competitive electric vehicle.

Portable electronics
Similar problems are to be found in other technologically important areas. The vast demand for portable electronics equipment in
the computing and communications fields bring with it a need for small, lightweight, rechargeable power sources. Both the business executive and the infantryman in the field would benefit from a lighter load to carry. It is not only important to achieve lower absolute weights and smaller volumes, to avoid the hand-held cellular radio-telephone or 'wrist-watch' device having a suitcase-size battery, but to be able to provide batteries that are suitably shaped, too. For example, a flat-screen television ideally requires a flat battery pack. There are also growing markets in the telecommunications and other industries for standby power sources. Here, too, there is a trend towards smaller electronics packages and correspondingly small power sources. Ni-Cd batteries have been used traditionally in these markets and, more recently, Ni-H batteries too, for space applications such as power sources for satellites where cycle life and reliability are also of prime importance; but the low energy densities so far achieved have restricted the electrical load capabilities at missions Space stations and deep space probes will require power sources with higher energy densities. Much better energy densities are theoretically available from alkaline-metal couples, but materials problems have restricted their use mainly to primary battery systems and to secondary batteries operating at high temperature. Of the latter, the sodium-sulphur battery is the best developed. It uses an Na*-ion conducting solid, sodium-beta-alumina, as a solid electrolyte and has to be operated at 350°C. Predicted energy densities are more than 100 Wh/kg. More prototype traction batteries have been made and vehicle demonstrations carried out in several countries. However, sodium-sulphur batteries are still not commercially available even after some 17 years of research and development by large teams of scientists around the world. Remaining problems include the reproducibility of manufacture and reliability in use of beta-alumina ceramic tubes, and the thermal control and safety at large cycles. High temperature systems of this kind will, even if successful, be useful only where large batteries are needed. A small, room-temperature, rechargeable lithium battery with a liquid organic electrolyte has recently become commercially available in Canada. Its cathode material (MoSx) leads to a low overpotential and moderate energy density. A useful life of more than 100 charge discharge cycles is quoted, but little information is yet available from field trials. Applications under consideration include photographic flashguns and electric wheelchairs.

Radical departure

Rechargeable all-solid-state lithium batteries now being developed at Harwell constitute what is perhaps the most radical new departure in battery technology for decades. They also promise very exciting commercial prospects. Based on thick-film polymer technology, with no liquid components, they offer very high energy density, mechanical flexibility and variable geometry as well as being robust and safe. This work has evolved from a programme begun here in 1975 to investigate materials for advanced alkaline-metal rechargeable batteries. It was shared between Harwell, universities in the UK and research and development establishments in Denmark. The Anglo-Danish Battery Programme as it became known was jointly sponsored at Harwell by the UK Department of Trade and Industry (DTI) and the European Community. The aim of the programme was to examine the properties and behaviour of several promising solid electrolyte and cathode materials described in the literature, to obtain a sound idea of their properties, define the problems to do with their use in batteries and to assess their compatibility with other materials in cells. Such work would enable us to find out reliably which materials might be technologically useful for electric vehicle batteries in the future. It was hoped to obtain a fairly hard-headed assessment of whether alkaline-metal batteries could be developed that would achieve their potential energy density advantages and so identify which materials could best be chosen for future cell development studies. A working temperature range of 100°C to 200°C was considered acceptable for a first generation EV battery.

All-solid-state

Because of persisting difficulties with organic liquid electrolyte batteries, all-solid-state cells were seen as the only practical way forward for operation at ambient and moderate temperatures. The cells developed in the programme have lithium anodes and a so-called intercalation or insertion compound as reversible cathodes. Examples are V2O5 and TiS. Although the early stages of the programme studied...
in depth the very interesting crystalline inorganic lithium-ion-conducting electrolytes LiI and LiIAlO3, the choice of this type of cell was made more realistic by the discovery of polymer-based solid electrolytes by Michel Armand and fellow workers in France. Certain polar organic materials such as poly(ethylene oxide) will dissolve alkali metal salts and manifest rapid alkaliion conductivity. The absolute conductivities of such polymer-based materials are not in general as high as those of crystalline solid electrolytes, but they may be made into thin, pinhole-free plastic sheets with good enough conductance for use in cells and batteries. Equally important is that the plasticity of the polymers overcomes the other big problem of solid-state battery systems, namely how to maintain good contact between laces.

Harwell staff have concentrated over the last four years on developing the technology for making the polymer-electrolyte plastic battery¹ and have built and tested cells. Techniques for continuous production of the electrolyte and cathode components in the form of thin films have been developed and their dimensions can be scaled-up when required. The thickness of a complete cell is only one or two hundredths of an inch (one-quarter to one-halt of a millimetre) and there are prospects of making even thinner cells. There are close similarities between the structure and fabrication technology of the battery and many products outside the traditional battery industry.

¹ This technology should not be confused with the so-called plastic batteries also under development which use electronically conducting polymers such as doped polyaniline as electrode materials, with organic liquid electrolytes. They offer only moderate energy densities.

Temperature range

At present the cells, which are poly(ethylene oxide)-based, operate most effectively at 100°C or just above, so they are quite suitable for that respect for vehicle traction service and for use in satellites. Earliest specialist applications may also be limited to very hostile environments. The temperatures of up to 150°C, a region where most conventional materials fail. They may include downhole instrumentation in the oil industry and certain low standby power sources. Furthermore, lower-temperature performance can be achieved with existing materials and cells when the power requirements are low, as for many micro-electronics jobs.

One attractive possibility in this field is the integration of the battery with the circuit it powers. The thin-film planar technology is compatible with conventional printed circuit board and hybrid electronic circuitry. For example, the technology lends itself to the development of a self-powered intelligent credit card incorporating a microprocessor. But for many other prospective uses, operation at room temperature and below is required, at high power levels. This will mean developing new cell materials, especially new polymer electrolytes. Work is now going on in many countries and a research and development programme here is being sponsored by an industrial group or 'club' of battery users, manufacturers and materials specialists. Supported by the DDI, our Solid-State Battery Working Party aims to provide the basic technology to make all-solid-state lithium batteries, based on polymeric electrolytes for as many applications as possible. Studies will concentrate at first on developing better electrolytes but expand as membership of the group grows.

Success in this area will open up many new uses in the military, industrial and domestic sectors. It might well lead to cordless vacuum cleaners, lawn mowers and power tools, and to new flashlights, toys and electronics and communications equipment.

The idea of batteries based on an all-solid-state polymer electrolyte, perhaps using various existing materials and construction technologies for different applications, holds out one of the most versatile and exciting prospects for battery development this century.
Always a move ahead

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**BETA TESTER**

This Transistor Beta Tester measures static gain (Beta) upto 300 at collector current upto 10 Amps and base current upto 1 Amp, at VCE of 4 Volts, as per international specifications. The currents are pulsed at 25% duty cycle of 50 Hz, avoiding excessive heating and power dissipation, in Transistor under test.

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Phone 5132195 5136601

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Satyanarayan Road
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**PIEZO BUZZER**

ION Electricals, have introduced Model 31PB35 solid state buzzer which emits a pulsed audio signal of 3 kilohertz at the rate of approximately 4 'beeps' per second.

The piezo buzzer measures 40mm in diameter and is provided with 120mm long wires to connect the supply. They find application in practically all electronic systems and in electrical panels. Typical examples are alarm clocks, telephone sets, gas detectors, medical instruments, microscopes timers etc.

**For further information please contact**

ION ELECTRICALS
3-57, Owners Industrial Estate
505, Gabriol Road, Mahim
Bombay 400 016
Phone 468157

**TEMPERATURE DATA LOGGER**

ION Electricals' Temp Data Logger is a microprocessor based system which accurately records the temperature (to 100 channels) at desired time intervals. The number of channels and the time interval can be programmed by means of a Key board/Thermometer. The print out gives the time (real or elapsed), channel number and the corresponding temperature reading. This logger is available in different temperature ranges from -50°C to 1800°C with a signal interfaced read out and print out having an accuracy of ± 0.3%.

**For further information please contact**

ION ELECTRICALS
3-57, Owners Industrial Estate
505, Gabriol Road, Mahim
Bombay 400 016
Phone 468157

**For details contact**

M/S EXCEL ELECTRICALS,
C-4, Raj Mall Apartment,
Caves Road, Jogeshwari (E),
Bombay-400 060

**Flat Cables**

Excel have come out with Henry Flat Cables satisfying UL and CSA standards; these cables are generally available in 6 to 12 ways either in soft Copper alloy with silver or gold plating and rated at 300V, 5A. Capable of operation in a temperature range of 45°C to 100°C, the cables can be used as jumpers for interconnects in electronics instruments, communication equipments, business machines and computers.

For details contact

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**KEY LOCK SWITCH**

ELCOM has recently introduced a Key Lock Switch Type KLS-5. This reliable Key Switch provides added safety to electrical and electronic equipments and prevents unauthorised use.

Panel Projection: 6 mm

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Rating: 125 V AC 5A, 250 V VAC 3A

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**For further information please contact**

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Vidyavartna (W), Bombay
Phone 5132195 5136601

**For details contact**

M/S EXCEL ELECTRICALS,
C-4, Raj Mall Apartment,
Caves Road, Jogeshwari (E),
Bombay-400 060
DIGITAL MULTIMETER

MECO has just introduced the model MTC6 Digital Multimeter which features a single knob operation for all functions. It measures AC & DC currents from 200 μA to 10 A with a minimum resolution of 0.1 μA, AC voltage up to 750 V, and DC voltage up to 1000 V. Resistance tests from 200 ohms to 20 megohms. Diode checks and continuity tests are also included. It has an accuracy of 0.5% 1 digit for DC Amps, Volt & Resistance measurements and 1.5% 3 digit for AC Volt Amp measurements. It can also measure temperature.

POWER PUSH BUTTON SWITCH

Rajkumar Engineers offer a new power push button switch incorporating the latest advances in switching technology. The switch is rated at 6 ampere continuous load and has double pole single throw switching configuration. The switch incorporates a built-in push switch contacts and fails-safe operation. It has built-in fuses for preventing electrical overload.

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For further information

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