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LIC
Looking in our tea cups, we did not feel like starting the new year with reflections on super-chips or solid-state audio, but decided to wait and see how last year's tea leaf patterns in this respect will fare. So, what would we like to muse over? Well, the first point is the state of technological development. This is still accelerating at an increasing rate; the super-chip of today is the standard chip of tomorrow. We regularly receive letters with cries for help like: "Help! I stopped my subscription two years ago, but because of withdrawal symptoms I have recently recommended it. But I don't understand the circuits any more!..." If we give free rein to our gaze into the future, we must assume that intelligent machines, far-reaching miniaturization, and affordable prices will become the norm. The second point is: where will we find ourselves in 1985? One thing is certain: new devices and equipment no longer amaze us. The housewife will have a microprocessor-controlled microwave oven which automatically weighs the food and sets the appropriate temperature. All she has to do is to indicate that she is putting in a chicken and the oven does the rest. Or does it? The first time the oven is being used, you hear cries from the kitchen "Why is that stupid thing not working? It is program three...chicken... well then, why don't you start? Oh, the door was not closed properly. Sorry!" Click. So, we are no longer overwhelmed with wonder, but we do remain critical. If a 'stupid thing' does not do what we expect it to do, it's no fun any longer.

Utensils and crazes
When something is new and not too expensive, it sells. With some luck (and a lot of publicity) it may become a craze. Or a fashion. Or a normal utensil for everyday use.

What's the difference?
Why were Newton's marbles, the hula hoop, and the Rubik cube crazes? Why were the Charleston, the mini skirt, and aluminium luggage racks in fashion? Why are telephones, automatic washing machines, and zips utensils? The difference appears to lie in the user-friendliness. Utensils are just, well, handy. They make it possible to do something you wanted to do in an easy manner. They have a purpose, they meet a need. Crazes and fashions are, initially, exciting, but after a while the novelty wears off — and all of a sudden they are no longer useful, or user-friendly; just plain dull. Which brings us to the home computer. Craze or utensil? As they are now, we would say: craze. They are affordable, exciting — even addictive. If you manage to work with them you continue doing so. Sometimes until two or three in the morning. But why? And here's the crux of the matter. Because those
"stupid things" do not understand — and therefore don't — what you want. They are not user-friendly. And that's why most computer owners get fed up with their machines. The standard games are boring and the 'family memory' was far more accessible when it was contained in the telephone book. Home programming is not so hot either. So?

In most of ten cases, the computer is put away in a cupboard. Nice when you have visitors, but for the rest... In the remaining case, some interest remains. Elektor readers are prominent here. They want more. For them the computer is a hobby, not a utensil. For that, it is not yet sufficiently user-friendly.

The future

Back to the tea leaves. What can we expect? Which crazes will come and go? What utensils will come and become 'normal'? As we said, the cheap home computer appears to have all the hallmarks of a craze. The new MSX sets promise to become one hell of a craze: they are almost 'real', there are promises of much software, and they are not too expensive. But... user-friendly? No, not really. Do they meet a real need? No, not really.

What about that pocket-diary-in-a-wristwatch recently launched by Seiko? There is some doubt here. An 'old-fashioned' diary is cheap and convenient, and you can enter or alter information in it without having to read the operating instructions. And yet, a watch is always with you, while a diary may accidentally be left at home. What are our real needs; in what direction should we look for future utensils? Let's see:

- **Peace and quiet**. A noise eradicator would be very desirable. Built into your easy chair, or at the head-end of your bed. Technically, it is quite feasible, but as yet very expensive.
- **Communication**, but selective. This is a wide field, but to name one aspect that is definitely technically possible: a new British Telecom telephone service, John indicates on his phone that he would like to speak to his brother. All subscribers indicate when they don't want to be disturbed; for instance, by a switch on their phone. On the first occasion both John and his brother are free and available, the computer makes the connection.

- **Information**. Assuming that you're interested in international news, chess, cartoons, and technical news, which paper do you read? Why, your own, personalized one, of course — ordered from a fully automated publishing company. Each morning your very own paper rolls from your own printer — no sports results, no stock exchange news, no gossip.
- **Literature**: books and magazines, for relaxation or learning. Currently, there are many advantages: they are easy to use, legible, and relatively cheap. A computer screen is definitely not an improvement! And yet, the electronic system has its good points: the information is distributed easily and cheaply and the 'covers' may be very compact — mini cassette or mini floppy. So, what do we need? A handy, not too expensive, battery-operated reading book with a clearly legible screen. Put in the cassette and on you go with your novel. When you've finished it, you call for a new 'book' — by telephone, of course! Now, that will be user-friendly!
- **Physical aids**, for healthy as well as for (lightly) handicapped people. Better learning aids, for example, but also night glasses (with light amplifiers), which are much more convenient and economical than torches. Or a muscle-enervating massage belt to enable you to lose those pounds during breakfast — now, that could become a craze (and, like its current mechanical counterpart, it would be quite useless).

- **Elektor**. What sort of articles will we publish in Elektor in the 1980s? Using the same criteria as today — practice-orientated, using modern technology, broadly dealing with all aspects of electronics — the contents are bound to be quite different. Or are they? We will publish audio preamplifiers, but with a 32-way input bus for those new audio ROMs.

And we will combine those new Mbyte memory ICs with those ridiculously cheap A/D and D/A converters to make a guaranteed reproducible echo unit.

We will make a de luxe house telephone exchange for connection to the normal telephone network: this will be allowed by then. We will make a 'music searcher' which tunes the radio (yes, that will still exist) to a transmitter that broadcasts the music of our liking and no advertising! We will... well, we'll see... In any case, we'll make it interesting!

---

**Computers of the future**

It is not all that long ago that computers worked only from a bunch of punch cards which could not be produced at home. Nowadays, computers are generally operated from a keyboard but this is still a long way from the desired goal of voice-actuated machines. Keyboards are highly restrictive because they mean that if a user wants to communicate with a computer he or she has to learn to write programs. As the main uses of computers will become centered more and more on office automation, data communications, and home work stations, it is extremely unlikely that more than a small proportion of users will be prepared to learn how to program — and why should they?

No, computers will have to come into much closer contact with the user to become a real tool of human thought. This means that computers have to become much cleverer than they are. In essence, a computer is nothing but an array of interfacing units: at the centre the microprocessor, swathed in software, machine code, compilers, assemblers, operating systems, languages, application programs, printers and/or screens. This is, of course, an unfortunate arrangement because any change at the user's end will normally affect all these peripherals, and therefore the very design of the computer.

Of course, even users of personal computers now have other devices at
their disposal for communicating with the computer. For example, the mouse is a small pointing device which when rolled along a desktop causes a pointer to move across the screen in a corresponding direction. Originally the mouse was operated through a pair of wires, but modern versions are cordless and communicate with the computer by infrared signals. The mouse is also used to select icons, which are small graphic representations displayed on the screen to illustrate a computer function.

These are but first steps towards personalization of the computer, that is, giving the user facilities for moulding the operations more to his own requirements. The next steps will probably have to wait until the 32-bit microprocessors (such as Motorola's 68020S, Intel's 80386, Zilog's 28000, or National Semiconductor's NS32032) and very large, inexpensive memories have become available in the course of the next few years. It is true, of course, that there are 32-bit computers on the market already, such as Apple's Lisa and Macintosh, both of which use Motorola's 68000 microprocessor. Unfortunately, the 68000 has only a 16-bit bus, so to the user these computers do not seem much faster than IBM's 16-bit PC. True 32-bit chips with a full-size bus will enable designers of PCs to give users much more flexibility; they can execute between two and three million instructions per second, that is twice as many main-frame computers, and can process software programs more than three times as fast as the 68000.

Power requirements of these new chips are the same as that of the 68000 although they contain three times as many transistors. This low power consumption, which minimizes heat problems, and the high speed coupled with a large memory mean that very small but very powerful computers can be built. As a result, highly complex mathematical and engineering problems can be executed by a desktop computer and up to twenty people can work on the same computer file simultaneously.

Personalized computers have recently become available in the USA from Metaphor. These machines are customized for groups of users, such as accountants. Metaphor expects users, untrained in programming, to take it from there and write further applications for themselves. So, here is already an example of what can nowadays be done by the user himself that had to be done by specialized programmers only a few years ago.

The two important developments are, however, the use of natural instead of man-made language (such as BASIC or FORTH) and graphics. The ability to speak into a computer instead of having to sit down at a keyboard will increase the uses of computers vastly. Basically, what is required for this is an interface between the user and the computer: a device such as a voice-activated typewriter (VAT) that can transcribe speech without having to understand it.

As the problems facing designers of automatic speech recognition (ASR) systems are enormous, large programmes, many government-sponsored, have been initiated in Britain (the Alvey programme, named after John Alvey who chaired the committee that established the programme in 1982); in Europe (the European Strategic Programme on Research in Information Technology - ESPRIT); in the USA (Defense Advanced Research Projects Agency - DARPA; - Microelectronics and Computer Technology Corporation - MCC - the civilian counterpart of DARPA; and Semiconductor Research Cooperative - SRC); and in Japan (Institute for new generation Computer Technology - ICT - and the National SuperSpeed Computer Project).

Several of the world's big computer companies have been working on automatic speech recognition (ASR) for some time. A few months ago, IBM announced that it had produced an experimental system with a ninety-five per cent recognition rate for a 5000 word business vocabulary. There are problems in going from ASR to ASR, of which one relies on a template recognition system. Templates are digital patterns used by a recognition algorithm to identify words. The other is based on pattern analysis of the forty phonemes that make up spoken English, and the 1600 transitions possible between each adjoining pair of them.

All the signs are that by the year 2001 we will be able to emulate HAL (but only as far as its positive aspects!) and command computers through natural language, because that is, and will remain, the most efficient and subtle, though complicated, instrument for human communication.

Visual representation is virtually useless to convey certain kinds of information. But when it comes to show the relation between, say, forecast and actual sales, pictures come into their own.

Unfortunately, many companies have been frightened by the experience of Mindset. This Silicon Valley company makes an IBM compatible PC that produces high-quality graphics. After this set had been hailed by the press at its launch early last year, it flopped. Although there were market reasons for this, the main disappointment was that the idea that good graphics would create its own market among general business users was wrong. None the less, most consultants are forecasting that the computer graphics industry is heading for a huge boom, with a growth rate of more than forty per cent per year for the remainder of the 1980s.

Good graphics will be possible because PCs are becoming powerful enough to use bit-mapping, a technique in which each pixel can be controlled individually. The most impressive PC with a bit-mapped high-resolution screen is Apple's Macintosh, while in the business market it is IBM's 3270PC/G (which, incidentally, also has a mouse).

Finally, two new printing technologies are becoming economically viable. Up till now, there have been three basic types of printer: daisywheel, producing good quality print slowly and loudly; dot matrix, which uses a row of fine needles shot forward by electrical pulses to form the shape of letters and figures end is faster but less clear than the daisywheel; and heat transfer, which also uses needles but, instead of moving, these heat up momentarily.

But the future will almost certainly belong to laser and LCD (liquid crystal display) printers, both of which are fast (6...7 pages of A4 per minute), noiseless, and give a print quality where you do not notice any dots (pixels). Printers using these techniques are still very expensive, although market forecasts are that there will be a laser printer on the market for under £1000 in about a year's time.
Commodore cassette interface

Necessity being the mother of invention this circuit was destined to be designed. The 'necessity' here is Commodore's insistence that the VIC 20 and C64 computers can only be used with a special cassette recorder supplied by ... Commodore. One of our designers balked at the idea of buying a cassette recorder only for his computer when he already had a perfectly good audio recorder. Some kindly soul directed his outraged energy towards the nearest soldering iron and so was born THE Commodore cassette interface by Elektor.

As in many home computers, the data output by the VIC 20 and C64 via the cassette interface is in the form of a square wave signal with an amplitude of 5 Vpp. The information input to the computer has the same form. The cassette connector also contains a so-called 'sense input' that enables the computer to check if the recorder's PLAY button is pressed. The Commodore will only activate its motor output if this is the case. The computer itself switches the recorder motor on and off and we will see later how this is actually done. First, however, we must see what happens if the computer wants to save a file on cassette.

THE interface in detail

The program to be saved appears in the form of pulses with an amplitude of 5 Vpp on the write output of the connector. This amplitude is, of course, much too large to be saved directly on the tape so the signal is first reduced to about 200 mV by voltage divider R13/R14. This signal is then suitable for recording on the tape. The procedure for loading a program is somewhat more involved. The signal supplied by the recorder via a DIN or loudspeaker output socket is nowhere near square in shape and its amplitude is also much too small, at about 200 to 300 mV. The signal must therefore be amplified and its shape improved. A single op-amp (A1) increases the signal's amplitude by about six times. The offset of A1, and consequently of A2, is set to half the supply voltage by means of R3 and R4. The second op-amp is set up as a schmitt trigger which takes the signal from A1 and forms it into a clean square wave signal with an amplitude of 5 Vpp. The computer can now load the program via the connec...
The motor in the cassette recorder must be switched on and off at the right times by the computer. Naturally enough this is done via a relay (Rel) instead of directly. When pin 3 of the connector goes high transistor T2 is switched on and causes the relay to operate. First of all, however, the computer must be made to think that the PLAY button is pressed. This condition is simulated by connecting the sense input to ground, which is exactly what happens in the Commodore data recorder when this button is pressed. If the sense input is connected straight to ground, as we have done, we can then simply forget about it. The power supply for the interface is very kindly provided by the computer. As figures 1 and 2 show, pins 1 and 2 of the cassette connector are GND and +5 V respectively. This makes a separate supply for the circuit unnecessary.

The interconnections
Before any data can be transferred all the electronics must be constructed and all interconnections must be made. A total of six links are needed at the computer side and the most important point here is to ensure that none of these are interchanged. The computer would not be very pleased with this so have a look at figures 1 and 2 to see where everything belongs before soldering any wires. The cassette recorder is more tolerant of wrong connections but it is far better if
the circuit works correctly first time. Again make sure to solder the right wires in the appropriate places. The layout usually used for a cassette recorder's DIN socket is illustrated in figure 3. The two terminals for the relay contacts (points R and S in figure 1) are linked to the recorder's remote input via a jack plug. If the tape recorder in question does not have any remote input this is no reason for panic; simply connect R and S in series in one of the voltage supply lines to the motor.

Installation and use

All the components must be fitted to the printed circuit board shown in figure 4 and when this is done a suitable case must be found for the circuit. Alternatively, it may be possible to include it within the cassette recorder case. Whichever of these is chosen there is one point to bear in mind: the connecting wires must not be made too long. A special connector is needed to link the interface to the computer's cassette input/output lines. This is a six-way printed circuit board connector with a spacing of 3.96 mm (0.156") between the pins. The wires can also be soldered directly onto the printed circuit board. We will be very brief in our instructions on using the circuit: refer to page 18 of the C64 user's manual.

The function of S1 in the circuit is clear: it is used to switch the motor on and off, which is very handy for winding the tape. If an error message is generated during loading the volume control on the cassette recorder is probably not correctly set. When reading tapes that you have not recorded yourself it may be necessary to re-align the record/playback head. If our experiences with this interface are anything to go by, however, errors will rarely occur, even when 'turbo' loading.

Parts list

Resistors:
R1, R2 = 4.7 k
R3, R4 = 2 k
R5, R8 = 22 k
R6, R11, R16 = 47 k
R7, R10, R15 = 10 k
R9 = 220 k
R12 = 220 k
R13 = 100 k
R14 = 1 k

Capacitors:
C1 = 10 n
C2 = 22 n
C3 = 22 µF 16 V
C4 = C7 = 100 n
C8 = 10 µF 16 V

Semiconductors:
D1, D2 = AA119
D3, D5 = 1N4148
D4 = LED
T1, T2 = BC547B
IC1 = LM387

Miscellaneous:
Rel = relay, 5 V PCB-mounting type UMS
Components — part no. 0065
S1 = single-pole toggle switch
6-way PCB edge connector with pin spacing of 3.96 mm (0.156") - Maplin, order no. F0249

Figure 3. Here is the arrangement most commonly used when a cassette recorder has a DIN socket for input/output.

Figure 4. Constructing the circuit is simply a matter of assembling the components on this printed circuit board. Make sure no wires are switched when making the interconnections.
Computers, video games, video cameras, games computers; all of these produce video signals that must be displayed via a television set. If the TV receiver in question does not have a video input and its owner is reluctant to vandalise it in order to fit one then this sort of modulator is the obvious solution. It is a simple circuit that processes video signals to enable them to be fed straight into the TV set's aerial input.

VHF/UHF TV modulator

A 'TV modulator' is really no more than a transmitter. It is a very small transmitter, admittedly, but none the less that is what it is. What does a modulator actually do? In general — and this design is no exception to the rule — it is a simple modulator that generates a frequency somewhere in the VHF or UHF region. The oscillator is modulated with the video signal and the modulated carrier wave thus generated is fed into the TV set's aerial input via a cable. Then all that remains to do is tune the TV to the correct frequency.

The layout

The whole business is not quite as simple as we have just suggested, of course, as the mini transmitter must meet certain requirements. The frequency stability must be very good as, indeed, must the quality of the display. The required frequency stability is achieved by the use of a crystal oscillator A well thought out choice of component values takes care of the display quality: the modulator allows a resolution of 80 characters per line, as this is a value that is often needed.

A very important feature of this circuit that must be decided is the transmission frequency. If this is only a single channel, as suggested above, it gives rise to some practical problems. Different users will want different channels, the carrier wave can become somewhat difficult to locate, and unless the frequency is exactly spot on no signal will be received. A much better idea is to ensure that the HF signal contains a large number of different frequencies. This makes it much easier to tune the TV set to one of the frequencies as there will surely be one to suit every user.

The block diagram of figure 1 shows how this is achieved. The TV modulator is made up of two parts, namely a modulatable crystal oscillator and a harmonics generator. The oscillator operates at a frequency of 27 MHz, which is quite low so inexpensive crystals are readily available. The harmonics generator converts the oscillator signal into a sort of frequency spectrum containing all the multiples of 27 MHz up to about 1800 MHz. The TV modulator's output signal is made up of a large number of little peaks, each of which is a complete transmitter signal. At least one of these will always be in band I (VHF channels 2...4), one in band III (VHF channels 5...12) and many of them will be in bands IV and V (UHF channels 21...69).

The circuit diagram

Like the block diagram, the circuit (shown in figure 2) is very straightforward. The crystal oscillator is based on a very fast HF transistor, T1 (EF86), which performs the amplitude modulation. Apart from this there is little to say about the oscillator except, perhaps, that it is essential to use the correct values for the components surrounding T1. This is, of course, simply common sense in this sort of HF circuit. The harmonics generator is formed by two Schottky diodes, D1 and D2. These diodes must switch very quickly in time with the 27 MHz signal so they provide strong harmonics up into the gigahertz range. The modulation depth can be set with P1, while the oscillator's d.c. value can be varied by means of P2. The combination of these two presets enables either positive or negative amplitude modulation to be selected. This is essential as the harmonics produced vary in this respect. We will discuss the calibration of P1 and P2 later in this article.

The power for the circuit can be provided by either an unstabilized 8...30 V or a stabilized 5 V. The latter could be taken from a computer's power supply and in this case IC1 is not needed.

Construction

The tiny printed circuit board designed for this circuit is shown in figure 3. It is

Figure 1. A TV modulator is, in fact, a small TV transmitter. In this case the transmitter consists of a modulatable (AMI) oscillator followed by a harmonics generator.
not double-sided as this was found to be unnecessary. Construction is thereby simplified and readers who do not buy the board through our EPS service (tut-tut) will find it easier to make themselves. Building the circuit is simply a matter of fitting the components onto the printed circuit board. The coils, often a source of much teeth-grashing and hair-pulling, will not be a problem in this case. Two of them, L1 and L3, are made by winding 3½ turns of enamelled copper wire (about 0.2 mm thick) on a 3.5 mm ferrite bead. Another, L4, is just one turn of copper wire (0.8...1 mm thick) air-wound with a diameter of 8 mm. The fourth inductor, L5, can simply be bought.

Any third overtone crystal with a frequency of between 25 and 30 MHz will work in this circuit. A number of suitable values are advertised in this issue. The only parts that might prove difficult to find are diodes D1 and D2. The ones stated in the parts list are available at the moment but do not give up hope if your corner shop does not have them. The only important thing is that they must be UHF Schottky diodes; the actual type number is of little consequence.

Calibration
Calibrating the modulator calls for a certain degree of care as it involves more than just 'set the preset to mid-position'. The setting depends, in fact, on the harmonic to which the circuit is tuned. Calibration should be carried out as follows:

- Set the TV receiver to maximum brightness and contrast.
- Feed a video signal into the modulator (a video recording of a test card, or a link to a computer's 'TV' socket, could be used) and connect the circuit's output to the TV's aerial input.
- Set P2 to mid-position and P1 to maximum resistance (fully anticlockwise).
- Tune the TV receiver to a harmonic, preferably one of the VHF bands (channels 2...12). The tuning is correct when the 'snow' on the screen disappears and/or the screen becomes dark.
- Turn P1 very slightly until 'something' becomes visible.
- Calibrate P2 to give the best possible quality image. If the result is not very good the wiper of P1 can be moved a bit more and P2 again trimmed to give a better image.
- If this still fails to provide an acceptable result tune the TV to the next harmonic. This must give a decent image.
The controls for bass, mid-range, and high frequencies on most commercial guitar amplifiers may be compared with those on a hi-fi installation. Unfortunately, they do not change the basic character of the sounds produced by a guitar string; to do so, many more additional units are required: phaser, chorus, flanger, fuzz box, and so on. In many cases, these units really do mellow the harsh notes produced by the guitar. The amplifier described here does not, and is not intended to, replace such additional units entirely. However, several of the add-on units are based on similar principles and can be imitated fairly easily, and well, by the voltage-controlled filter on which the design of the present amplifier is based. Mixing the outputs of a voltage-controlled filter (VCF) allows the continuous transition from all pass to notch mode. Furthermore, the signal from the integral fuzz circuit may be added to the outputs of the VCF, so that with only four potentiometers a whole spectrum of tone colour variations becomes available.

**Voltage-controlled filter (VCF)**

The VCF is a simplified version of that used in the Formant synthesizer (see *Elektor (UK)* December 1977, page 12-27). It is built from opamps A2, A3 and A4 as shown in figure 1, which function as high pass, band pass, and low pass filter respectively. Stereo potentiometer P3 enables the setting of a specific turnover point, that is, the centre frequency of the band pass filter.

**Overdrive (fuzz) circuit**

Either the direct or the filtered signal from the guitar may be fed to opamp A5 by switch S1. The gain of the amplifier can be set within wide limits by P8; this is vital because the stage following A5 needs a threshold to function as limiter and so provide the required amount of distortion. The use of three pairs of diodes results in a smoother onset of limiting, that is, a progressive increase in distortion, which provides a tone reminiscent of valve amplifiers. The operation of the overdrive circuit is clarified in figure 2.

**Mixing**

Potentiometers P6...P9 allow the mixing of the outputs of the filter and the distortion generator. the wipers of all four are connected to the inverting input of opamp A7. Preset P10 enables the setting of the required feedback factor: the higher its value, the greater the gain of A7.

**Reverberation unit**

Reverberation springs have been a welcome addition to guitar amplifiers for a long time. Although they do not perform miracles, they add to the fullness of the sound. The principle on which they work is that the sounds to be reverberated are magnetically coupled to one or two metal...
springs. Because of the elasticity of the springs, the mechanical waves to which the signals from the guitar have been converted take a certain time to reach the other side of the spring where they are converted to electrical signals. Integrated a.f. amplifier IC3 drives the input coil: a standard opamp would not be able to provide sufficient energy, that is, output current.

Opamp A8 is a mixer in which the direct and the reverberated signals are added together. Potentiometer P12 enables continuous adjustment of the level of the echo. The relatively low value of R17, compared with that of feedback resistor R16, provides a fiftyfold gain of the reverberated signal.

Calibration

The potentiometers are all brought out at the front panel and their setting will be discussed under operation and setting up.

Depending on the type of pickup used, the peak value of the signals produced by an electric guitar vary widely. Preset P1 determines the gain of input amplifier A1. To start with, set the wiper of this control to the centre of its travel. Then connect the output of A1 (pin 7) to the output amplifier, and connect an electric guitar to the input of the circuit. If the 30-watt a.f. output stage described elsewhere in this issue is used, set the potentiometer P13, between A1 and that amplifier to maximum. Also, set the volume control on the guitar to maximum.

The maximum required volume can now be set with P10, but only after P6 . . . P9 have been turned open (wipers at output of opamps A4, A3, and A2 respectively). P3 and P4 have been set to the centre of their travel, and P8 and P12 so that their wipers are at earth potential. The setting of P2 is immaterial. When all this is done, the basic sound of the guitar, without distortion and reverberation, should be heard in the loudspeaker. If the sound is distorted, it probably means that A1 is overloaded. The remedy is to reduce its gain with P1. If you have an oscilloscope, check that the signals at the output (pin 7) of A1 are not being limited.

It may also be that the output stage is overloaded; in that case, reduce its gain with P13 until the sound is fairly soft. If there is still distortion, A7 or A8 may be overloaded. The remedy for this is to

Figure 1. Circuit diagram of the preamplifier.

Figure 2. A clean sine wave (a) at the input of the overdrive (fuzz) circuit appears flattened (b) at the output if its peak value is equal to, or exceeds, the thresholds. G1 . . . G3, or the three pairs of limiting diodes. At x the first diode pair starts to conduct, at y, the second also, and at z all diodes conduct.
reduce the gain of A7 with P10. Again, if you have an oscilloscope, the output of A7 (pin 8) or of A8 (pin 14) may be checked for clipping. It is, however, very unlikely that there is overloading of these stages.

**Setting the reverberation**

The level of the signal applied to the reverberation exciter coil is determined by preset P11. To find the correct level, first set P12 to maximum. Next, move the wiper of P11 slowly from earth potential and simultaneously pluck one of the guitar strings. If everything is all right, the echo should become clearer and clearer. However, at a certain point, that is, when the output level of IC3 becomes too high, the echo becomes muffled and suffers from frequency-dependent distortion. To avoid this happening even when the guitar is plucked vigorously, carry out this test with firm plucking of the string. If the echo is too weak with P11 and P12 at maximum, it may be enhanced with P10, even though this also increases the level of the direct signal.

**Operation and setting up**

**Playing without overdrive (fuzz):** set P9 to zero (wiper at earth) and with P6... P8 choose the desired bass, mid-range, and treble response. It is important that the setting of each of these controls is compatible with that of the others. When all three are set for identical gain, the output of the guitar sounds virtually natural. Potentiometer P4 is of considerable importance to the operation of the VCF: it determines the quality, Q, that is, the slope of the pass band of the filter. When the Q is high (steep slope) it is possible to produce artificial resonance peaks in the band-pass characteristic which give the sound a distinct colouring. This is also affected to some extent by the setting of P3.

Varying P3 (imagine this control fitted in a foot-operated swell) with Q high and only the low-pass filter section operating causes a wa-wa effect. With a low Q and the mid-range frequencies attenuated, slowly altering the crossover frequency gives rise to a phasing effect.

When the wiper of P4 is at earth potential, the VCF functions as an oscillator and it is therefore necessary that P5 is adjusted so that with maximum Q the filter just does not oscillate.

**Playing with overdrive (fuzz):** when switch S1 is in position 1, the entire sound from the guitar becomes overdriven.

Unlike many other guitar amplifiers, the present one allows the continuous mixing of the original and overdriven sounds: this may be arranged by a foot switch connected to jack socket S (see figure 1). If only the overdriven sound is wanted, potentiometers P6...P8 must be turned off completely (wipers at earth). The degree of overdrive may be set with P2 to individual taste.

When S1 is in position 2, only those frequencies that lie above the crossover point set by P3 will be overdriven. If you mix the fuzzy high frequencies with the original low ones, a very pleasant, hoarse sound ensues that cannot be produced by a traditional fuzz box (see figure 3).

Because of space considerations, we cannot describe all possible sound variations, but hope that the examples given will spur you on to further experimentation.

**Power output stage**

A low-weight, portable guitar amplifier of modest dimensions requires a power output stage that is small, reliable, efficient,
and yet provides sufficient power to the audience whose hearing aids would tilt the audience towards their hearing aids.

To cut a long story short, we have opted for the 30-watt output stage described elsewhere in this issue. The complete set-up gave very satisfactory results during tests and operation in small halls; it would probably not be quite suitable for use in larger halls.

**Power supply**

Power for the pre-amplifier is derived from the output stage of the pre-amplifier already fitted with appropriate take-off terminals. If you do not use the 30-watt output stage, you need a supply that is capable of providing +18 V@35 mA (positive line) and ±22 mA (negative line).

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**Figure E** View of the top of the chassis and the view of the front panel. Important to adhere to the wiring layout to prevent unwanted hum. All signal lines must only be connected to earth where shown or at the front panel. It is important to adhere to the wiring layout to prevent unwanted hum.
Loudspeaker

Never use a loudspeaker designed for use in hi-fi installations for the following reasons: The amplitude of a vibrating guitar string is not particularly large; in the case of the top strings, it is hardly possible to see with the naked eye whether they are vibrating, especially if plucked only lightly. The amplification consequently required to make them audible is quite considerable.

If, however, a string is plucked vigorously, because of the type of music or the temperament of the player, it is deflected quite a distance from its rest position. The instantaneous voltage then induced in the pick-up coil reaches a very high peak and, in modern hi-fi equipment, this is faithfully transferred to the loudspeaker which in consequence may easily be damaged or destroyed. Fortunately, there are loudspeakers available which have been specially designed for use with electric guitars. They are characterized by a very rigid suspension of the cone and their ability to cope with the wide dynamic range of electric musical instruments.

Basically, the loudspeaker should be able to handle not less than 50 watts (sine wave) and have an input impedance of 8 ohms or 4 ohms. Note that mid-range and treble speakers are not just superfluous but unwanted! After all, we are not looking for linear transfer of the guitar sounds: it is the unfaithful reproduction that makes the music of electric guitars so popular!

Construction

The complete amplifier, including loudspeaker, may be housed in a case as suggested in figure 4. The shape corresponds closely to current market trends. Dimensions are primarily dependent upon the loudspeaker: unfortunately, we have not been able to find a suitable speaker that would make it possible to house the amplifier in a truly portable case.

The top compartment of the wooden case offers ample space for the pre-amplifier, output stage, and power supply. The best material to use is 19 mm (¾ inch) chipboard. The various panels should be fastened together with dowels and wood glue; if you must, chipboard screws may also be used.

The completed case may then be covered in, say, black leatherette and the corners protected by suitable metal corner pieces to give the whole a professional appearance.

The electronic circuits are best mounted onto a chassis which is fastened to the front panel so that the complete amplifier may be slid in and out of the upper compartment. The front panel should be fastened to the case with suitable chipboard screws. It is wise to fit two runners at the underside of the chassis so that it does not lie directly on the wood: this has the advantage that any fixing screws for the transformers, PCBs, and so on may protrude from the underside of the chassis without causing any problems.

Some useful hints

If the wiring to the potentiometers, the power lines, and the wires connecting the pre-amplifier to the output stage are not placed with care, the amplifier may not respond as intended. The input impedance of the loudspeaker must be well-matched to that of the pre-amplifier. A frequency response of +6 dB/octave is recommended.

The amplifier will not be very loud, and an output stage is necessary to boost the signal. The power supply should have regulation to protect the components from supply transients.

To avoid hum and noise, the amplifier should be shielded from the mains transformer and the loudspeaker should be placed as far as possible from the mains transformer. The screened housing of the unit does not offer all that much protection against the strong electro-magnetic field existing in the immediate vicinity of the transformer. It is also better to fit the unit rigidly to the chassis to prevent any mechanical vibrations from the loudspeaker and mains transformer being transferred to it. This is easily accomplished with a felt washer fitted between the chassis and the unit housing; it is wise to glue the washers in place.
The input of the device is formed by differential amplifier T2/T3 whose emitter resistance consists of current source T1/D1/D2. The output of the amplifier is fed to driver T6 whose collector resistance is formed by current source T4. Transistor T5 provides a constant bias voltage for the output transistors; the bias allows a quiescent current of about 50 mA through these transistors. The output transistors are arranged as quasi-complementary darlington: T7 and T9 form an n-p-n darlington; T8 and T10 are the complementary pair. Any asymmetry of T8/T10 is negated by diode D5.

Circuit description

The amplifier circuit, shown in figure 2, is designed for operation from a ±25 V symmetrical power supply. The full 50 V decoupled by C4 and C8, is applied to the output transistors, pins 6 and 8, in the STK077. The supply for the input and driver stages is decoupled by R3/C3 and R5/C7 respectively and applied to pins 10 and 4. Feedback is arranged by connecting the output, pin 7, to the inverting input of the differential amplifier, pin 3, via R6. The gain, A, is determined by the feedback factor, that is, the ratio R6/R4 = A = (R6 + R4)/R4.

When planning the power output stage for the guitar amplifier described elsewhere in this issue, we came across an interesting hybrid IC made by Sanyo: the STK077. In contrast to a monolithic IC where all the components are manufactured into or on top of a single chip of silicon, a hybrid IC consists of several separate component parts, attached to a ceramic substrate, that are interconnected by an appropriate matallization pattern or by wire bonds. Hybrid ICs are frequently encountered in medium power (30...60 W) hi-fi equipment. They are, however, also eminently suitable for use in home-constructed amplifiers, because they are more reliable and smaller than circuits built up from discrete components, and are not so vulnerable and susceptible to oscillation as monolithic IC stages. Hybrid ICs are generally available with power ratings up to 70 W and are normally reasonably priced.

30 watt a.f. output stage

The STK077 is a 30 watt hybrid IC that is ideal for use in small mono a.f. amplifiers or medium power stereo equipment. It is also of interest to those who want a small amplifier for fitting into an active loudspeaker box. The innards of the STK077 form a fairly conventional a.f. amplifier circuit as can be seen from figure 1. Note that the power transistors are mounted direct on the cooling area of the device to ensure better heat dissipation.

With values shown this amounts to nearly 27 dB. The input signal is applied to the non-inverting input (pin 1) of the differential amplifier. DC zero potential is ensured by resistor R2, which carries the base current for T2. Pin 2 is the earth terminal which is internally connected to the metal base of the STK077. Stability of the output transistors is arranged by various methods. On board there is a Miller capacitor between base...
and collector of driver T6, while externally capacitor C5 is connected between pins 3 and 5. Capacitor C9 and resistor R7 at the output, pin 7, ensure a defined load at high frequencies and this enhances the stability under no-load conditions. Finally, the input has been provided with an RC low-pass filter (R1/C1) which increases the rise time of the input signal and so reduces the transient intermodulation distortion (TIM).

The power supply, with the exception of the mains transformer, is housed on the same printed circuit as the amplifier. It consists of an unregulated circuit: four standard diode rectifiers, and two electrolytic smoothing capacitors each shunted by a foil capacitor.

When a mains transformer with $2 \times 18$ V secondary is used, the direct output voltage under no-load conditions is of the order of 25 V, falling to about 22 V when a normal load is connected. A 1 A transformer can be used for output powers up to 20 W.

More power

With a ± 20 V power supply, the STK077 provides 20 watts into 6 ohms, or 30 watts into 4 ohms. In the latter case, both the third harmonic distortion and the current consumption are somewhat higher than in the former. If you want higher power, one of the series STK078...STK083 may be used: the printed circuit board remains unchanged, but it is, of course, necessary to use an appropriate mains transformer and higher rated electrolytic capacitors. Data for these are given in table 2.

Practical tips

The mains transformer may have a single centre-tapped secondary or two separate windings. In the latter case, proceed as follows: connect one of the terminals of secondary 1 with one of secondary 2 and measure the a.c. voltage between the two free terminals. If this is 0 V, the terminals of one of the secondaries must be changed over so that across the free terminals an a.c. voltage of twice the rating of one of the secondaries is measured. The interconnected terminals become the equivalent of the centre tap which is connected to earth as shown in figure 2.
30 watt a.f. output stage

Parts list

Resistors:
R1 = 1 k
R2, R8 = 56 k
R3, R0 = 100 k
R4 = 2 k
R7 = 427
P1 = 100 k logarithmic potentiometer

Capacitors:
C1 = 470 p
C2 = 1 μ/16 V
C3, C7 = 220 μ/35 V
C4, C8 = 10 μ/35 V
C5 = 1p8
C6 = 47 μ/16 V
C9 = 47 n
C10, C12 = 4700 μ/40 V
C11, C13 = 330 n

Semiconductors:
D1 = D4 = 1N5401
IC1 = STK077 or
STK078 STK083

Miscellaneous:
S1 = DPST means switch
Tr1 = mains transformer, secondary 2 x 18 V/1 A
F1 = fuse, 100 mA, slow blow
F2 = 1 A (8 Ω loudspeaker) or 1.6 A (4 Ω loudspeaker) slow blow (2 seconds)
Heat sink temperature rise 1.5 K/W
Printed circuit board 85001

Figure 3. The printed circuit board is not only for use with the STK077 but also with other members of the family, STK078, STK083, which give output powers of not less than 24...40 watt into 8 ohms, depending on which member is used.

Failure of one of the power lines during operation of the amplifier would destroy the IC. It is, therefore, vital to ensure that both power lines are connected properly at all times. Furthermore, under no circumstances should either the positive or the negative line be protected by a fuse. It is, of course, also important that the voltages across the two secondaries as well as capacitors C10 and C12 are identical.

The value of the thermal rating of the heat sink stated in the parts list and table 2 applies to the amplifier being driven hard. If the amplifier is intended for domestic (music) use only, the value may be

Table 1

| Supply voltage, 
| ±32 volts |
| Case temperature - maximum |
| ±22 volts |
| Short-circuit duration - maximum |
| 85°C |
| Load resistance - recommended |
| 2 seconds |
| - minimum |
| 8 ohms |
| Quester current - maximum |
| 4 ohms |
| Power into 8 ohms - minimum* |
| 100 mA |
| Bandwidth - at 1 W into 8 Ω |
| 50 mA |
| Output direct voltage - maximum |
| 20 watts |
| Input voltage (rms) - for 20 W into 8 Ω |
| ±70 mV |
| Input impedance |
| 10 Hz...30 kHz |
| ±500 mV |
| Current consumption - at 20 W into 8 Ω |
| 10 Hz...30 kHz |
| ±90 kilohms |
| - at 30 W into 4 Ω |
| 1 A |
| - at 30 W into 4 Ω |
| 1.5 A |

*In range 20 Hz...20 kHz, THD = 0.3%, \( U_{b} = ±22 V \)
somewhat lower. It may be useful to drill out the fixing holes in the heat sink slightly to avoid mechanical stress during its installation. The use of silicone heat transferring grease is strongly recommended.

If the amplifier is used for mono applications, a fuse may be fitted in the loudspeaker lead: this is shown in dashed lines in figure 2. The fuse should be of the medium slow (about 2 seconds) type. Values for use with other ICs in the series are given in table 2.

The heat sink and printed circuit board should be fixed to a chassis with the aid of an aluminium angle piece as shown in figure 4, since the terminals of the IC cannot support the PCB.

As always in a.f. amplifiers, the wiring layout should be thought out carefully. On the premise that any wires may cause problems, we reduced the amount of wiring by designing the power supply and the amplifier on one PCB. The only wires consequently required are three to the mains transformer, two to the loudspeaker, and a screened one for the input signal.

If two amplifiers are built for stereo applications, the mains transformer of twice the rating stated in the parts list. Separate power lines should then be connected to each of the PCBs. Separate earth return lines for each loudspeaker are also required: this means that each PCB is connected to the appropriate loudspeaker by a two-core cable.

If you want to use a 4-ohm loudspeaker, the mains transformer should be capable of providing a secondary current of 1.5 A: alternatively, a transformer with lower secondary voltage (2×15…16 V) may be used. The heat sink should also be adapted to the higher dissipation, for instance, 1.5 K/W instead of 1.7 K/W The only other difference between the 4-ohm and 8-ohm versions is that the former has a slightly higher third harmonic distortion (THD) factor than the latter, as shown in figure 5.
Whenever two (or more) large programs must exist at the same time in a 6502's memory there is bound to be a conflict as regards page 0 and the stack (page 1). The situation could arise if a BASIC interpreter and a DOS (disk operating system), or both of these and a video handler, are being used simultaneously. One of the accepted methods of solving this problem involves reserving two areas in random access memory where these pages are 'duplicated', giving, for example, E000...E0FF for page 0 and E100...E1FF for the stack. Every time the computer changes from one program to the other the contents of these areas of RAM are swapped with the appropriate contents of pages 0 and 1. This removes any possibility of corrupting the pointers on page zero or the contents of the stack.

**JSR SWAP**

One of the notable characteristics of the 6502 microprocessor is the way it uses pages 0 and 1. The 256 bytes from 0000HEX to 00FFHEX can be addressed using commands specific to this zone. This is known as page zero addressing: the most significant address byte is not specified as it is implicit in the operation code. The same 256 bytes can be used as 16-bit pointers for indirect indexed addressing of the rest of the memory. The 256 bytes from 0100HEX to 01FFHEX form the 6502's stack. This is a register generated by the processor itself to enable it to store certain information. It operates on the principle of 'last in first out' so the processor can only work with the last item stored on the stack. An internal stack pointer continually indicates the address of this last item.

It is obvious that the slightest careless change of the parameters saved on these two pages will upset the operation of a program that is to be run — usually with no possibility of correcting the error. When two programs are run in parallel it is essential that they do not destroy each other's page 0 and 1 parameters. This is an extra worry for the programmer, particularly as it can be an insoluble problem. As soon as the programs that are being run reach a certain size it is better to find a way to break away from the shackles governing the use of pages 0 and 1.

The routine proposed here is used to move the contents of page zero and page one to another area of RAM where they can be changed at will. At the same time the contents of the RAM area in question is transferred to pages 0 and 1. The name of the routine is SWAP, for obvious reasons.

Using this routine means that the programmer no longer has to worry about the contents of pages zero and one when leaving one program to carry out another. All he has to do is run the SWAP routine. Page zero (0000HEX...00FFHEX) and page one (0100HEX...01FFHEX) of the first program are saved at E000HEX...E1FFHEX, and the contents of pages 0 and 1 for the second program, which had been stored at E000HEX...E1FFHEX, are transferred to E000HEX...E1FFHEX. When returning from the second to the first program the SWAP routine is again executed and the same procedure is carried out again to return the two pairs of pages zero and one to their original locations. The locations we have used to store pages 0 and 1 (E000HEX...E1FFHEX) can, of course, be changed to suit the system with which the SWAP routine is used, provided the area reserved is in random access memory. Similarly the SWAP routine itself must be run in RAM. A look at the last line of the listing will show why this is necessary. Indexing and swapping are the two procedures that make this routine possible so bear this in mind.
Most of the principles involved in programming in BASIC have already been discussed. Most of the remaining BASIC statements will now be explained.

Having studied this third part of the series, it should be possible to write even fairly complicated programs; the last part of the series will deal with trouble-shooting in programs (‘de-bugging’).

There are several ways to enter data into a computer. If something is to be calculated, the ‘data’ usually consists of numbers. In Part 2, these were entered by assigning values to variables or by entering the numbers as part of the program. However, a different approach will often prove more useful in practice, using either of two further BASIC statements: INPUT and READ...DATA...

INPUT
By using the INPUT statement, data can be entered while the program is running. Or, to be more precise: when the computer finds an INPUT statement in the program, it stops and waits for the data to be entered before continuing with the program.

The complete statement consists of ‘INPUT’ followed by the name of a variable. For example:

```
> 10 INPUT A
> 20 PRINT A
> 30 END
> RUN
?
> 256
> 256
> BRK AT 30
```

When running the program, the computer prints a question mark as soon as it finds the INPUT statement on line 10. It then waits until a number is entered, followed by the CR key. As soon as the number ‘256’ was entered, this value was assigned to the variable A - after which the rest of the program could be carried out.

The same statement can be used to assign values to several variables at the same time: ‘INPUT A, B, C,...’. When the question mark is printed, all corresponding numbers must be entered: ‘? 123, 62, 23,...’. The INPUT statement can also be used to enter text variables, as will be explained in Part 4. The advantage of using the INPUT statement is that it opens the possibility of dialogue with the computer. Depending on intermediate results, for instance, the program can be re-run with new values until a desired final result is achieved. For instance, let us assume that we wish to know the returns after a certain number of years (N) from a personal investment (I) at various interest percentages (P).

The final value (F) is equal to:

```
F = I x (1 + P/N) N
```

In BASIC, this becomes:

```
F = 1 x (1 + P/100) N
```

A suitable program is therefore as follows:

```
> 10 PRINT "ENTER INITIAL INVESTMENT."
> 11 PRINT "INTEREST RATE."
> 12 PRINT "AND NUMBER OF YEARS."
> 20 INPUT I, P, N
> 30 LET F = I x (1 + P/100) N
> 40 PRINT "THE FINAL VALUE IS:", F
> 50 END
> RUN
```

```
ENTER INITIAL INVESTMENT: 1000
INTEREST RATE: 5
AND NUMBER OF YEARS: 10
THE FINAL VALUE IS 2367
```

In other words, with an initial investment of £1000 and a 5% interest rate, the final value after 10 years will be £2367.

READ...DATA...

Another way of entering data is the use of so-called ‘data blocks’. A data block is a group of data, preceded by the DATA statement; the various numbers and/or texts are separated by comma's. A
data block is usually located at the end of a program; it is entered prior to running the program. In the main program, READ statements are used to recall the data as required; each new READ statement causes the next number, text or group of data to be recalled. For example:

```
> 10 READ A, B, C
> 20 D = A + B * C
> 30 READ E
> 40 F = D/E
> 50 PRINT D, F
> 60 DATA 1, 2, 3, 3
> 70 END
> RUN
> 6 2
> BRK AT 70
>```

In line 10, the first three data are read from the data block on line 60 and assigned to the variables A, B and C. In other words, A becomes 1, B becomes 2 and C becomes 3. Then D is calculated (line 20); the next number is recalled from the data block (line 30; E becomes 3); and so on.

As can be seen, several READ statements can be used — the data will be read out consecutively. Similarly, several DATA statements can be used; however, there is little point in this — they are simply used in consecutive order — and it makes it more difficult to locate and modify the data at a later date.

Obviously, it is important that enough data is stored in the data block. If, after reading the last of the data, the program encounters a further READ statement, it will print some comment on the lines of 'OUT OF DATA IN xxx' (where 'xxx' is the line number of the READ statement where the data block proved to be empty). In some BASIC dialects, the same data block contents can be re-used several times: the RESTORE statement causes the computer to start again at the beginning of the block.

The READ . . . DATA . . . statements are not known in NIBL.

REM
The REM statement (for 'REMark') is used to add explanatory text to the program, as an aid to the programmer. The text is simply entered after the REM statement; it will be ignored by the interpreter, but will reappear when a LIST command is given.

This statement will prove its value when a program has not been used for some time: it serves as a quick reminder of the meaning of variables, the importance of sections of program, etc. For example, in the 'personal investment' program given above:

```
> 1 REM THIS PROGRAM CALCULATES
> 2 REM THE FINAL VALUE
> 3 REM OF AN INITIAL INVESTMENT
> 4 REM AFTER n YEARS
> 5 REM AT AN INTEREST RATE OF P PERCENT
> 10 PRINT "ENTER INITIAL INVESTMENT;"
> 11 PRINT "INTEREST RATE;"
> 12 PRINT "AND NUMBER OF YEARS;"
> 20 INPUT I, P, N
> 30 LET F = 1 + (1 + P/100) ^ N
> 40 PRINT "THE FINAL VALUE IS", F
> 50 END
> (etc.)
```

The program itself is not affected in any way by the REM statements; they only reappear when a program listing is requested. They do, of course, use up some memory space — but there will normally be sufficient memory available.
Standard functions
To simplify programming in BASIC, 10 standard mathematical functions are available:

<table>
<thead>
<tr>
<th>function</th>
<th>standard</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIN(X)</td>
<td>sine x</td>
<td>x is the angle in radials.</td>
</tr>
<tr>
<td>COS(X)</td>
<td>cosine x</td>
<td></td>
</tr>
<tr>
<td>TAN(X)</td>
<td>tangent x</td>
<td></td>
</tr>
<tr>
<td>ATN(X)</td>
<td>arctangent x.</td>
<td></td>
</tr>
<tr>
<td>EXP(X)</td>
<td>e^x (e = 2.71828 ...).</td>
<td></td>
</tr>
<tr>
<td>ABS(X)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOG(X)</td>
<td>log</td>
<td></td>
</tr>
<tr>
<td>SQR(X)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INT(X)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SGN(X)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note that for the sine, cosine and tangent functions the angle must be expressed in radians (1 rad. = 57.2958°, or 1° = 0.017453 rad.); for the arctangent function, the result will be expressed in radials. The LOG (natural logarithm) and SQR (square root) functions automatically take the absolute value of x, without giving an error indication. For instance: SQR (-4) = 2.

The INT (integer) function sometimes causes confusion. It produces the largest whole number that is smaller than or equal to x. For positive numbers, this simply means omitting the decimal fraction: INT (2.78) = 2. For negative numbers, however, the result is one less than one might assume: INT (-2.78) = -3!

As can be seen from the examples given above, the number ('X') must always be included in brackets. Usually, it is also permissible to use a variable or even an algebraic expression here. A few examples are given in the following program:

```
> 10 REM EXAMPLES OF STANDARD FUNCTIONS
> 20 PRINT "ENTER ANGLE IN DEGREES"
> 30 INPUT A
> 40 LET 8 = A/57.2958
> 50 REM B IS ANGLE IN RADIALS
> 60 PRINT "THE SINE OF"; A; "DEGREES IS"; SIN (B)
> 70 PRINT "INT(5.3) = "; INT(5.3)
> 80 PRINT "INT(-8.5) = "; INT(-8.5)
> 90 PRINT "INT(7) = "; INT(7)
> 100 END
> RUN

ENTER ANGLE IN DEGREES
? 30
THE SINE OF 30 DEGREES IS 0.5
INT(5.3) = 5
INT(-8.5) = -9
INT(7) = 7
BRK AT 100
```
It shouldn't come as a surprise that there are exceptions to the rules given above. Some BASIC dialects don't use the absolute value of \( x \) in the LOG and SQR functions if a negative value is entered for \( x \) — they print an error indication.

In Tiny BASIC (and, therefore, in NIBL) these standard functions are unknown. For that matter, the INT function would be pointless, since Tiny BASIC only recognises whole numbers in the first place. NIBL does recognise certain other functions; these will be discussed in part 4.

Jump statements

In all program examples given so far, the programs were executed in a fixed (numerical) order. The statement with the lowest line number was carried out first, and so on. Where a different order is required, 'jump statements' can be used: 'GOTO', 'IF...THEN...' and so on.

GOTO

The GOTO statement is used when a 'jump' to a specified line number is required in the program. Since no initial check is required (to see whether certain specified conditions are met), GOTO is known as an 'unconditional statement'. An example:

\[
> 5 \text{ N} = 0 \\
> 10 \text{ PRINT N} \\
> 20 \text{ N} = \text{ N} + 1 \\
> 30 \text{ GOTO 10} \\
> 40 \text{ END} \\
> \text{ RUN} \\
> \text{ 0} \\
> \text{ 1} \\
> \text{ 2} \\
> \text{ 3} \\
> \text{ (etc.)} \\
\]

In this program, \( N \) is first made equal to zero and this value is printed. In line 20, the value is increased by 1 ('incremented'); line 30 initiates a jump back to line 10, where the result (1) is printed; and so on. The computer will continue to run around this 'loop', printing all numbers from 0 up — until it either runs out of paper or reaches its maximum count.

Obviously, if something like this occurs when running a program (due to a programming error), there must be some way to stop the computer. There is: the 'BREAK' key. As soon as this key is operated, the computer will stop the program and print out 'BREAK AT 20' or something similar.

IF...THEN...

Often, a jump to a new line number is only required if certain conditions are fulfilled. The 'conditional statement' offers the possibility of executing different sections of program, depending on intermediate results. In general, the statement will be entered as

IF (relational expression) THEN (line number).

The 'relational expression' will normally be some kind of comparison, for instance '\( X = 10 \)' or '\( A > B \)'. If the result of the comparison is 'true', the computer will jump to the specified line number; if not, it will simply proceed to the next program line.

As an example, let us assume that a program is required that will print out the multiplication table of any number ('\( X \)'). The flow chart for a suitable program would be as shown in figure 1. The sequence of operations is as follows: after the 'initialisation' procedure — in this case, making \( N = 1 \) — the computer will request the value of \( X \) (step 2). In steps 3 and 4, \( 1 \times X \) is calculated and printed, after which \( N \) is incremented by 1 (step 5). Then, in step 6, the value of \( N \) is checked: if it is smaller than or equal to 10, the computer must jump back to step 3 for the next calculation. After calculating and printing all values up to \( 10 \times X \), \( N \) will become 11 in step 5, the result of the comparison in step 6 will be 'false' and the program will have reached the END.
The corresponding program is as follows:

```plaintext
1  BEGIN
   Include N = 1
   INPUT X
   Calculate M = N + X
   PRINT M
   N = N + 1
   IF N <= 10 THEN 50
   END
```

In NIBL, if a jump to a line number is required 'GOTO' must be used instead of 'THEN'. The two possibilities are therefore as follows in NIBL:

IF (relational expression) GOTO (line number), and IF (relational expression) THEN (statement).

FOR ... NEXT ...
Another way to run through the same section of program several times in succession is by means of the FOR ... NEXT ... statement. This really consists of two statements that must be entered on different program lines, as illustrated in the following example:

```plaintext
10 FOR A = 1 TO 5
20 PRINT A
30 NEXT A
40 ENO
50 RUN
```

In the FOR statement, a variable (A), an initial value (1) and a final value (5) are specified. The section of program between the FOR and the NEXT statements is executed several times, starting with the initial value for A and then incrementing it by 1 until the final value is reached.

The initial and final values need not be given as numbers. Both variables and expressions can also be used (for instance: 'FOR A = N TO 50 * N'). The final value should, of course, be greater than (or at least equal to) the initial value.

It is not a good idea to use the 'running variable' (A in the example given above) at any other point in the program — except for other FOR statements. The statements between FOR and NEXT are often referred to as the 'FOR-NEXT block'. Before executing a FOR-NEXT block, the computer first calculates the initial and final values for the running variable. If these values depend on another variable, its value is taken at that moment; once calculated, the initial and final values remain unchanged as the block is executed, so that even if the value of the variable is then altered this will have no effect on the final value.
A more 'practical' example of the FOR ... NEXT ... statements is a program for the calculation of $A!$. 

$A! = 1 \cdot 2 \cdot 3 \cdot \ldots \cdot (A-2) \cdot (A-1) \cdot A$. For example: $3! = 1 \cdot 2 \cdot 3 = 6$. By definition, $0! = 1$.

A flow chart for a suitable program is given in figure 2.

After the initialisation procedure, the value for $A$ is entered (a positive number). If $A = 0$ or 1, the result will be 1 and there is no point in running through the whole program — in fact for $A = 0$ it wouldn't work, since the final value in the FOR statement would be less than the initial value — so the result can be printed immediately. For all other values of $A$, the calculation described above is performed in the FOR-NEXT block and the result is then printed. The corresponding program is as follows:

```basic
> 10 REM CALCULATION OF A!
> 20 LET N=1
> 30 PRINT "ENTER A"
> 40 INPUT A
> 50 IF A <= 1 THEN 90
> 60 FOR X = 1 TO A
> 70 LET N = N * X
> 80 NEXT X
> 90 PRINT A; "! = "; N
> 100 ENO
> RUN
ENTER A
? 3
3! = 6
BRK AT 100
```

After writing a program like this, it must be checked with several values for the variables which should give known results (in this example, say, 3 and 5); special attention should be paid to values that require a different procedure (0 and 1 in this program).

FOR ... TO ... STEP ...

In the FOR ... NEXT ... statements as described so far, the running variable is increased by 1 each time round the loop. This is not always desirable: an increase by a larger or smaller amount may be required. In that case the STEP statement can be added, as follows:

FOR I = -90 TO 90 STEP 15

The running variable will now be increased in steps of 15. Other steps can be specified, and even negative steps are permitted — in other words, the running variable is decreased step-by-step. For example:

FOR I = 0 TO -90 STEP -10

A certain amount of care must be taken to ensure that the running variable can reach its final value with the specified steps. It would be asking for trouble, for example, to specify:

FOR I = 0 TO 90 STEP -10

DO ... UNTIL ...

The DO ... UNTIL ... statement is only known in relatively few BASIC dialects. The reason for
discussing it here is that this statement is also known in NIBL. As an example of its use, let us consider the following program section:

```
> 170 N= 0
> 180 DO
> 190 N=N+1
> 200 PRINT "EXAMPLE OF A DO - UNTIL LOOP"
> 210 UNTIL N= 5
> 220 . . .
```

The statements between DO and UNTIL are repeated for as long as the expression after UNTIL remains 'false'. As soon as it becomes 'true' the computer moves out of the program 'loop' and proceeds with the following statement. In the example given above, the text will be printed 5 times.

Subroutines, GOSUB . . . RETURN
When writing large programs, 'subroutines' can be extremely useful. It is often the case that a certain section of the program is required several times—for example, a complicated input/output routine or the A1 calculation described earlier. This program section is then entered after the main program, as a so-called subroutine. When it is required in the course of the main program a GOSUB statement is used, followed by the first line number of the subroutine. The subroutine itself will normally be concluded with a RETURN instruction, causing the computer to jump back to the line number immediately following the GOSUB statement in the main program.

As an example, let us assume that the computer is being used as an aid to circuit design, and that we will regularly be using two resistors in parallel to approximate a desired resistance value. A section of the main program and the subroutine might then be as follows:

```
> 110 PRINT "SELECT TWO RESISTANCE VALUES FOR R2!"
> 120 GOSUB 500
> 130 A=P

> 500 REM SUBROUTINE FOR CALCULATING PARALLEL RESISTANCE
> 510 PRINT "ENTER VALUE FIRST RESISTOR"
> 520 INPUT X
> 530 PRINT "ENTER VALUE SECOND RESISTOR"
> 540 INPUT Y
> 550 P= X*Y/(X+Y)
> 560 PRINT "THE PARALLEL RESISTANCE IS", P
> 570 PRINT "IS THIS VALUE SATISFACTORY?";
> 580 PRINT "IF SO, ENTER 1; IF NOT, ENTER 0"
> 590 INPUT Z
> 600 IF Z=0 THEN 510
> 610 RETURN
```
When the computer reaches the point in the main program where it needs the value for R21 — which will be approximated by connecting two resistors in parallel — it prints out the corresponding request and then jumps to the subroutine. Once there, the request is made more specific by asking for the value of the first resistor. Having then requested and received the second value, the parallel resistance is calculated and printed. This is followed by the query whether or not the value proves satisfactory. Depending on the answer, the computer will either repeat the subroutine (asking for new values) or else jump back to the main program and assign the calculated value to the corresponding variable (A) in the main program.

Loops within loops are also possible — in fact the program given above is an example: the subroutine, effectively, is a loop within the subroutine, an IF . . . THEN . . . statement is used to create a further loop.

Figure 3 illustrates 'loops within loops' in a flow chart. In this case, however, loop 3 is 'dangerous'. If loop 2 is either a FOR-NEXT or a DO-UNTIL loop, a jump to a line number outside this loop is not permitted: the computer must first be given the chance to complete its countdown (final value in the FOR-NEXT statement) or fulfill the condition specified (in the OO-UNTIL statement).

Furthermore, a program should not loop-the-loop ad infinitum. Each loop within another loop is referred to as 'one (further) level down' and when 'nesting' loops in this way there is a maximum number of levels (depending on the BASIC dialect) that should not be exceeded. In NIBL, for instance, the maximum nesting depths for the various types of loop are as follows:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOSUB RETURN</td>
<td>B levels</td>
</tr>
<tr>
<td>FOR-NEXT</td>
<td>4 levels</td>
</tr>
<tr>
<td>OO-UNTIL</td>
<td>B levels</td>
</tr>
</tbody>
</table>

If the computer detects loop programming errors, it will indicate this by printing out some suitable comment. In NIBL, for instance, the indications are as follows:

<table>
<thead>
<tr>
<th>Error Code</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEST ERROR</td>
<td>there are too many loops within loops</td>
</tr>
<tr>
<td>FOR ERROR</td>
<td>FOR is not followed by NEXT</td>
</tr>
<tr>
<td>NEXT ERROR</td>
<td>NEXT was not preceded by FOR</td>
</tr>
<tr>
<td>NOGO ERROR</td>
<td>the line number indicated in a GOTO or GOSUB statement does not exist</td>
</tr>
<tr>
<td>RTRN ERROR</td>
<td>RETURN was not preceded by GOSUB</td>
</tr>
<tr>
<td>UNTL ERROR</td>
<td>UNTIL was not preceded by DO</td>
</tr>
</tbody>
</table>

A program example: Pay as you earn

To illustrate the possibilities of the BASIC theory discussed so far, let us consider a program that can calculate the costs involved in hire-purchase or pay-as-you-earn. In this case we will assume that:

- A fixed sum is repaid each month, which includes interest: the monthly payment M. This sum is to be calculated.
- The cost price of the item that we wish to buy is C.
- A starting capital, S, is available.
- A loan, L, is therefore required: L = C - S.
- The interest rate is P%.
- The loan is to be repayed within N years.
In the course of the program, we will also calculate:

- The amount already repaid \( R \) after \( X \) years.
- The amount still to be repaid \( O \), for Outstanding) after \( X \) years.
- The total interest, \( I \), paid in \( N \) years.
- How many times the cost of the item has been paid after \( N \) years \( (F) \).

To sum it up, the following inputs are required:
- the cost price, \( C \);
- the starting capital, \( S \);
- the interest rate, \( P \);
- the total number of years, \( N \);
- if required, an intermediate number of years, \( X \).

Based on this data, the following will be calculated:

- The loan, \( L = C - S \);
- The monthly payment,
  \[
  M = \frac{1}{12} \cdot \frac{L \cdot P^N}{100} \cdot \frac{1}{\left(1 + \frac{P}{100}\right)^N - 1}
  \]

- The amount repayed after \( X \) years,
  \[
  R = L \cdot \frac{1 + \frac{P^X}{100}}{\left(1 + \frac{P}{100}\right)^N - 1}
  \]

- The amount outstanding after \( X \) years,
  \( O = L - R \);
- The total interest paid in \( N \) years,
  \( I = M \cdot 12 \cdot N - L \);
- How many times the cost has been paid,
  \( F = \frac{1 + L}{L} \).

In these calculations, \( 1 + \frac{P}{100} \) appears several times. It is a good idea to calculate it at the beginning of the program and assign the value found to a further variable, \( V \). The various formulae will then appear in BASIC as follows:

\[
\begin{align*}
L &= C - S \\
V &= \frac{1 + \frac{P}{100}}{100} \quad \text{in} N \\
M &= L \cdot \left(\frac{P}{1200} \cdot V \cdot (V - 1)\right) \\
R &= L \cdot \left((1 + \frac{P}{100})^X - 1\right) / (V - 1) \\
O &= L - R \\
I &= M \cdot 12 \cdot N - L \\
F &= \frac{1 + L}{L}
\end{align*}
\]

Which brings us to the flow chart and program:
10 PRINT "ELEKTOR SOFTWARE SERVICE"
20 PRINT "LOAN REPAYMENT"
30 PRINT "WHAT STARTING CAPITAL IS AVAILABLE?"
40 INPUT S
50 PRINT "WHAT IS THE COST PRICE?"
60 INPUT C
70 LET L = C - S
80 PRINT "THE NECESSARY LOAN IS"; L; "POUNDS"
90 PRINT "WHAT IS THE INTEREST RATE?"
100 INPUT P
110 PRINT "IN HOW MANY YEARS MUST THE LOAN BE REPAYED?"
120 INPUT N
130 LET V = (1 + P/100) ** N
140 LET M = L * (P/1200) * V / (V - 1)
150 PRINT "THE MONTHLY PAYMENT IS"; M; "POUNDS"
160 PRINT "DO YOU WISH TO KNOW THE AMOUNTS ALREADY REPAYED?"
170 PRINT "AND STILL OUTSTANDING AFTER A NUMBER OF YEARS?"
180 PRINT "PLEASE ENTER 1 FOR YES, OR 0 FOR NO"
190 INPUT W
200 IF W = 0 THEN 320
210 IF W = 1 THEN 250
220 PRINT "PLEASE STUDY THE KEYBOARD CAREFULLY, THEN"
230 PRINT "ENTER 1 FOR YES, OR 0 FOR NO, TRY AGAIN"
240 GOTO 190
250 PRINT "AFTER HOW MANY YEARS?"
260 INPUT X
270 LET R = L * ((1 + P/100) ** X - 1) / (V - 1)
280 LET O = L - R
290 PRINT "AFTER"; X; "YEARS"
300 PRINT "YOU WILL HAVE REPAYED"; R; "POUNDS"
310 PRINT "AND"; O; "POUNDS WILL REMAIN OUTSTANDING"
320 LET I = M * 12 * N - L
330 PRINT "AFTER"; N; "YEARS, YOU WILL HAVE PAID"
340 PRINT "A TOTAL OF"; I; "POUNDS INTEREST"
350 LET F = (I + L)/L
360 PRINT "YOU WILL HAVE PAID"; F; "TIMES THE ORIGINAL LOAN"
370 END
Lines 220, 230 and 240 are included in the program in case an 'impossible' answer is given ('5', for instance) instead of 0 or 1. Since neither of the conditions given in lines 200 and 210 are then fulfilled, the computer will warn the operator and jump back to line 190 for another try.

Having entered the program, it can be tried out:

```plaintext
> RUN
ELEKTOR SOFTWARE SERVICE
LOAN REPAYMENT
WHAT STARTING CAPITAL IS AVAILABLE?
? 0
WHAT IS THE COST PRICE?
? 10000
THE NECESSARY LOAN IS 10000 POUNDS
WHAT IS THE INTEREST RATE?
? 9
IN HOW MANY YEARS MUST THE LOAN BE REPAYED?
? 30
THE MONTHLY PAYMENT IS 81 POUNDS
DO YOU WISH TO KNOW THE AMOUNTS ALREADY REPAYED
AND STILL OUTSTANDING AFTER A NUMBER OF YEARS?
PLEASE ENTER 1 FOR YES, OR 0 FOR NO
? 2
PLEASE STUDY THE KEYBOARD CAREFULLY, THEN
ENTER 1 FOR YES, OR 0 FOR NO. TRY AGAIN
? 1
AFTER HOW MANY YEARS?
? 10
AFTER 10 YEARS
YOU WILL HAVE REPAYED 1114 POUNDS
AND 8886 POUNDS WILL REMAIN OUTSTANDING
AFTER 30 YEARS, YOU WILL HAVE PAID
A TOTAL OF 19160 POUNDS INTEREST
YOU WILL HAVE PAID 2.916 TIMES THE ORIGINAL LOAN
```
QUESTIONS
1. Is it permissible to enter more information in a 'data block' than is actually required in the program? And what about storing less data than required?
2. What use is the REM statement?
3. Can extensive use of the REM statement cause problems?
4. What effect will 'jump' statements have on the time it takes the computer to run the program (the 'execution time')?
5. When using the FOR...TO...STEP statement, should the final value always be larger than the initial value?
6. What is the advantage of using subroutines?
7. When using FOR-NEXT and DO-UNTIL loops, why is it not permitted to 'jump out of the loop'?

ANSWERS TO QUESTIONS IN PART 2.
1. If an interpreter program were stored in RAM, it would be lost when the computer is switched off. It would then have to be re-entered before running even the shortest of programs. For this reason, it is normally stored in ROM.
2. The effect of the SCRATCH command is to erase the current program and the display.
3. The CLEAR command is used to reset the variables to 0. This command is often given before the RUN command; in fact, in some BASIC dialects it is effectively included in the RUN command.
4. The errors in the program lines are as follows:
   a) 150 LI ST 5: a space in the 'key word' (LIST) is forbidden.
   b) 10 PRINT 15: a space within the line number is forbidden.
   c) 160 PRINT CHAIR: quotation marks should be included ('CHAIR').
   d) 170 PRINT 1263 14: a space within a number is not permitted.
   e) 190 LET A = 0.31: in most BASIC dialects that recognise decimal fractions, '.31' should be written instead of '0.31'.
   f) 200 PRINT 4.35E1.2: the number following the E must be a whole number — the decimal point is never permitted here.
5. a) \(3 \times 2 + 8 + 15/3 = 19\).
   b) \(17 - 24/2 = 13\).
6. In BASIC, a variable should consist of one letter followed by not more than one digit, so 'A15' is not permitted.

Summary of statements and commands used in part 3.

- **INPUT variable(s)**: This statement causes the computer to request keyboard entry of value(s) that must be assigned to the specified variable(s).
- **READ variable(s)**: The variable(s) listed after the READ statement(s) are assigned the value(s).
- **DATA data, data...**: given after the DATA statement.
- **RESTORE**: This statement causes the data block to be re-used from the beginning.
- **REM text**: The specified text appears in a listing, but has no effect on the program.
- **GOTO line number**: This causes a jump to the specified line number.
- **BREAK**: A key on the terminal that is used to stop the program.

- **IF comp. ... THEN line number ... THEN statement ... GOTO line number**: If the result of the comparison after **IF** is true, the computer 'jumps' to the specified line number; otherwise the program is continued on the next line. In NIBL, a statement can be given instead of a line number; if a jump to a line number is required, 'GOTO' must be used instead of 'THEN'.

- **FOR...TO...STEP**: A 'running variable' is assigned an initial value, both as specified after **FOR** (e.g. FOR A=1). The statements between **FOR** and **NEXT** (the 'FOR-NEXT block') are then carried out; the running variable is increased by the specified step (e.g. STEP/3), after which the FOR-NEXT block is repeated; and so on until the final value specified after **TO** (e.g. TO 90) is reached or exceeded. If no **STEP** is specified, the step is automatically taken as 1.

- **DO UNTIL comp.**

- **GOSUB line number**: This causes a jump to the subroutine that starts at the specified line number.

- **RETURN**: Last statement in a subroutine. It causes a jump back to the main program.
A very large low-frequency range is not necessarily a good thing. Often when a record is played at a reasonable volume the woofers occasionally 'strike' far further than the normal (acceptable) distance. This is usually due to undesirable distortion in the range of about 1 to 10 Hz. This phenomenon is limited only to record players; it is not noticed with compact disc players, radio tuners or tape players. The reason is that these last three have a high-pass filter of about 20 Hz fitted somewhere in the electronics or in the signal source. As far as this circuit is concerned, therefore, we are only interested in the record player.

For most people a record player is still the best source of high-quality sound reproduction. (The CD — compact disc — system may be technically better but is far less popular.) A lot of attention is paid to the MM (moving magnet) and MC (moving coil) inputs in 'reasonable-quality' amplifiers as the best results are possible by making use of these inputs. A good amplifier must nowadays have a frequency range right down to (practically) d.c. values — the merit of which we will not discuss — but when combined with a turntable this can make life difficult for loudspeakers. In order to remove the problem, however, we must first of all know how it arises.

Resonance and warped records
Most subsonic problems are caused by resonance in the turntable and pick-up arm. It all starts at the point where the arm pivots, its fulcrum in other words. The arm always pivots on some sort of elastic structure to allow the needle to move freely in the record grooves. Because there is a reaction between the mass of the arm and the elasticity of the mountings the assembly will have a resonant point. The frequency at which resonance occurs depends on the mass of the arm and the type of material on which it pivots. The extent of the resonance depends mainly on the inherent damping of the fulcrum and any damping intentionally built in. When choosing a cartridge to fit to an arm, or vice versa, care must be taken to be sure that the resonant frequency of the combination is not in the audible range. By the same token the resonant point must not be so low that it is triggered by warps in the record or by a vibrating floor. A resonant frequency of about 10 Hz is generally considered to be optimal, although traces ultra-low frequency signals.

rumble detector

Manufacturers of audio equipment are constantly competing against each other by improving the quality of their products. As a result even inexpensive amplifiers now have an extremely good frequency range, especially at low frequency. A lower cut-off point of a few hertz is certainly no exception and some actually go right down to d.c. This is all to the good as far as the quality of sound reproduction is concerned but it is also disadvantageous to a certain extent.

Subsonic noise can be passed on to the loudspeakers and could even damage them. Murphy's Law of Acoustics comes into play here, of course: as this noise is subsonic it cannot be heard so how do you know that it is there? That can be very difficult ... unless you build this rumble detector, which indicates, by means of a LED, when the subsonic part of an output signal becomes too great.
in practice a value between 5 and 15 Hz is acceptable. Unfortunately it is usually impossible to predict beforehand what the resonant frequency will be if a new arm or a new cartridge is bought. The only thing to do is to put your faith in an experienced audio shop. Most of us already have a certain combination of arm and cartridge and unless this gives terrible results we are not likely to change it.

The next problem is that of resonance in the chassis. Like the arm, the chassis will probably be mounted on springs or some other elastic assembly. Understandably, this also has a resonant point. In a well-designed turntable the resonant frequency will be about 2 to 4 Hz so that it cannot influence the resonance of the arm. The turntable is then relatively immune to sounds in the room (such as somebody walking around) and the arm can cope with warped records. If the chassis is not mounted on an elastic assembly there is one less resonant point to worry about, but this sort of turntable is more sensitive to outside interference, like those same heavy footfalls and feedback from the loudspeakers.

If a record that is being played has a bump in it or is warped there is quite a likelihood that the pick-up arm will start to resonate. The result is a subsonic 'spike' that will be strengthened by the amplifier and fed through to the loudspeakers. Even if the resonant point is well damped this will still happen. When somebody forgets to tread softly their heavy footfalls can cause the chassis to resonate, with the same result. The loudspeaker cones again thump out a note that nobody hears.

Clearly subsonic noise can very easily be produced by a turntable but it is not so easy to get rid of it. A good steep subsonic filter with a cut-off frequency of 16 to 20 Hz is ideal for this but such a filter is rarely included in an amplifier. If a filter is provided it is usually a rather imprecise affair that also removes some of the low frequency sounds which should be heard. That does not seem to leave any options open, but the situation is not by any means hopeless. Provided the loudspeakers do not deflect too much the subsonic signals in themselves will cause no damage. That idea was the inspiration for this circuit, which monitors the subsonic content of the signal at an amplifier's loudspeaker outputs and lights a LED to signal when it becomes too great. The listener can then take appropriate measures. This may involve reducing the volume setting, examining the record for bumps or warps or mounting the turntable more firmly, for example. Whatever measures are needed the rumble detector will not effect the quality of the hi-fi system as it does not involve connecting anything in the signal line.

The circuit

The circuit has a very simple layout, consisting of only a low-pass filter for each channel (left and right) followed by a common LED for the indication. The filter roll-
off characteristics must be very steep to prevent the circuit from reacting to bass frequencies that are acceptable for the loudspeakers. This is the reason for using 24 dB/octave fourth-order Butterworth filters. (For detailed information about this and other types of filters refer to the article ‘active crossover filter’ published in the October 1984 issue of Elektor.) The actual multiple-feedback arrangement used for the filters makes them very stable and that is more than enough justification for their relative complexity. Each filter consists of two 12 dB/octave sections — A1/A3 and A2/A4. The component values chosen set the cut-off frequency to about 10 Hz so signals up to about 12 Hz can be detected. The output signals from the filters are half-wave rectified and then added together. The resultant signal charges capacitor C17 quickly. When the voltage on this capacitor reaches about 2.5 V transistor T1 conducts and causes the LED to light. After the subsonic signal has passed the LED remains lit for a certain time, dependent upon the d.c. voltage across C17.

Power for the circuit is provided via two voltage regulators, IC2 and IC3. The maximum input voltage to this power supply section is 30 V. This can be supplied by a small transformer (2 x 15 W/50 mA, for example) in combination with a bridge rectifier and two electrolytic capacitors (such as 470 µ/25 V). If the amplifier has a suitable symmetrical 15 V from which a tap-off can be taken the components marked with an asterisk in the parts list can be left out. The current consumption is a mere 20 mA so this will not prove an excessive burden to an amplifier.

The last thing to be done is to connect the circuit in parallel with the amplifier’s loudspeaker outputs and the detector is ready for use.

Parts list

Resistors:
R1...R6 = 47 k
R7...R12 = 100 k
R13, R14 = 100 k
R15 = 33 k
R16 = 10 k
R17 = 1 k

Capacitors:
C1, C2, C21*,
C22* = 330 n
C3, C4 = 220 n
C5, C6 = 180 n
C7, C8 = 27 n
C9, C10 = 470 n
C11, C12 = 150 n
C13, C14 = 39 n
C15, C16 = 18 n
C17 = 47 µ/16 V
C18...C20 = 100 n

Semiconductors:
D1, D2 = 1N4148
D3 = LED, red
T1 = BC548C
IC1 = TL084
IC2* = 7815
IC3* = 7816

* = not needed if a symmetrical 15 V supply is used

Figure 2. Voltage regulators are among the components found on the printed circuit board. If + and -15 V supply can be tapped off the amplifier these two stabilisers are not needed.

Filter component values:

Butterworth 4th order
(24 dB/octave)

C5 + C7 = C6 + C8 = 1.85/6 n F
C1 + C3 = C2 + C4 = 3/3.7 n F

where R = R1 = R2
R3 = R4 = R5 = R8

C13 + C15 = C14 +
C16 = 0.77/6 n F

C9 + C11 = C10 + C12 =
3/1.54 n F

where R = R7 = R8 =
R9 = R10 = R11 = R12

(All values are given in Ω, Hz and F)
Microprocessor-controlled frequency counter

Superlatives simply have to be used when describing this frequency counter, but we will try not to let it get out of hand. We think it is only natural to feel a certain amount of pride, however. Here, at last, is a do-it-yourself frequency meter whose capabilities, features and ease of use are comparable to much more expensive ready-made (professional) equipment. This is a tribute to the Elektor designers who continually burned the midnight oil working on the design. Their advice to anybody who is thinking of building or buying a new frequency counter is to read this article and study the circuit diagram first. The chances are that this will be your next frequency meter.

Many of our readers regard microprocessors as a scourge and something that has no place in a respectable 'electronic' circuit. Even having read the title on this page we hope that you have none the less read this far because we are now going to entreat you to bear with us and read the remainder of this article. This frequency counter does contain a microprocessor but for all intents and purposes it can be considered as just another 'black box'. Its use does, however, allow the design to be made more versatile and totally removes the need for a user's manual. Surely this is enough reason to turn a blind eye to the fact that this test instrument is 'cursed' with a microprocessor.

Let us look at the frequency counter's features one by one, starting with the auto-ranging possibility. In most meters this would have required a handful of components but in this design the 'calculator' does all the work.

The second point is the measuring method used, which was mentioned in the introductory article published in last month's issue. This so-called reciprocal measuring is only possible with the aid of a microprocessor as there are a lot of calculations to be made. The advantages of this method are maximum accuracy with a very short measuring time. It is used both for frequency and period measurements. A secondary benefit is that multi-position rotary switches are unnecessary as simple push buttons are sufficient.

If the circuit has a microprocessor anyway why not use an alphanumeric display? This, again, is easier to use. The frequency meter plays a game of question and answer with the user, who then makes a choice of the function desired by pressing a YES or a NO button. The display always shows what is being measured and what the units are: such as 'FREQ 1.234567 KHZ' or 'PER 856459 MSEC'. The price of the alphanumeric display and the associated controller IC is comparable to that of a set of good 7-segment displays plus drivers so cost does not enter into the equation. Extensions and modifications can easily be included in this frequency counter, usually this is a matter of changing part of the software. This line of thought could lead to such things as an IEEE output or feeding in offset frequencies.

Finally, we draw your attention to the front panel foil with built-in low-pressure membrane switches. This gives the project a very professional appearance and simplifies fitting it into the case.
The measuring principle

If the frequency counter electronics are considered in the form of blocks a first rough sub-division leaves us with the three parts shown in figure 1: the microprocessor, the counter hardware and the display controller. The microprocessor section consists of a standard 6502 system with RAM (6115), EPROM (2733) and PIA (6821). The microprocessor works with the program stored in the EPROM and uses the RAM memory as a notepad to store data. Communication with the other hardware is via the PIA (peripheral interface adapter). The display controller will be described in next month’s issue so we will not deal with it now. The counter section makes up most of the circuit so we will look at that in detail, using block diagrams and timing charts, to give a better understanding of the operation of the whole circuit.

All the hardware is controlled by the microprocessor, with the aid of a pair of multiplexers to select the various measuring procedures. Each of the possibilities will be discussed in detail on the basis of a timing chart and a block diagram containing only the components appropriate to a particular function. The multiplexers are considered as straight-through links. First, however, we must see how all the measurements are made.

A lot of calculation

The article in the last month’s issue (called ‘part 0’ because it was only an introduction, intended to whet your appetite) sketched over the frequency counter’s modus operandi. The microprocessor starts by setting the programmable divider to its lowest value. This means that the divider stops the measurement after a single period of the input signal. This is a test to prepare for the actual measurement so that the right division factor can be selected. The period time is worked out from the test and the processor then calculates which multiple of this period can be stored in the counter within the desired measuring time. Based on this the programmable divider factor, which is always a power of 2, is set. The measuring time is then defined by: \(2^n \times T\), where \(T\) is the period time measured and \(n\) is the number selected for the divider. The number of period times that are counted is always a power of 2 so the measuring time for different frequencies can also vary by a factor of 2. As an example, assume an accuracy of 6 figures is selected. The gate time (measuring time) for this accuracy is at least 0.1 s. If the frequency to be measured is 5 kHz its period time will be \(T = 200 \mu s\). After the test measurement the microprocessor quickly makes the following calculations:

\[2^n \times 200 \times 10^{-6} > 0.1, \text{ so } 2^n \geq 500, \text{ giving } n = 9 \text{ and } 2^n = 512.\]

The last number is the factor for the programmable divider. The gate time is then:

\[512 \times 200 \times 10^{-6} = 0.1024 \text{ s}.\]

If the frequency were 2.6 kHz the period would be:

\[T = 385 \mu s.\]

\[2^n \times 385 \times 10^{-3} > 0.1, \text{ whereby } 2^n \geq 260, \text{ which gives } n = 9 \text{ and } 2^n = 512.\]

The same division factor is selected but the gate time is now:

\[512 \times 385 \times 10^{-3} = 0.197 \text{ s}.\]

At 2.5 kHz the gate time does become less as the division factor is then \(2^n \geq 256.\) The measuring time is then by:

\[2^n \times 400 \times 10^{-6} = 0.1024 \text{ s}.\]

When the ‘real’ measurement has been made the contents of the counter \(X\) is read out by the processor. The result is the gate time multiplied by \(10^6\) (the reference frequency of 10 MHz). The gate time is \(2^n \times T, \text{ so } X = 10^6 \times 2^n \times T.\) Taking the example of \(f = 3.6 \text{ kHz} \text{ we see that } T = 1/2600 \text{ s. This gives } X = 10^6 \times 512 \times 1/2600 = 1969260.\) Based on this figure and the division factor which is already set the microprocessor can calculate the frequency or period time, whichever the user has chosen.

\[f = (10^6 \times 2^n)/X = 2.60000 \text{ kHz}\]
**Frequency and period measurements**

The set-up used for the frequency and period measurements is shown in figure 2a. The output signal of FF1 is fed to N4 and the Q output of IC3 is connected to FF4's clock input (via a multiplexer in each case). The sequence of events is shown in the timing chart (figure 2a). First the 32 bit counter is reset and the hardware is enabled by means of the START signal. The lowest possible division factor, $2^0$, is selected for IC3. The next rising edge of the input signal makes FF1's Q output high so N5 can then feed the input signal to IC3. At the same time the CNT input of IC5 goes low so it starts counting 10 MHz pulses. The second rising edge of the input signal causes the Q output of IC3 to go high. (This output becomes '1' after the $2^n$-th rising edge if a division factor of $2^n$ is selected.) The

$$T = \frac{X}{(10^7 \times 2^n)} = 384.615 \mu s$$

That, basically is how the frequency and period time are calculated. We will now look at the electronics needed to achieve this.

For the actual measurement FF3's Q output is connected to N4 and the Q output to FF4's clock input (see figure 3a). The microprocessor then sets IC3 to the division factor that it has selected. The first rising edge after the START signal takes FF1's Q output high so N5 can then pass the input signal on to IC3. After $2^n$ rising edges the output of IC3 becomes '1'; this signal clocks FF3 and only then can IC5 start counting 10 MHz pulses. The next clock pulse for FF3 comes after exactly $2^n$ periods and FF3 then flips and stops counter IC5. At the same time the READY line then becomes zero and resets FF1. This flip-flop's Q output then goes low with the result that IC5 stops counting. Even though IC3's division factor was set to 4 the output becomes high after a single input-signal period. The contents of IC5 is the result of counting 10 MHz pulses for one period and this figure is used to decide what division factor has to be set for the actual measurement.

For the actual measurement FF3's Q output is connected to N4 and the Q output to FF4's clock input (see figure 3a). The microprocessor then sets IC3 to the division factor that it has selected. The first rising edge after the START signal takes FF1's Q output high so N5 can then pass the input signal on to IC3. After $2^n$ rising edges the output of IC3 becomes '1'; this signal clocks FF3 and only then can IC5 start counting 10 MHz pulses. The next clock pulse for FF3 comes after exactly $2^n$ periods and FF3 then flips and stops counter IC5. At the same time the READY line then becomes zero and resets FF1. This flip-flop's Q output then goes low with the result that IC5 stops counting. Even though IC3's division factor was set to 4 the output becomes high after a single input-signal period. The contents of IC5 is the result of counting 10 MHz pulses for one period and this figure is used to decide what division factor has to be set for the actual measurement.
this is done the result is passed to the display and the circuit is then ready to start the next measurement.

**Pulse time**

Pulse time is measured on the basis of the circuit seen in figure 4. The signal is input via an EXOR gate (N1) to enable the microprocessor to define whether the '1' or the '0' time is measured. The timing chart of figure 4b assumes that N1 does not invert the signal so the '1' time is measured. The input signal's first rising edge. The 32-bit counter is triggered via N5 and stops again at the input's falling edge. At the falling edge a clock pulse is fed to FF4 via FF2 and N3. The READY line (which goes low) then informs the processor that the measurement is complete and FF1 is also prevented from reacting to any more input signals. The contents of the counter is then written to the display and the circuit is ready to start the next measurement.

**Counting pulses**

This is the easiest function so its block diagram (figure 5a) is also the most straightforward. Again N1 enables the microprocessor to choose whether the counter reacts to a rising or falling edge at the input. The input signal is then used to clock counter ICS directly (so the 10 MHz reference frequency is no longer connected to the counter's ALTCNT input). The microprocessor regularly examines the contents of the counter and outputs the result to the display. The actual components used for each of the frequency counter's functions were given in each of the block diagrams so they can be more or less ignored in the actual circuit diagram. This is a distinct advantage as the circuit's complexity makes it difficult to see directly which parts relate to which function.

![Figure 4](image4.png)

Figure 4: Pulse times are measured using the layout seen here and the appropriate signal changes are indicated.

![Figure 5](image5.png)

Figure 5: Very few components are needed for the event counter function, which uses this set-up.
The frequency counter circuit

The circuit diagram is divided into two parts: the processor section (figure 6a) and the counter hardware section (figure 6b). The power supply has been included in the drawing of figure 6a.

There is little need to say anything about the 6502, 2732 and 6116 in the processor system, especially as they are being treated as 'black boxes' in this circuit. The address decoder, IC8, and PIA, IC7, also belong to the processor section but they have been drawn in figure 6b because of the large number of connections between these ICs and the hardware section.

A breakdown of the addressing ranges is given in the margin here as we must say something of the address decoding. The decoding method used is very wasteful of memory space but its great advantage is its simplicity as it requires only a single IC. Furthermore it works very well in this application, even leaving a block of 8 K free. The clock signal for the 6502 is taken from the 10 MHz reference via decade divider IC18. The circuit can cater for either a 2732 or 2764 EPROM (IC16) so there is room for software expansion. The system is reset on power-up by means of C5, R50 and N13.

Many of the components found in figure 6b are already known from the block diagrams. The display and its controller...
Figure 6b. The remainder of the circuit consists mainly of the counter hardware. Some of the components do not actually belong here. IC7 and IC8 are part of the processor section and the display with its controller is really a separate subsection all of its own.
are also shown in this section but we will not deal with them until next month. All the 'boxed-in' parts of this diagram are found on the display printed circuit board. A number of points about this main circuit diagram must now be clarified.

At the input is the pair of four-bit multiplexers found in IC1. One of these multiplexers is used for choosing an input A, B or C/16. If a prescaler is included in the circuit (this will be published next month with the input amplifier) the C/812 input can also be used. The prescaler is designed to handle the frequency range from 100 MHz up to 1.2 GHz. If link PR is fitted the circuit 'knows' that the prescaler is not fitted and the menu published last month applies. If, on the other hand, the prescaler is included points P and R must be linked with a wire bridge. An extra choice is then included in the menu.

Choosing FREQUENCY and C-INPUT would normally be followed by the question DIG. PRECISION? Instead the query displayed is: FREQ, 100 MHz? If the reply is NO the counter then asks FREQ, 100 MHz? Depending on the answer to this question the input multiplexer chooses input C/16 or C/812. The other section of IC1 drives LEDs D14...D16 via N9 and N10. The TRIGGER LED, D1, is driven by monostables MMV1 and MMV2. This LED always flashes if there are active edges at the input. If the input signal frequency is low, 2 Hz, for example, D1 flashes with each active edge. At higher frequencies the LED simply flashes at a constant easily visible rate but there is then no disconnection made between a frequency of 100 Hz and one of 10 MHz. This does not matter, of course, as the only intention of the LED is to show the user that the counter is being triggered.

The SCRl and CNTRES signals (scan reset/load and counter reset, both of which come from the address decoder) are synchronized to 90 by means of FF5 and FF8 to remove any spikes that might be present. This brings us to the heart of the circuit, the LS7060, whose internal layout is shown in Figure 2. This is a dedicated counter IC containing a 32-bit binary counter complete with latch, multiplexer and three-state data outputs, all of which is microprocessor-bus compatible. To achieve the same result in TTL would require about 16 ICs so IC7's price is not as exorbitant as it might seem.

The contents of the 32-bit counter is stored in the latches as soon as the SCAN RESET/LOAD input goes from '0' to '1'. At the same time the scan counter is reset and the left most multiplexer feeds the eight least significant bits to the data outputs. If an ENABLE pulse is now fed to the IC (CNRl goes low) these eight bits are placed on the data bus by the output drivers so that they can be read by the microprocessor. Should the E line return high the contents of the scan counter is increased so that the next eight bits are sent to the output drivers. The next E pulse places these eight bits on the data bus so after four enable (CNTres) pulses the processor has read all 32 bits. A logic zero of at least 1 ms on pin 37 of the IC resets the 32-bit counter. This is taken care of by the CNTRES line in the circuit. The microprocessor generates the signal by simply placing the address for the CNTRES block momentarily on the address bus. In this way output 4 of the address decoder IC5 is activated and this

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Figure 7. The LS7060 is a dedicated counter IC, which means that it is quite expensive, but not in terms of what it provides.
signal is passed via E6 to IC5's R input. The LS7650 IC also has two clock inputs, COUNT and ALT COUNT. One of these is used as the clock input while the other serves as the enable input. We will not deal with the remaining pins of IC7 here as the TEST COUNT, SCAN and CASCADE ENABLE are not used in our frequency counter circuit.

The gate LED, D2, indicates the time during which a measurement is made, and will light if there is a '1' on line PBS or on output Y1 of IC4. We have already seen from the block diagrams that the Y1 output defines the 32-bit counter's measuring time for frequency and period measurements. When the event counter mode is selected the input is connected to Y1 and IC5 counts the incoming pulses. The circuit is then measuring continuously, even if a lot of the time is spent waiting for a pulse, so the gate LED should light continually. For this reason the processor places a '1' on the PBS line. For pulse width measurements either the '1' or the '0' part of the signal is measured. A long pulse time (0.5 s, for example) can easily be seen on the LED but this is not so if the measured time is short (a repetition frequency of 1 kHz and a pulse time of 200 ms, for instance). A delay built into the software takes care of the problem. After taking a measurement the processor waits for about 200 ms before starting to measure again. The LED is driven by PBS for a few milliseconds so that it flashes visibly. The software delay also works on the display, and in this way the last digit does not keep changing from one value to another (if, for instance, the pulse time is between 200.0 µs and 200.1 µs).

The gate LED makes one short and one long flash during frequency and period measurements of signals below about 100...200 Hz. The short flash is the test, while the actual measurement is made during the long flash. The LED only flashes once when very low frequency signals are being measured as the maximum measuring time is then shorter than the signal's period. In this case the 'test' is the actual measurement.

Finally there is STPLED D5, which indicates that the display is frozen and that no more measurements are being carried out. This LED is linked to output 'S' of the address decoder and lights if the relevant memory block is addressed. The processor must then run through a loop in which the LED is constantly addressed. This is the only thing the processor has to do in the HOLD state. The display controller (IC6) ensures that the read-out remains fixed.

The display section is a completely independent part of the circuit. The ASCII data that must be displayed is sent to the controller IC by the processor. This information is then stored by IC6, which also takes care of driving the display. The processor only intervenes by transmitting new data if the displayed information has to be changed.

The power supply section seen in figure 6a shows that several different voltages are needed. A heating voltage of 6 V, a.c. is fed to the fluorescent display from one of T11's windings. The same transformer provides a regulated -24 V, d.c. that is also used for the display. The remainder of the circuit is powered by the regulated 5 V line. Two more supply voltages (5 V and -5 V) are needed for the input stage. The diagram shows a single mains transformer with a total of three secondary windings but the same effect can be achieved with two or with three separate transformers.

The crystal oscillator

The crystal oscillator is a very important part of the frequency counter as it determines the accuracy to a large extent. The design used is shown in figure 8. The crystal is in series resonance as this guarantees quite good stability. Both sides of the crystal are terminated into a low impedance in order to prevent its Q factor from being unnecessarily reduced. The MOSFET at the output acts as a buffer between oscillator and frequency meter. This oscillator circuit has been fitted to a separate small printed circuit board, and there is a good reason for this. The oscillator shown is quite acceptable but a very precise, temperature-stable crystal oscillator is needed to achieve an accuracy of six or seven digits. A cautious estimate gives the oscillator of figure 8 a stability of at most 10 ppm (parts per million) in a temperature range of 15° to 35°C. This means that the accuracy is far from optimal but it is good enough for the average hobbyist especially as the temperature within the case will settle down to a constant value within quite a short time. Some people will, of course, demand that measurements be accurate to six or seven digits. This can be achieved by substituting a special temperature-compensated oscillator in place of the one shown here. Such an oscillator will be expensive but it can easily be incorporated into this frequency counter.
A self-testing circuit

The frequency meter is made up of three printed circuit boards:
- the main board, which is double sided with through-plated holes
- the display board, and
- the crystal oscillator.

The first to be built is the crystal oscillator (if it is used). The series capacitance indicated in figure 8 is needed if the crystal has a capacitance of 30 pF. The capacitor and trimmer will have to be changed if different crystals are used. (Keep the trimmer as small as possible to prevent deterioration caused by its poor temperature stability.) The circuit is connected to a regulated supply and tested to see if the oscillator is supplying a 10 MHz signal. The output is probably distorted but this does not matter as it is caused by the capacitive load of the probe. A 10 MHz oscilloscope is needed during construction of the frequency counter so this is something you will have to get your hands on.

The next part to be tackled is the main printed circuit board, starting with the discrete components. Some of the capacitors and resistors (and one diode) must be mounted vertically. Sockets (preferably low-profile types) should be provided for all ICs, which must not be fitted yet. The eight lines indicated as K3 can be fitted with soldering pins. One of the voltage regulators, IC21, is connected to the board by means of three thick flexible leads about 10 or 11 inches long (roughly 25 cm). A pair of capacitors, C12 and C13, solder directly to the IC's pins. The regulator is not fitted with a heat sink but rather mounts straight onto the back panel of the VERobox. The heat generated is conducted through the metal plate and to aid this process silicone grease should be applied between voltage regulator and back panel. The photographs show where and how this IC must be fitted.

The mains transformer possibilities have already been mentioned but one point to note is that the case recommended does not leave a lot of room to play with. The fewer and the smaller the transformers the better they can be fitted into the available space. The 10 V winding is first soldered to the board and the output of IC20 is measured. This should be 5 V. The 24 V winding is now connected and the appropriate voltages measured: —5 V at pin 7 of K3 and —24 V at pin 19 of K2. The oscillator board can now be mounted on the main board. Be particularly careful to prevent short circuits between the 5 V copper track and the ground connection to the oscillator board. The U~ connection is not used by the Elektor oscillator. It provides an unregulated 9...12 V d.c. for crystal oscillators that need more than the +5 V we have used.

Two of the IC5, IC8 and IC19, are now fitted to their sockets. A square wave of 1 MHz should be present at pin 12 of IC18. Hexadecimal number 5A6 must then be set on the data bus by means of eight 10 k resistors as shown in the margin here. The resistors are temporarily soldered to connector K1 and the 6502 can then be inserted into its socket. When the power is switched on again there should be a square wave of 250 kHz on address line A1, 125 kHz on A1, 62.5 kHz on A2, and so on down to 7.6 Hz on A15. This is easily checked with the oscilloscope as the period doubles each time. All address lines are available at connector K1. If the frequencies are not correct or if they are simply not present check pin 40 of IC16 (RES), which should be ‘1’. Similarly NM1 and IRQ should be ‘1’. On pin 39 (E2) there should be a (rounded) 1 MHz square wave. If there are signals on the address bus, but not the correct ones, it is possible that the 10 k resistors are not properly connected and that something other than $AA (101010100) is present on the data bus. A further, ever-present, possibility is that an address line may be shorted to another line.

The resistors are left where they are and IC3 and IC14 are fitted. Outputs ’0...7’ of IC5 should then in turn become logic zero for 16.4 ms. Pin 9 of IC14 must become ‘0’ at the same time as pin 4 of IC8 and the same applies for pin 6 of IC14 and pin 5 of IC8. If this checks out the 10 k resistors can be removed.

Now we move on to the display section but first the heating voltage for the filament must be measured. Connect 330 Ω across the transformer’s 6 V winding and measure the a.c. voltage across the resistor. It will usually be a little higher than 6 V. The series resistance needed to give a voltage drop of 5.8 V across the 330 Ω resistor can be calculated from the formula: \( R = \frac{u}{f} \times 330 \), where \( u \) is the voltage measured. Divide the result by two and use the nearest E12 or E24 value.
Figure 9: Due to space considerations the main printed circuit board for the frequency counter is shown here at 75% of full size. Note that C3, C5, C6, C11, C14, C15, D13 and some of the resistors must be mounted vertically.
for R9 and R42 on the display board. The display board can now be assembled except that the display itself and IC8 should not yet be fitted. Do not use a socket for IC8. Note that the tops of the LEDs should extend 1.5 mm above the board and that transistor T2 is laid flat on top of the board. Use as thin a capacitor as possible for C4 or fit it on the reverse side of the printed circuit board. 

Figure 10. The display section is lifted on this printed circuit board. The 16-digit alphanumeric display is soldered straight onto the board and only bent back after testing is completed.

Parts list
- Main board and display board

Resistors:
R1, R2 = 100 k
R3, R4, R9 = 390 k
R5, R6, R51-R64, R67 = 2k2
R6 = 948
R7, R8 = 220 k
R10...R41 = 100 k, 1/8 W
R42 = 22 k
R43, R44, R50 = 1 k
R45, R48, R66, R68 = 10 k
R65 = 690 k

Capacitors:
C1, C2 = 0.47 µ/10 V Ta
C3, C14 = 47 µ/10 V
C4 = 10 µ/25 V
C5 = 100 µ/10 V
C6 = 470 µ/40 V
C7 = 170 µ/40 V
C8 = 220 µ/25 V Ta
C12, C13 = 47 µ/25 V Ta
C15 = 47 µ/40 V
C16, C18, C23 = 100 n
C17 = 10 µ/10 V Ta

Semiconductors
D1 = LED, 5 mm yellow
D2, D5, D14, D15 = LED, 5 mm red
D3 = 15 V/400 mW zener
D4 = 5V/400 mW zener
D6, D8...D12 = 1N4001
D7 = 4 V/1 W zener
T1 = BC547
T2 = BC567
IC1, IC4 = 74LS153
IC2 = 74LS221
IC3 = 74LS292
IC5 = LS7090 (LSII)
IC6 = 10837-50 (Rockwell - available from Regisbrook)
IC7 = 6821
IC8 = 74LS42
IC9 = 74LS86
IC10 = 74LS08
IC11 = 74LS132
IC12...IC14 = 74LS74
IC15 = 6502
IC16 = 2732
IC17 = 4716
IC18 = 74LS90
IC19 = 74LS132
IC20 = 7805
IC21 = 7805

Miscellaneous:
F1 = fuse, 100 mA slow blow
D1 = Fujitsu 16-digit alphanumeric fluorescent display, type number 16-SY-0321 (available from Regisbrook)
S1, S5 = membrane switch in front panel foil
S6 = miniature double-pole mains switch
TR1 = mains transformer (6 V/25 mA, 10-12 V/200 mA) and 24 V/250 mA heater for IC21
connector for cable from front panel foil (7 way right angled, 2.54 mm/0.1" centres)
Veroboard no. 075-014110 (dimensions 206 x 140 x 75 mm)
front panel no. 84097 F

* = see text
cable from the membrane switches in the front panel clips into the connector between R4 and K2. A length of 20-way ribbon cable about 7 inches (17 cm) long is soldered directly into the holes for connector K2 on the reverse side of the display board. The other end of the cable is then soldered directly to the main board (do not use soldering pins at either end). The numbers linked by each wire in the cable must, of course, be the same on both boards.

With the power switched on the voltages on the display board can be checked.

There should be a -5 V dc on pin 8 and -10 V on pin 18. The d.c. voltage on the common line for R9...R4 should be -24 V. Switch the power off and solder IC6 directly onto the board. The pins of the display are pushed through the board until they extend by about 1 mm and are then soldered. Do not bend the display parallel with the board yet, until testing is complete it is left standing straight out like this. Returning to the main board IC16, complete with its program, is inserted into its socket. Switch the power on again and then touch the NMI line (pin 4 of K2) to ground for an instant. The self-test program in the EPROM then starts.

The first function of this program is to test if it is itself correctly stored in IC6. If it is, stop LED D5 lights for about 1 s to show that all is in order. If the LED remains out the EPROM is probably incorrectly programmed or one of its pins is not making proper contact. This assumes, of course, that the LED is fitted properly and that the wiring between the two boards is also correct.

After D5 has lit up the power can be switched off to enable IC7 to be fitted into its socket. The power is turned on again and the '0' pulse is again applied to the NMI line. Each of connections PA9...PA7 then goes high for 1 s then turn so LEDs D3, D4, D16 and D18 start flashing (on for 1 s and off for 8 s). There is also a '1' running through lines PB8...PB6 (except for PB4).

Provided the '1' keeps running and the LEDs flashing the circuit is correct so far. Otherwise check IC7's socket to ensure that all the pins of the chip are inserted correctly. Next it is IC17's turn to be fitted. Substitute a wire bridge for S3 on the display board so that the circuit thinks that this push button is pressed continuously.

Power is again applied to the circuit and the NMI line momentarily grounded. The gate LED should light for a short time. If this does not happen there is something wrong in (or with) the RAM. The gate LED may also fail to turn off and the stop LED may light and if this happens it indicates a problem, probably a programming error, in the EPROM.

It may be an advantage at this stage to see exactly what the test program does. If switch S3 is closed (or bridged) and NMI receives a short '0' pulse the program tests itself and lights the stop LED for about one second. The microprocessor then examines PB7. If this line is '1' the PIA is then tested but if it is '0' (as it is when S3 is bridged) the RAM test procedure is started. This involves copying the contents of the EPROM to the RAM and then comparing what is stored in both. Assuming this test gives a positive result the gate LED lights briefly. Immediately after this the EPROM is tested: all the bytes are summed and a checksum byte is added. The result must be 000. Any other result indicates one or more faults in the EPROM and the stop LED then lights. The power can now be switched off and the short circuit for S3 removed; the wire used to provide pulse to the NMI line. Connect the 6 V winding of the mains transformer to the display board. When the power is now switched on the display shows the text OVERFLOW, PLEASE RESET or FREQ. X.XXXXX HZ. This is an indication that the display board is correct. If nothing appears on the display the connections to the display board from the main board and from the transformer should be checked. Test also that the 6 V a.c. is present. Remove the power again and install the remaining ICs into the main printed circuit board. The cable from the front panel can also be fitted into its connector. This cable is actually a thin plastic 'tail' with the wires from the front panel's switches embedded into it.) Treat the ICs carefully, especially the 74LS293 which is very sensitive.

Once again the power is applied to the circuit. The display should show FREQ. 0.000000 HZ. Press the menu button once and the NO button three times. The display is now EVENT COUNT? Press the YES button three times and the display will indicate TOTAL 0. Apply a square wave (about 1 Hz) at TTL level to pin 2 of K3 and measure if this signal is also present on pin 9 of IC1, pin 3 of IC5, pin 7 of IC4, pin 8 of IC9 and pin 1 of IC6. Both pin 8 of IC9 and pin 2 of IC5 should be zero.

If the circuit is working correctly each incoming pulse will be added to the total shown on the display. The trigger LED should also flash with each pulse and the gate LED should light continuously. If this does not happen the problem is almost certainly to be found in around IC5. All the frequency meter's functions should now operate properly. Doubting Thomases can check this by comparing signals at various points in the circuit with the appropriate timing charts.

**Casing the circuit**

Before any part of the circuit can be fitted into the case the necessary ventilation holes must be drilled in both upper and lower sections. Assuming the recommended type of box is used the main printed circuit board will fit snugly inside parallel to the bottom and can be fixed to the mounting bosses with self-tapping screws. An insulating ring must be placed under the bolt beside K1. The mounting boss at the front left-hand corner of the
The attractive finished appearance and correct operation of the meter can only be assured if the front panel foil available through Elektor's EPS service is used. It is an essential part of the circuit as it contains the membrane switches used to control the frequency counter. This foil is quite thick so the slots provided in the case to accommodate the metal panel supplied with the box will be too thin to accept both of these at the same time. For this reason a sheet of aluminium about 1 mm thick and with the same dimensions as the front plate supplied must be used instead. Use the template provided with the front panel foil to drill all the necessary holes in the new front plate. The display board can be fixed to the plate by means of four countersunk bolts or with four bolts stuck to the inside of the panel. The locations for these holes or bolts are indicated by the template and it is important to note that the bolts may not protrude by more than 15 mm. The holes for the BNC sockets are drilled undersize and then filed to the right shape and size. One side of each hole is flat so the sockets cannot turn. The slot for the front panel cable must also be cut and then a final check made to make certain that everything fits as it should. The backing paper can now be taken off the front panel foil. Pass the cable through the slot and then stick the foil carefully and accurately onto the aluminium front plate. Any excess foil should now be cut off with a sharp knife. There is a thin layer of protective plastic on the front of the foil that can be removed when the case is completely finished.

The wires to the mains switch can now be soldered in place. Note that they must rise straight up from the switch as otherwise they might foul the capacitors on the display board. (The sketch in the margin here indicates what we have in mind.) Insulate the connections very well, with short lengths of heat-shrink tubing, for example.

All the components must now be fixed to the front panel. A 10 k potentiometer must be fitted to the hole left in the display printed circuit board. The type used should ideally have small dimensions and an insulating washer must be used at the copper side of the board. This potentiometer will be used later — when the input stage is added to the meter. Bend the display carefully towards the board and over IC6. Do this correctly and the display will fit exactly in the window in the front panel. Fix the display board to the front panel by means of the bolts already discussed.

The mains transformer is now fixed to the rear panel of the case so that its mounting bracket is about 2 mm below the top of the box. Fit the transformer above IC16, IC7 and IC11 in order to leave room for the input stage next month. Also fitted to the back panel is IC30 and in this case some heat-conducting paste must be used between IC and metal. The mains cable, naturally enough, feeds through the back panel, preferably by means of the chassis plug and socket arrangement normally used for laboratory test instruments. Before screwing the top onto the case a heatsink must be fitted onto IC21. The oscillator in the circuit may only be correctly calibrated with reference to another (accurate) frequency counter. Measure the frequency at pin 1 of IC16 and use the trimmer to set this to exactly 10 MHz. Fit the top onto the case and leave the meter on for about half an hour. Measure the frequency again and if necessary re-trim C3.

The constructional details of this frequency counter have been dealt with in much more detail than is usual in our circuits. We felt that this was necessary as it is a very important test instrument and the instructions given should enable any hob- bylist to build a working example. Next month we will describe the input amplifier with the prescaler. All of the counter's functions are self-explanatory and selection is simplicity itself but it is always useful to familiarise yourself with any new equipment by experimenting with it.

Table 2 This headump is the program that tests, drives and controls the frequency counter circuit.
CMOS function generator

The aim of this project was to produce a simple, cost-effective, general purpose audio generator, which was easy to build and use. This aim has certainly been achieved, since the circuit offers a choice of sine, square and triangle waveforms and a frequency range from about 12 Hz to 70 kHz, yet uses only one CMOS hex inverter IC and a few discrete components. Of course, the design does not offer the performance of more sophisticated circuits, particularly as regards waveform quality at higher frequencies, but it is nonetheless an extremely useful instrument for audio work.

Block diagram

Figure 1 illustrates the operating principles of the circuit. The heart of the generator is a triangle/squarewave generator consisting of an integrator and a Schmitt trigger. When the output of the Schmitt trigger is high, the voltage fed back from the Schmitt output to the input of the integrator causes the integrator output to ramp negative until it reaches the lower trigger threshold of the Schmitt trigger. At this point the output of the Schmitt trigger goes low, and the low voltage fed back to the integrator input causes it to ramp positive until the upper trigger threshold of the Schmitt trigger is reached. The output of the Schmitt trigger again goes high, and the integrator output ramps negative again, and so on. The positive- and negative-going sweeps of the integrator output make up a triangular waveform, whose amplitude is determined by the hysteresis of the Schmitt trigger (i.e. the difference between the upper and lower trigger thresholds). The output of the Schmitt trigger is, of course a square wave consisting of alternate high and low output states.

The triangle output is fed through a buffer amplifier to a diode shaper, which rounds off the peaks and troughs of the triangle to produce an approximation to a sinewave signal. Any one of the three waveforms may then be selected by a three-position switch and fed to an output buffer amplifier. The frequency of all three

Using only one inexpensive CMOS IC and a handful of discrete components, it is possible to build a versatile function generator that will provide a choice of three waveforms over the entire audio spectrum and beyond.

signals is varied by altering the integrator time constant, which changes the rate at which the integrator ramps, and hence the signal frequency.

Complete circuit

The practical circuit of the CMOS function generator is given in figure 2. The integrator is based on a CMOS inverter, N1, whilst the Schmitt trigger uses two inverters with positive feedback, N2 and N3.

The circuit functions as follows: assuming, for the moment, that the wiper of P2 is at its lowest position, when the output of N3 is high a current

\[ \frac{U_b - U_t}{P_1 + R_1} \]

flows through R1 and P1, where \( U_b \) is the supply voltage and \( U_t \) is the threshold voltage of N1. Since this current cannot flow into the high impedance input of the inverter, it all flows into C1 or C2 (depending on which is selected by S1).

The voltage drop across C1 thus increases linearly, so the output voltage of N1 falls linearly until the lower threshold voltage of the Schmitt trigger is reached, when the output of the Schmitt trigger goes low. A current

\[ -U_t \frac{P_1}{P_1 + R_1} \]

now flows through R1 and P1. This current also flows into C1, so the output voltage of N1 rises linearly until the upper threshold voltage of the Schmitt trigger is reached, when the output of the Schmitt trigger goes high and the whole cycle repeats.

To ensure symmetry of the triangle waveform (i.e. the same slope on both positive-going and negative-going portions of the waveform) the charge and discharge currents of the capacitor must be equal, which means that \( U_p - U_t \) must equal \( U_t \). Unfortunately, \( U_t \) is determined by the characteristics of the CMOS inverter and is typically 55% of supply voltage, so \( U_p - U_t \) is about 2.7 V with a 6 V supply and \( U_t \) is about 3.3 V.

This difficulty is overcome by means of P2, which allows symmetry adjustment. Assume for the moment that R4 is connected to the positive supply rail (position A). Whatever the setting of P2, the high output voltage of the Schmitt trigger is always \( U_p \). However, when the output of N3 is low, R4 and P2 form a potential divider so that a voltage from 0 V to 3 V can be fed back to P1, depending on the wiper setting of P2. This means that the voltage across R1 and P1 is no longer \(-U_t\) but
If the slider voltage of P2 is about 0.6 V then \( U_p - U_t \) will be around -2.7 V, so the charge and discharge currents will be the same. Of course, the adjustment of P2 must be carried out to suit each individual function generator, owing to the tolerance in the value of \( U_t \). In cases where \( U_t \) is less than 50% of the supply voltage, it will be necessary to connect the top of R4 to ground (position B).

Two frequency ranges are provided, which are selected by means of S1; 12 Hz-1 kHz and 1 kHz to about 70 kHz. Fine frequency control is provided by P1 which varies the charge and discharge current of C1 or C2 and hence the rate at which the integrator ramps up and down.

The squarewave output from N3 is...
A simple transistor tester—An adapter for your multimeter.

This simple circuit checks the functioning and measures the current gain (hFE) of PNP or NPN bipolar transistors. It operates by feeding a known constant current into the base of the transistor and measuring the collector current. Since the collector current of a non-saturated transistor is hFE times the base current (which is known) it is a simple matter to calculate the value of hFE, and in fact the meter which measures the collector current can be calibrated directly in hFE.

Since both PNP and NPN transistors must be tested, two constant current sources are required, to provide a negative base current for PNP transistors and a positive base current for NPN transistors. The voltage dropped across the LED causes a constant current to flow through the emitter resistor of the TUP and a corresponding constant collector current, which flows into the base of the NPN transistor under test. This current can be set to 10 µA by connecting a 50 µA meter between points B and E and adjusting P1.

The lower LED and TUN constitute the negative current source. Here again, this may be set to 10 µA by connecting a microammeter between the lower points B and E, adjusting P2.

When a transistor is plugged into the appropriate socket, a current of 10 µA will thus flow into the base and a current of hFE times this will flow through the milliammeter. The full-scale deflection of the milliammeter depends on the maximum hFE to be measured. Since the collector current is hFE times the base current (which is 0.1 mA) a reading of 1 mA corresponds to an hFE of 100, so a 5 mA meter is to hand it can be calibrated in hFE values from 0 to 500, which should be adequate for most run-of-the-mill transistors. However, for testing "C" versions of small-signal transistors, which can have gains up to 800, a 10 mA meter calibrated 0 to 1000 could be used, or a lower f.s.d. meter shunted to read 8 mA and calibrated 0 to 800.

Readers may have noticed that it is actually the emitter current of the PNP transistor that is measured, which is of course 1/hFE times the base current. However, since few transistors have gains less than 50 the worst error introduced by this is less than 2%, which is probably less than the error of the milliammeter.
This time base circuit is built using normal readily available CMOS ICs and a cheap crystal. The circuit gives the constructor the possibility of 50 Hz, 100 Hz or 200 Hz. The 50 Hz reference frequency is an ideal time base for the construction or calibration of electronic clocks, frequency meters and so on. Because of the flexible supply voltage requirement, it is also a good basis from which to build a digital clock for the car.

IC1 contains an oscillator and a 21/2 divider. Providing the oscillator loop is correctly calibrated using C2, the output at pin 3 (Q14) will produce a 200 Hz square wave. With the help of the two flip-flops in IC2 and this square wave voltage is then divided by two and then by four resulting in two further outputs of 100 Hz and 50 Hz, the latter from pin 1. Readers who have a frequency meter can calibrate the circuit by simply connecting the meter to pin 7 of IC1 (Q4) and adjusting C2 until a reading of 204,800 Hz is indicated.

As a matter of interest, anyone without a frequency meter should not despair since setting trimmer C2 to about midway will provide sufficient accuracy for most applications. The 100 Hz output is useful for the construction of digital counters. For this purpose we suggest that a 1:10 divider (like the 4518) is connected to the 100 Hz output pin. The power supply requirements are:

- from 5 . . . 15 V and 0.5 . . . 2.5 mA.

### economical crystal time base

a 50 Hz ‘bench mark’

### low voltage stabiliser

battery powered voltage regulator

Depending on their condition 1.5 V batteries supply a voltage of 1.2 . . . 1.7 V. This circuit can be very useful when a project has to be fed with a constant, low voltage. With an input voltage of 1.2 . . . 1.8 V this stabiliser produces a relatively constant voltage of 1.15 V with a maximum load of 5 mA. T2 cuts off at a minimum battery voltage of 1.2 V with a load of 5 mA.

The output voltage tends to increase with a higher battery voltage, causing T2 to conduct and reducing the base current of T1 and T3 (indirectly), so that the output voltage will remain 1.15 V.

The internal impedance of this low voltage supply is 1 to 2 Ω. The output voltage will only be reduced by 70 mV when changing the battery voltage from 1.8 V to 1.2 V.

(ITT application)
When deciding which capacitors to use, consideration should be given to reliability, the permissible range of operating conditions, size and so on. Size is important especially when building high density circuits, and last but not least price. Keep in mind, that, any need for special current limiting resistors is going to increase the overall cost of using tantalums. Even so, tantalum capacitors are used widely, where the operating characteristics of the capacitor is critical. Quite a few Elektor circuits specify the use of tantalums, and not just because they are small and good to look at. They have a stable capacitive value, and a long shelf life. The impedance is virtually unaffected by frequency changes. So, on the face of it tantalums are ideal. However, they do have one major drawback; price!

By comparison the tantalums have a wide operating range as far as temperature is concerned, making them suitable for filters and oscillators. Hence the reason why they are widely used in Elektor designs. Most of you by now probably think that the writer must be completely sold on tantalums. Not so! They do have, what can be termed as inconveniences, rather than faults or disadvantages:

- The voltage level they can sustain when connected the wrong way round is extremely small, even for a very short interval. They break down rapidly and can explode easily.
- Their a.c. voltage performance is poor and further diminished at high frequencies and temperatures.
- The charge/discharge rate resistance is 3 Ω/V, making it necessary to use series resistors.
- A surcharge, whether it is of a thermo, current, or voltage nature, will cause immediate breakdown, short circuiting and a possible explosion.
- The price of each item is quickly approaching prohibitive levels.

All in all tantalums are certainly not perfect, mind you what is these days! Should series resistors not be used in order to limit the charge/discharge rate, then the results are always fatal. This is because field crystallisation will occur, causing short circuiting. At the beginning of the article we explained all the advantages of using tantalums; impedance, heat dissipation, life span, high frequency performance and so on. But, it seems that it did not take us very long to arrive at the conclusion that even these are not as good as we would wish. As with many things, it is a fact of life that the more you use something the less appealing it becomes. Notice that we do not say everything,

electrolytics run dry

everything you wished to know!

So far for many industrial and professional applications wet electrolytics and tantalums have ruled the roost. With new innovations and technological advancements, it is now possible to use alternatives which can be cheaper and more reliable. Many factors need consideration when making the right choice, and a good knowledge of the merits and limitations of the different types available is useful. In fact a comparison shows that the new solid aluminium electrolytics, can be used as alternatives for tantalums, and in many respects can be seen to be better.
since the good things in life are always welcome.

Furthermore, capacitor manufacturers have been taking advantage of a relatively new development. Using deeply-etched foil an axial-lead solid aluminum electrolytic has been created, achieving a high CV density making them less expensive replacements for tantalums. Although they are not going to replace the latter completely, they will be widely used in a variety of industrial and professional equipment.

Solid aluminium capacitors

The solid aluminium electrolytic has a comparable performance with the tantalum type, but not only is it cheaper, but it does have a few advantages. Figure 1 shows the different components which go to make a tantalum.

There are a lot of similarities in construction with the solid aluminium type (SAL). Looking at figure 1, you will note that the former has layers of silver, graphite and manganese dioxide (MNO3) which form the cathode. Then comes a dielectric layer and finally the anode made of tantalum. This is sintered to the tantalum oxide (dielectric layer).

Figure 3 shows the make up of a SAL. The cathode is composed of the same materials as the tantalum. The real difference between the two lies in the fact that, the anode is composed of deeply etched aluminium and that the dielectric layer is aluminium oxide Al₂O₃. Hence the remarkable conductivity of the solid aluminium electrolytic!

These SALs, to coin a phrase, are very robust to say the least. They can operate near their maximum temperature ratings without shortening their life span, and do not have any catastrophic failure mechanism. In other words they are not going to blow-up in your face at the wrong moment. An added bonus is the fact that series resistors are not needed.

The values already available are in the range 47...1000 μF and one major manufacturer has proposed to make smaller ones with 0.22...47 μF, but, it may take some time before these are available. They are slightly larger than their equivalent counterparts, and although being less expensive than tantalums they are marginally more costly than the wet type.

Present applications include telecommunications, space programs, and power stations. Their small size and robustness make ideal for the automobile industry. Because they are being improved upon all the time, a rosy future lies ahead of them.

To summarise the main characteristics of the SAL are:
• Lower price.
• Their voltage rating remains unchanged throughout the operating range, even at high temperatures (-80 to 175°C).
• The allowed d.c. voltage (reversed) is around 33% of their rated voltage.
• Does not require current limiting.
• a.c. voltages (up to limits) can be handled and do not adversely affect their performance.
• Their impedance fall more steeply with increasing frequency than any other type.
• They can withstand 50/100 Hz a.c. voltages up to a level which is 80% of their d.c. rating.
• Temperature stable, and low failure rate coupled with longevity.
Output amplifier IC
Type LM 1875

The LM 1875 from National Semiconductor is a monolithic output amplifier that can provide up to 20 watts audio power of excellent quality. It is housed in a TO-220 encapsulation in which you would normally expect no more than a small voltage regulator. Maximum output power is 35 watts into 8 ohms, but the distortion at this level is no longer acceptable for Hi-Fi purposes. At 20 W, however, the harmonic distortion is only 0.05% at 1 kHz. The bandwidth is a very reasonable 70 kHz, while the slew rate of 8 V/μs is excellent for this type of IC. Other plus points are the very good hum suppression of 94 dB, the thermal protection circuit, and the short-circuit protection.

Further characteristics are given in Table 1. The LM 1875 has five connecting pins: two for the supply voltages (positive and negative), one for the output, and two for the inputs (inverting and non-inverting). Two possible circuits are given in figure 1: one with a symmetrical supply (a) and the other for use with an asymmetrical power supply (b). Figure 1a is noteworthy for the minimal number of additional components required: two diodes, D1 and D2, for the protection of the output transistors, high-pass filter C5/R5, input filter C1/R1, negative-feedback network R2/R3/R4/C2, and decoupling capacitors C3 and C4. The gain, A, is determined by

\[
A = \frac{1}{R4/R3}
\]

The characteristics in figure 2 show the total harmonic distortion, THD, versus power output and frequency and the supply voltage. Because of its small dimensions, the quality of the output, and the small number of external components required, this IC is eminently suitable for use in active loudspeaker systems.

### Table 1
Absolute Maximum Ratings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Voltage</td>
<td></td>
<td>± 30 V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage</td>
<td></td>
<td>VEE to VCC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Temperature</td>
<td></td>
<td>0°C to +70°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage Temperature</td>
<td></td>
<td>-65°C to +125°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Junction Temperature</td>
<td></td>
<td>150°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Dissipation (Note)</td>
<td></td>
<td>30 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead Temperature (Soldering, 10 seconds)</td>
<td>300°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Electrical Characteristics

\[
V_{CC} = 30 V, \quad V_{EE} = -30 V, \quad T_{TAB} = 25°C, \quad R_L = 8 \Omega, \quad A_V = 32 (30 \, \text{dB}), \quad f_0 = 1 \, \text{kHz}, \quad \text{unless otherwise specified}
\]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Current</td>
<td></td>
<td>POUT = 0 W</td>
<td>60</td>
<td>100</td>
<td>mA</td>
</tr>
<tr>
<td>DC Output Level</td>
<td></td>
<td>THD = 1%</td>
<td>0</td>
<td></td>
<td>V</td>
</tr>
<tr>
<td>Output Power</td>
<td></td>
<td>POUT = 20 W</td>
<td>30</td>
<td></td>
<td>W</td>
</tr>
<tr>
<td>THD</td>
<td></td>
<td>POUT = 20 W, f0 = 20 kHz</td>
<td>0.05</td>
<td>0.6</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POUT = 30 W</td>
<td>0.2</td>
<td>0.4</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POUT = 30 W, f0 = 20 kHz</td>
<td>0.1</td>
<td>1.0</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>POUT = 20 W, RL = 4 Ω, f0 = 20 kHz</td>
<td>0.4</td>
<td>0.6</td>
<td>%</td>
</tr>
<tr>
<td>Offset Voltage</td>
<td></td>
<td>POUT = 20 W, f0 = 20 kHz</td>
<td>30</td>
<td>60</td>
<td>mV</td>
</tr>
<tr>
<td>Input Bias Current</td>
<td></td>
<td>-5</td>
<td>-2</td>
<td>5</td>
<td>μA</td>
</tr>
<tr>
<td>Input Offset Current</td>
<td></td>
<td>-1.5</td>
<td>0</td>
<td>1.5</td>
<td>μA</td>
</tr>
<tr>
<td>Input Sensitivity</td>
<td></td>
<td>POUT = 20 W, f0 = 20 kHz</td>
<td>400</td>
<td>450</td>
<td>mVrms</td>
</tr>
<tr>
<td>Open Loop Gain</td>
<td></td>
<td>PSRR</td>
<td>90</td>
<td></td>
<td>dB</td>
</tr>
<tr>
<td>PSRR</td>
<td></td>
<td>VCC, 120 Hz, 1 Vrms</td>
<td>52</td>
<td>95</td>
<td>dB</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-VEE, 120 Hz, 1 Vrms</td>
<td>52</td>
<td>95</td>
<td>dB</td>
</tr>
<tr>
<td>Max Slew Rate</td>
<td></td>
<td>8</td>
<td></td>
<td></td>
<td>V/μs</td>
</tr>
<tr>
<td>Current Limit</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Equivalent Input Noise Voltage</td>
<td></td>
<td>800 Ω, CCIR</td>
<td>3</td>
<td></td>
<td>μVrms</td>
</tr>
</tbody>
</table>

Note: Assumes T_{TAB} to 60°C max. For operation at higher tab temperatures and at ambient temperatures greater than 25°C, the LM 1875 must be derated based on a maximum 150°C junction temperature. Thermal resistance depends upon device mounting techniques.

Table 1. Absolute maximum ratings and electrical characteristics.
Figure 1. Two possible circuits for an output amplifier based on the LM 1875: one for use with a symmetrical power supply (a) and the other for an asymmetrical supply (b).

Figure 2. Total harmonic distortion versus power output (a); total harmonic distortion versus frequency (b); power output versus supply voltage (c); internal dissipation versus ambient temperature (d).

Figure 3. Printed circuit layout of the two suggested circuits of figure 1: (a) with symmetrical and (b) with asymmetrical power supply.

Literature:
National Semiconductor: Preliminary Application
Note on the LM 1875

National Semiconductor addresses:
United Kingdom:
301 Harpur Centre
Home Lane
Bedford
Phone: (0234) 47147

Outside Europe:
2900 Semiconductor Drive
Santa Clara
California 95051
USA
Phone: (408) 721-5000

Denmark:
Bianco Lunos Alle 1
1868 Copenhagen V
Phone: (01) 213211

Southern Europe:
Via Solferino 19
20121 Milano Italia
Phone: (02) 6596146

Spain/Portugal:
c. Agustin de Foxa 27 (d.)
E-Madrid 16
España
Phone: (01) 7332264

Northern Europe:
Postaddress Box 2016
S-127 02 Skårholmen
Sverige
Phone: 08-970190

Outside Europe:
2900 Semiconductor Drive
Santa Clara
California 95051
USA
Phone: (408) 721-5000
SOLDERING STATION
The SOLDEX soldering station has been developed specially for soldering micro electronic components like LSI chips, MOS devices and other sensitive components. The bit tip size range is 1.5, 2.5 and 3.5 mm diameter, for precision soldering work. The construction is slip in type and provides easy interchangeability. The station contains a soldering stand and the bit is positively connected to the earth pin of the power plug to prevent static build up.

Nominal power consumption is 25 watts, but the circuit can draw up to 50 watts if necessary. The soldering iron weighs 95 gms.

DIGITAL MEGGER
Arun Electronics have developed a new insulation tester with digital readout. This fully solid state unit does not require any hand driven mechanism for generating test voltages. The instrument operates directly from the mains supply and has built-in DC to DC converters to generate the test voltages.

The measurement ranges available are 20, 2000, and 10000 Megohms. Linearity is claimed to be 0.1% throughout the range.

For further information, write to:
Arun Electronics Pvt. Ltd.
B-125, Ansa Industrial Estate.
Saki Vihar Road, Saki Naka.
Bombay 400 072

MICRO ANALYSER
Electronumerics have introduced EN 85, a system analyser for software development, testing and trouble shooting of 8-bit systems based on 8085, 2-B0 etc.

The EN 85 is a compact unit with stand alone capability and is useful for manufacturing industries as well as in field applications. This analyser system is used to examine and modify the memory locations, execute the programme up to a particular address and stop or step through a programme at a time or one machine cycle at a time.

WIRE STRIPPER
Efficient Engineers have developed a thermal wire stripper which gives neat, clean and fast stripping of PVC and Mafco coated wires, flat cables and Tallow coated cables. This is an easy to use tool which does not require adjustments for varying wire diameters. It can strip wires with a wide range of diameters. A strip stop guide is provided to set the length of insulation to be stripped. The unit operates directly on mains supply.

For further information, write to:
Thermal Sensors
37, Electronics Complex,
Kushaguda,
Hyderabad 500 762

RELAY SOCKETS
Essen Denki now introduce two new plug-in type relay sockets. The DS-08 is for 8 pin and DS-11 is for 11 pin configurations. These sockets can be snap mounted on DIN rail taking only 36 mm length of the rail. They can also be mounted on chassiss using two screws. The body is moulded in flame retardant glass filled thermoplastic resin. Screw terminals are provided with captive U washers for secure wiring. Snap on receptacles can also be connected to the spade terminations after removing screws and washers.

For further information, write to:
Essen Denki
386, Industrial Area,
Chandigarh 160 002

STEPPING MOTOR DRIVES
Spectrum offers ‘Amey’ stepping motor drives in 3 models. The possible application areas are X-Y-Z positioning and movement, Rotary and linear indexing, Feeders and length control, Flow control etc. The range covers stepping speeds up to 6000 steps/sec driving up to 5Kg-Cm torque rated stepping motors.

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For further information, write to:
Spectrum Sales and Service Pvt. Ltd.
63, Bharatpur, No. 2, Eradawane.
Pune 411 008
DIGITAL MULTIMETERS

Digital Instruments Corporation have introduced three new models of digital multimeters, DM 520, DM 525, DM 525S. All the models have three and a half digit, half inch LED/LCD display. The measurement ranges are AC/DC voltages from 200 mV to 600 V rms AC/12 KV DC, AC/DC currents from 200 μA to 2 A and resistances from 100 milliohms to 20 megohms. Input impedance is claimed to be very high. Model DM 525S has facility for optional external shunts. Models DM 520 and DM 525 have very high accuracy in AC measurement over the entire audio range of frequencies. All models are provided with autopolarity and decimal points. They are fully protected against overloads in all ranges.

For further information write to:
Digital Instruments Corporation
Near Tower, Saspur Bogha
Naroda Road, Ahmedabad-382 345

CONTACT CLEANER

Kli-Nit Contact cleaner CT-2 is now available with an extension for pin point application on the inaccessible electrical contacts. Kli-Nit contact cleaner CT-2 when sprayed, not only cleans the contact but also reduces frizzing as well.

The product is now available in 250 ml and 350 ml aerosol containers to suit the requirements of different users.

For further information write to:
Klikronics Pvt Ltd
Dada Bhai Vaidya X Marg
Bombay 400 027

CLIMATE ANALYSER

Indoor Climate Analyser Type 1213 is a handy, easy to operate, portable instrument for evaluating all of the basic parameters which influence the thermal environment and its effect on human life.

The analyser has a 20 character alpha numeric display. It has five transducers which can measure air temperature, surface temperature, radiant temperature, humidity and air velocity. The measurements are carried out and recorded automatically. Four different recording periods of 1, 6, 24, and 120 Hours are available. Measurements are spaced evenly throughout the recording period and the analyser can be left unattended.

For further information, write to:
Suresh Electrics and Electronics
Manasarovar, 3 B, Camec Street,
Calcutta 700 016

LINE FREQUENCY METER

The new line frequency meter from JIVAN Electro Instruments is based on the latest CMOS technology for high stability and noise immunity. The display is 4 digit, half inch seven segment LEDs. The resolution is 0.01 Hz and the accuracy is claimed to be ±0.1% of the reading. The unit can be made available in two ranges of 99 99 Hz and 999 9 Hz. High and low alarm facility can also be provided.

For further information, write to:
JIVAN Electro Instruments
394, G I D.C. Estate,
Makarpura,
Baroda 390 010

MINIATURE HIGH-V RELAYS

Kitovac Corporation have announced a complete new range of miniature High-Voltage relays. Available in SPDT, SPST, full-safe and latching configurations, the range includes relays with ratings up to 10 KV. The light weight miniature relays are offered in low cost commercial version and also in a military version. They are suitable for application in digital transducers, laser systems, medical instruments and several other industrial applications.

For further information, write to:
Kofer-Tek International
257, Kilpauk Garden Road,
Madras 600 010.
valve amplifier (December 1984)

Apparantly not all the capacitors were blown away before we finalised this article. The test voltage of ±10.4 V given at pin 2 of the EL846 shows that it has been 0 V. This +10.4 V refers to the potential difference between cathode and grid rather than an absolute value.

burglar deterrent (December 1984)

In figure 2 and the parts list R7 is given as 1 kΩ. Depending on individual circumstances it may be necessary to change this for a value of 1 kΩ W.

ZX81 cassette pulse cleaner (November 1984)

The first paragraph of the text states that a logic one is represented by eight pulses. This is incorrect; it should, in fact, read nine pulses.

real time analyser (part 1) (April 1984, page 4-740)

The Voltage Regulators should be type 7812 and 7912 respectively as shown in the circuit diagram. Where the text and parts list read 7805 and 7905 this should be corrected to 7812 and 7912 respectively. Likewise, voltages of ±8 V and ±12 V should read ±12 V and ±12 V.

how to recycle dry batteries (November 1984, page 11-58)

In fig. 5 the range mentioned as 220 ohms should actually be 2 kΩ. In the last sentence of the article the mention of S1 is incorrect it should be S2.

capacitance meter (March 1984, paga 3-42)

The note in the margin on page 2-55 is incorrect. It Meter board:

PI sets the display to '0' in ranges a, b and c.
P3 sets display to '0' in ranges b, c.

funny bird

Laumann circuits, Page 8-82
T1 is drawn erroneously as an NPN type, whereas it is, of course, a PNP type.

FM pocket radio (August/September 1984, page 8-321)

Transistor T8 must be BC550C with the collector connected to +5 V.

direct-coupled modem (November 1984, page 11-347)

It appears that the missing link in our November issue is still not the complete solution to FF3 setting inadvertently on switch 2. A satisfactory solution is to connect a 470 pF capacitor between pins 2 and 3 of IC7 and to ensure that C21 in positions TELEPHONE and MODEM is connected to earth via one of the unused sections of switch S2.

digital tachometer (October 1984, page 16-36)

The formula given in the last part of the marginal note beside figure 2 (page 9-47) is not right. It should state:

The frequency range is then 686 .1194 Hz.

elaborinth (April 1984, Page 4-307)

The last address and data (888 FF) in the header in table 1 should be deleted.

petrol saver (April 1984, page 4-18)

In some cases, it may be advantageous to replace the part of the circuit shown in 1 by that in 2...
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2.74 elektor india february 1986
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