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A high quality transistor/valve design

DIGITAL CODE LOCK
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DIGITAL PULSE TRANSMISSION

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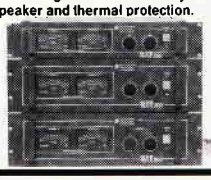

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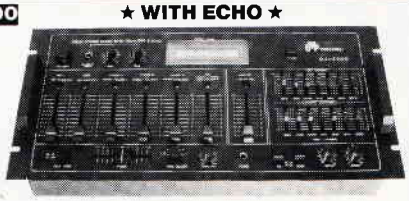

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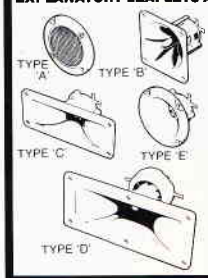

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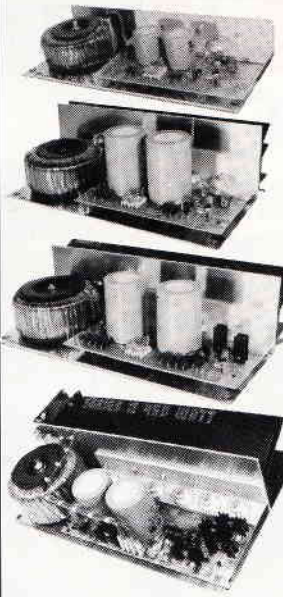

OMP/MF 100 Mos-Fet Output power 110 watts R.M.S. into 4 ohms, frequency response 1Hz - 100KHz -3dB, Damping Factor >300, Slew Rate 45V/uS, T.H.D. typical 0.002%, Input Sensitivity 500mV, S.N.R. -110 dB. Size 300 x 123 x 60mm.
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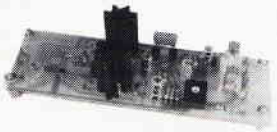

PHOTO: 3W FM TRANSMITTER

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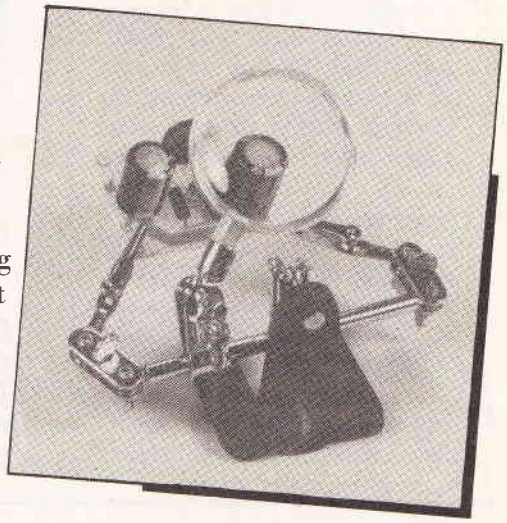

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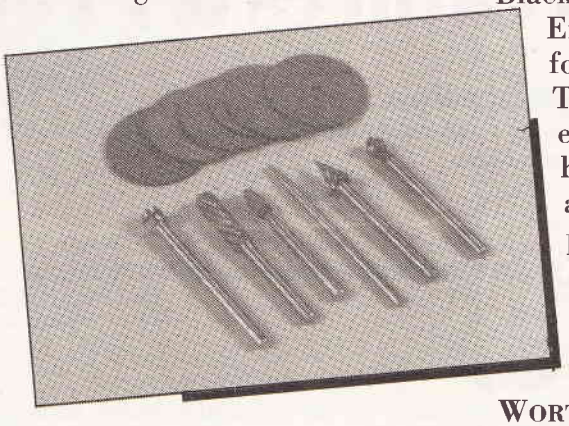

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In this third part Mike Meechan ties up some constructional loose ends with the master controller and 8kW Dimmer pack.

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Not only is there a curious fascination with valves but the use of such devices for audio can be advantageous. Couple them with the versatility of the transistor and you have the best of both worlds. Jeff Macaulay outlines the theory and construction of this audio project with a lower-than-expected voltage supply.

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Protect your valuables with this combination lock. The construction is brought to you by Edward Barrow.

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Paul Coxwell examines transformer action in this final part of his beginner series.

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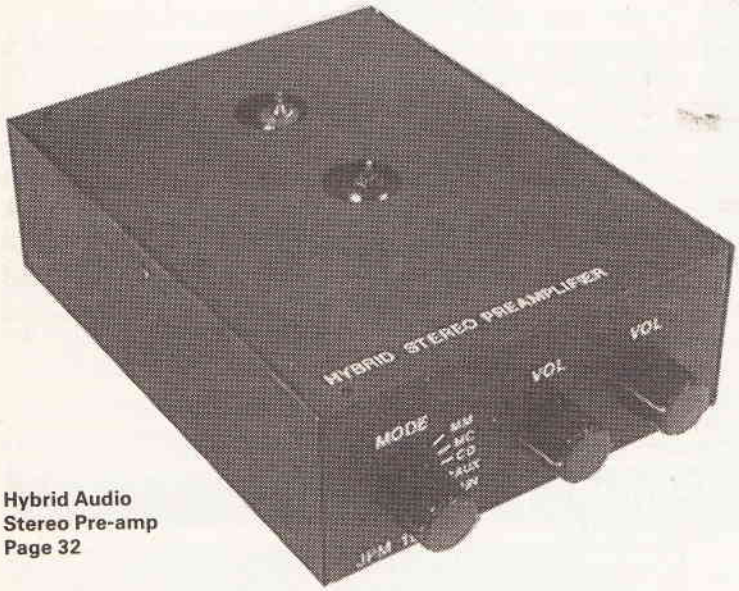

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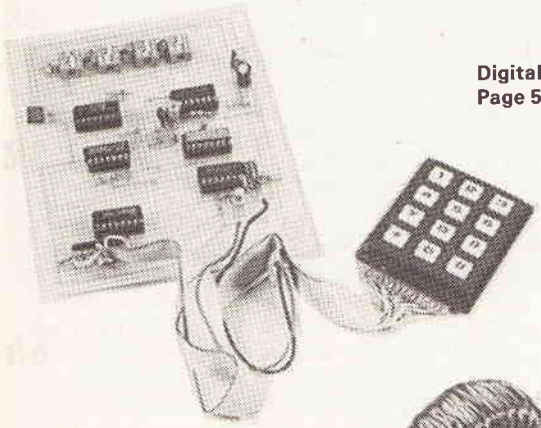

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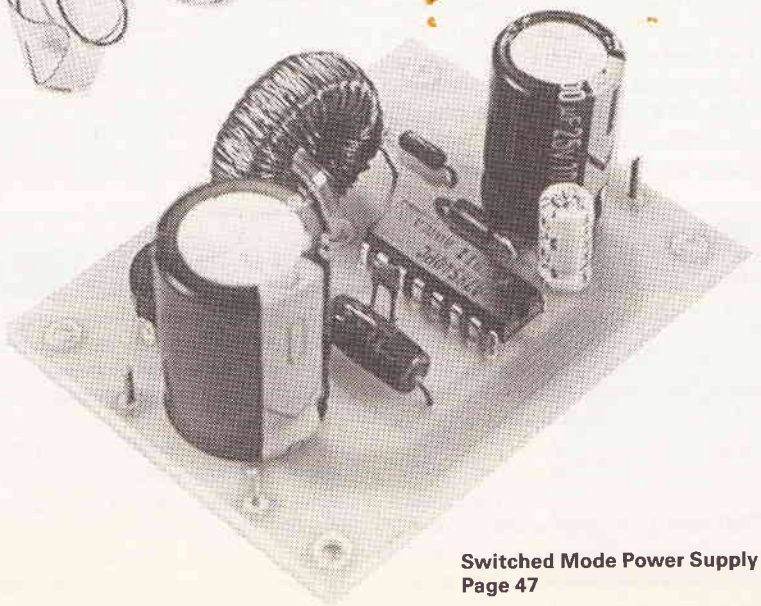

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Editorial

Technomania

One thing we have to be careful of here at ETI is not to publish the sorts of projects that would be as useful as an electric fridge on a desert island. Some are glaringly obvious like musical toilet rolls that play tunes every time you pull the roll or an electronic milk monitor to tell the household that the fridge is devoid of milk.

Some project ideas appear in the 'let's find a use for it' category and could fill some spare time in construction on a cold night.The final category are the ones where we wonder how we could ever do without.

But it has to be said a gadget-ridden home would lead to a waste of resources. Consumption of electricity, replacement of batteries and maintenance are all aspects we could do without. The degree of usefulness for any aid depends upon who is using it and for what purpose.Some may find an automatic stock- taker for food that prints out a shopping list ready for your next shopping trip, really useful. Why go out shopping? What's wrong with teleshopping? say the residents of Milton Keynes whose houses are wired for everything. It is true, we could amuse ourselves ordering by TV screen when the system has been fully implemented nationwide by most shops, but it still doesn't tell us what we need. Using the same system of bar code reading is ideal since most items have these labels, but it might be difficult for the poor old laser to zig zag its way through all the nooks and crannies of the cupboard terrain like a cruise missile seeking out the targets. Maybe that's where those involved in military semi intelligent targetting systems (leave the machines to argue amongst themselves over matters of war) should divert all their accumulated knowledge into 'home-help' systems.

Technology has taken away some of the tiresome and dreadful jobs in society leaving more time to be creative in other areas, but for some it does then present the problem of what to do next!

Paul Freeman

OPEN CHANNEL

There's no doubt in my mind, and I'm known for my accurate predictions — if only by my cat and all you ETI readers — that Philip's digital compact cassette (DCC) is going to win the race to gain credibility as a new digital audio recording medium against Sony's mini-disc.

Needless to say, I've recounted the main differences between the two technologies in this column before. Briefly, DCC is a tape medium which uses a stacked recording and playback head to layer digitally converted audio parts onto tape, with pretty conventional electromagnetic techniques. Mini-disc, on the other hand, is much like a compact disc using magnetic-optical techniques to create a reusable format.

Nothing remarkable here you might say, and there's potentially nothing between the two in the end result. Big difference between them, however, is apparent when you note the fact DCC is backwards compatible in that it can be used to replay conventional minicassettes — the kind we all know, use and love in analogue form. So, your valuable cassette collection containing all the archived accumulations of the last decade or two's influence on your musical sentimentality is not simply defunct if you choose the DCC route.

Choose mini-disc though and your cassettes rely on you maintaining a cassette player alongside your mini-disc player. What the world does not need at this time is yet another black box sitting in the heartlung machine which masquerades as your hi-fi system in the corner. We're all still smarting from a wonderful conversion to digital compact discs which, in reality, only meant you need to keep your grotty old LP turntable as well as your new CD machine. Ain't technology wonderful.

Naturally Sony is playing down this simple advantage. But it's enough to make me put my money on DCC. It's also enough to make Matsushita and Thomson (which both helped in DCC development), Grundig, Tandy and Kenwood join the ranks of manufacturers who will be promoting FCC and not mini-disc. Interestingly, it is rumoured Sony will also produce DCC equipment.

We're Alright, MAC

There is growing concern among satellite broadcasters that D2MAC is not where it's at. After being almost bamboozled by the science of higher quality pictures and sound if broadcasters transmit signals in the D2MAC format, than being hoodwinked into rushing towards agreeing an operational date, theyr'e all now having second thoughts.

Originally, the European Commission was persuaded to go the D2MAC route by a consortium of European manufacturers headed by Philips and Thomson. Quite naturally, they wanted a format which would beat off Japanese attempts to impose high definition television systems on the European market. At the time any of the MAC variations (specifically DMAC and D2MAC) seemed able to do this job and provide a basis for development into our own high definition television system.

All this is great — MAC does provide this option and ensures existing users don't need to buy new and expensive high definition televisions yet, if they don't want to. They do, however, need slightly more expensive MAC receivers.

These manufacturers and the European Commission assumed, though, two things which I do not believe have been shown to be the case. First incorrect assumption was that users actually wanted high definition television. Second incorrect assumption was that a two-stage process to get it is necessary at all.

Proof the first assumption is incorrect can be seen by the public's acceptance of Sky Television's satellite broadcasts (using bogstandard PAL transmissions), alongside its almost total dismissal of British Satellite Broadcasting's (BSB) MAC transmissions.

If the first assumption is proved incorrect by this argument, then it's only a small step to realise the second is also incorrect, simply by default.

Société Européene des Satellites (SES) the organisation running the Astra satellites which broadcast the five Sky Television (now British Sky Broadcasting after the merger with BSB) channels has made it clear it believes D2MAC is a dead duck. Most channels transmitted from the 32 existing transponders from its two satellites are already broadcasting in conventional PAL formats. Viewers are apparently more than pleased with the quality. Cost of conversion to MAC formats is not therefore seen as a viable imposition on users.Such is the strength of the SES (and other broadcasters) argument that the EC seems to be in minor disarray over the question. A recent deadline for agreement on high definition television was cancelled, simply because nothing would have been agreed. While manufacturers are only to happy to impose a standard, users at the front-end feel they should have been consulted.

It all boils down to the fact D2MAC transmissions only form a stepping-stone towards a high definition television system. True, while D2MAC itself allows a higher quality picture to be received than PAL formats, the higher quality is only barely perceivable, if at all to the untrained eye. It is by no means high definition. So what's the point of changing to D2MAC?

It is only with the adoption of HDMAC formats in years to come that true high definition television will be possible. In effect D2MAC is a stepping-stone which we could well do without.

Keith Brindley

ETI NEWS

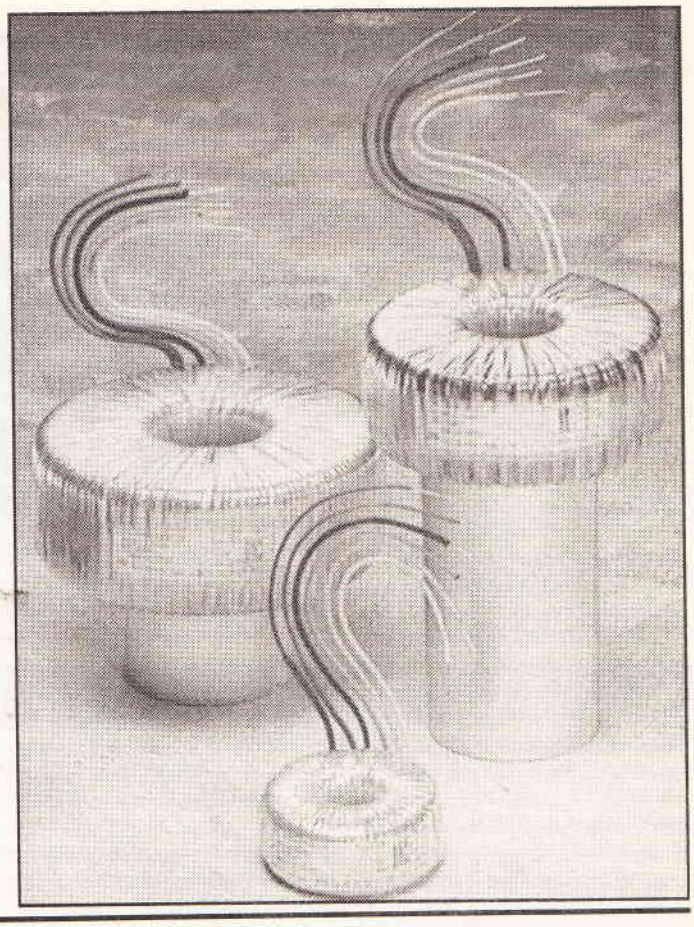
TOROIDS FOR EUROPE

A new range of toroidal transformers, made by Avel in their South Wales plant, can now be supplied for use in professional electronics equipment manufactured by member countries of the EEC as they adopt the 230V mains supply voltages by the year 2003. The Avel toroid specification includes 220, 230 and 240V single wound primary windings which will meet DIN IEC38 nominal operating voltage range requirements of 207 and 253V. The operating frequency range is 47 to 400Hz (nominally 50 to 60Hz); and the power ratings are 30, 60, 100, 120, 160, 230 and 530VA.

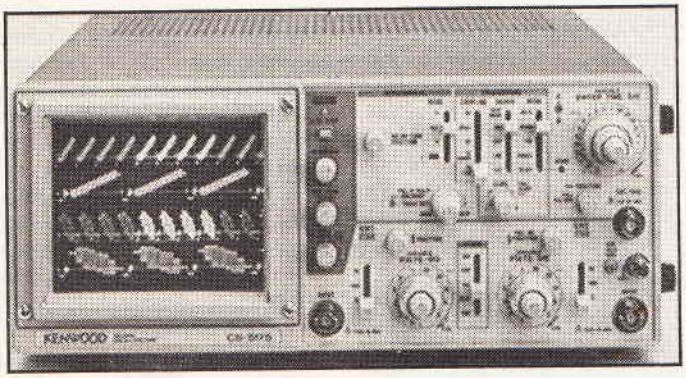
The secondary windings are wound on the outside of the primaries and enable virtually any dual secondary voltage to be provided from 6 to 240V RMS. The secondaries can be connected in series or parallel, but if they are isolated, the applied potential must not exceed 250V DC. The primary to secondary must withstand 2500V RMS; and each transformer is flash tested at 4kV RMS.

These toroids have built-in thermal cut-out protection; the permitted operating temperature rise is between 55 and 65°C depending on the VA rating. Toroidal transformers are 50% lighter, have eight times lower radiated magnetic field, 50% lower volume and have very low open circuit power loss — when compared to stacked lamination types.

Contact for further information: Avel-Lindberg Ltd, Tel: 0708 853444.



LOW COST 100MHz OSCILLOSCOPE



A dual channel four trace 100MHz oscilloscope model with delayed timebase is now available from Thurlby-Thandar Ltd.

Input sensitivity can be varied between 1mV/division and 5V/division in 1-2-5 steps with fine adjustment over the whole range. A signal delay line enables a display of leading edges. Crosstalk between channels is quoted at −40dB or lower at 1kHz.

Sweep times on the main (A) timebase can be varied between 0.05µs/division and 0.5s/division and between 0.05µs/division and 50ms/division on the delayed (B) timebase. The ×10 magnifier gives a maximum sweep speed of 5ns/division.

To ensure measurement reliability, the major specifications of vertical axis sensitivity and sweep time are guaranteed to within ±3% from 10 to 35°C and at humidities up to 85%. Other specifications are within stated limits.

The true alternate delayed sweep allows an intensified portion of the waveform of sweep A to be observed using sweep B simultaneously with the original waveform. If this is performed on both input channels then a four trace display is possible.

A vertical signal output scaled to 50mV/division enables connection of a frequency counter for accurate measurement while observing the waveform.

Observation of both vertical and horizontal TV signals with stable triggering is made possible with the video clamp function. The large, dome-mesh, post accelerator (12kV) CRT provides high intensity and excellent resolution while eliminating parallax error. Auto-focus maintains a clear, sharp waveform display at all times.

The CS5175 cost £920.00 plus VAT including two probes.

Further information contact: Thurlby-Thandar Ltd, Tel: 0480 412451.

LOW COST PULSE GENERATOR

The TG105 is a low cost full function portable pulse generator. It offers a frequency rate of 5Hz to 5MHz and provides fully variable period and pulse width with a variable output level of 0.1V to 10V from 50 ohms. Free-run, single shot, gated and triggered modes are standard as in a TTL and sync output.

The TG105 is housed in a compact rugged case which measured 255mm × 150mm × 50mm and weighs 1200gm. It is priced at £129.00 + VAT.

Further information please contact Thurlby-Thandar Ltd, Tel: 0480 412451.

EASY VCR PROGRAMMING ON THE WAY

Ease of use and ease of programming remain key issues with the minority of video recorder users according to Ferguson. Despite the increased ownership of VCRs in this country, with UK household penetration now standing at 73%, a startling proportion of users still experience real difficulty in programming their video. 28% of all adults find programming their VCR arduous, and this proportion rises to even higher percentages in the case of female users (35%) or those over 45 years of age (50%).

Some attitudes identified by Ferguson's research, showed the programming to be complex and inflexible, too many features like complicated remote control units and too many buttons.

Some of these problems will hopefully be solved because as from this December, Channel 4 goes on air with Programme Delivery Control (PDC), a fully interactive system that introduces error-proof video recording from teletext by sending programme start and finish codes to the VCR. A derivative of the VPS/VPT system invented by Thomson, PDC was shown by Ferguson for the first time in the UK at the Video Show earlier this year on the Ferguson Videostar FV54LX (due to be launched in August). The PDC system signals a new era in video programming and will be launched in this country as 'Startext', a name agreed by BREMA members that is easily understood and remembered by both trade and consumer alike.

Text programmable VCRs, allowing the timer to be set directly from the teletext TV schedule pages, have existed in the UK

for two or three years now. Simple button selection on the remote handset moves a cursor down the text TV pages and the desired programme, start and stop time are stored in memory. This system provides one of the simplest methods of programming a VCR to date, however, if the programme to be recorded is delayed for any reason, perhaps because a sporting event preceding it overruns, then the programme times will need updating.

Startex works differently as, when the broadcasters trasmit the TV timetable as teletext pages in advance, each programme is assigned a unique label that allows the VCR to store that individual programme in the timer's memory. In addition to sending the VCR labels that identify a particular programme, a continuous stream of information is also sent, corresponding that what is actually on-air at that moment. With a timer event programmed in the VCR's memory, the Startext circuitry within the VCR scans the continually incoming stream of text information, waiting for the label that tells it that the programme is indeed on-air. The VCR matches the programme on-air label with the label stored earlier from the programme listing pages and, in this way, timer recording occurs at the correct start and stop times.

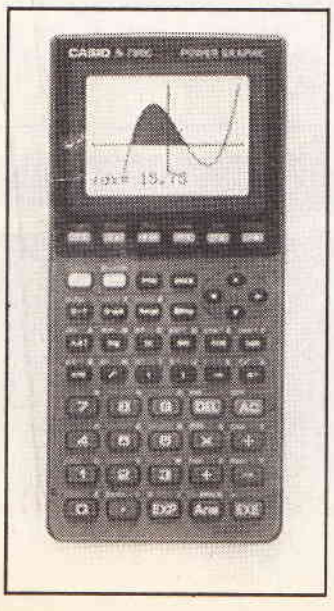
Video programming from teletext was originally patented by Thomson subsidiary, Telefunken, under the acronym VPS (video programming system), with the first text programming VCR being launched in Germany, under the Telefunken brand, in the Autumn of 1985.

Ferguson/Thomson led discussions with BREMA, the BBC, the IBA and the EBU, to establish text programming in the UK and, in the Autumn of 1989, standardised teletext programming for VCR use, jointly with the BBC and the IBA. In February 1990, Ferguson launched the first Fastext VCR in the UK.

Since then, the principles of PDC have been discussed and laid out by BREMA and UK broadcasters, and a final PDC code of practice finalised with the EBU in April of this year. Having run tests since April, Channel 4 have undertaken to start broadcasting full PDC transmissions from December.

The first Ferguson video recorder to incorporate Startext is the FV54LX, a 4-head dual azimuth long play VCR available in August, retailing at around £399.99. Incorporating a Fastext decoder, the FV54LX also provides full text facilities. This offers a distinct upgrade opportunity for the many non-text households in the UK (household penetration of TVs with text currently stands at only 34%) and, as the FV54LX allows text operation through both SCART and RF sockets, the VCR can be used for text operation by those with only an RF socket on their TV. Users can also record subtitles in colour.

GRAPHIC CALCULATOR



Casio have introduced the fx-7700G Graphic calculator. Priced at £79.99, the fx-7700G uses a high contrast 16-character by 8-line display. Graphing facilities include polar co-ordinate, parametric, inequality and user generated graphs, all with various zoom options. Also included are Standard Integrals, and the creation and manipulation of Matrices up to 9 × 9.

The fx-7700G further adds calculations in fractions, and instant replay function, 4000 program steps (which can be spread over 38 areas), multi-statement program lines and powerful statistical and linear regression functions.

To make the fx-7700G easy to use, the keyboard has a new format for improved ergonimics, with compass layout cursor keys, and an independent graph variable hot key for X, theta and T.

Another important innovation is the fx-7700G's flexible menu system, where six exclusive function keys are used to call up submenus, for related groups of operations, on the display. This not only speeds complex operations, but also reduces keyboard clutter, by reducing the number of functions on each key.

The fx-7700G comes with a slide on hard cover that fits over the front or back of the calculator, and incorporates a rubber foot to prevent it slipping on a desk. Programme contents are protected by a separate lithium battery. The 217 page instruction manual is extensively indexed and had a 'quick start' section for those who are new to graphic calculators.

Further information contact Casio Electronics Co Ltd, Tel: 081 450 9131.

HIVOLT PACKS

WALLIS Hivolt has introduced a range of high performance power sources, offering increased packing density for high voltage applications at affordable prices.

Offering up to 8kW of very stable DC power, the OL8000 generation of custom designed power sources are able to meet applications such as ion implantation, high power X-rays, and electron beam welding.

Wallis Hivolt has manufactured the OL8000 range of switched-mode power supplied using Insulated Gate Bipolar Transistor (IGBT) technology. This provides numerous benefits, including the very rugged nature of the technology and its extended safe operating area. Thus the OL8000 range offers immunity to flashover and a high degree of operational integrity.

Power in the range of 80kV at 100mA, to 200kV at 40mA can be supplied by the OL8000 range. This range can be extended up to 400kV at 15mA, or down to 80V at 100mA in special units. Ripple figures for the range are less than 0.2%, with 0.1% units available on request. Power density of up to 2W per cubic inch is offered by the range.

Contact Wallis Hivolt, Tel: (0903) 211241.

BRITISH EQUIPMENT TO MONITOR SOLAR POWER STATIONS

British company Campbell Scientific Limited has been chosen to supply data logging equipment to monitor the performance of Switzerland's expanding programme of solar-powered Photovoltaic Power Stations (PVPs).

Switzerland already has the lowest per capita consumption of fossil fuel in Europe, and is determined to decrease it further through alternative energy sources. Using all technically feasible sites in the Swiss Alps, it is estimated PVPs with a peak power of 45MW could produce up to 65,000MWh of energy per annum, giving Switzerland a major lead in the harnessing of solar energy in Europe.

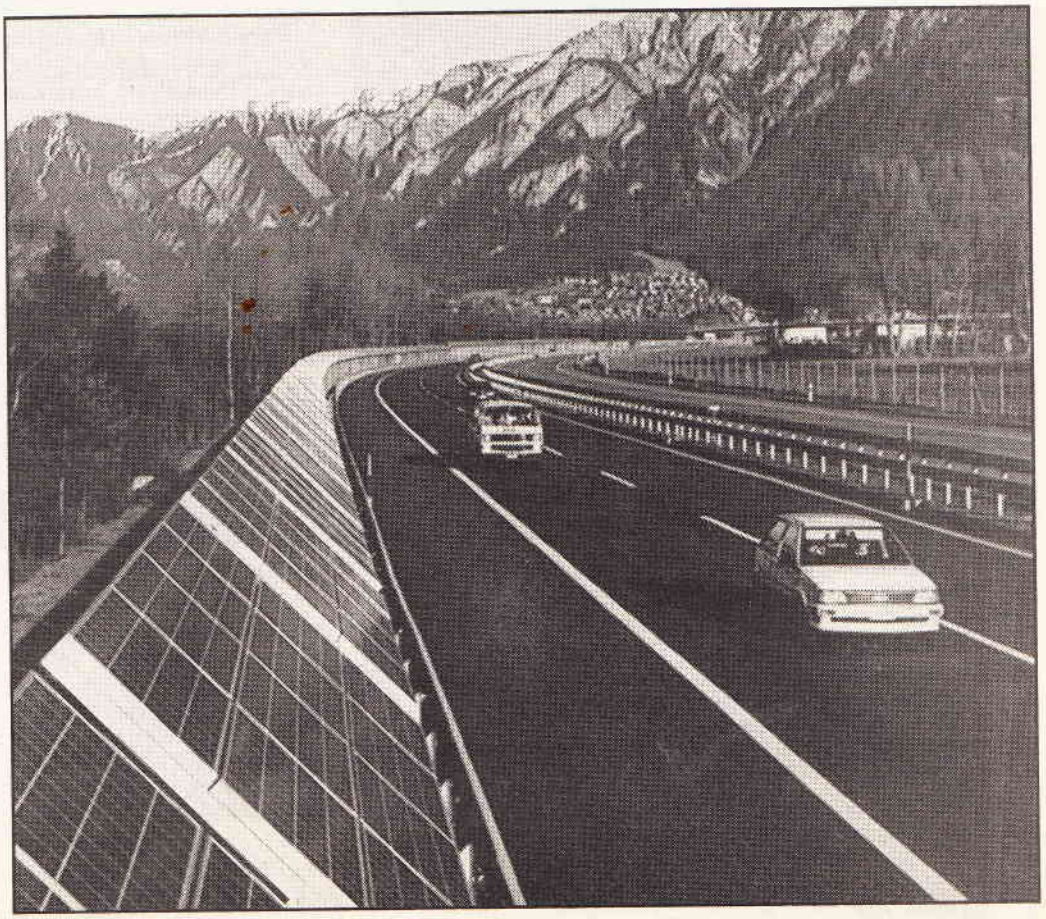
The Swiss are tackling the problem of space needed for PVPs, and environmental impact, by building them on existing structures. Their first full-sized PVP (pictured here) has been built on top of 830 metres of existing sound barrier on the N13 Motorway bwtween Felsburg and Domat/Ems, and the Department of Energy has ordered a further 100kV peak plant to be constructed in 1992 on the south side of the railway line between Bellinzona and Locarno in the Canton of Ticino, Southern Switzerland. The mountng structure will be the foundation of a district heating pipe.

Two further PVPs have been commissioned by local authorities, also to be built in 1992. A 100kW peak plant on the south side of a motorway near Basel, mounted on a newly-constructed sound barrier, and a 140kW peak plant along a funicular mountain railway in St Moritz. These plants will be partly financed by the Swiss Federal Government.

Switzerland is approaching the second problem of PVPs — the relatively high costs per unit of electricity — by developing new methods of designing, constructing and operating PVPs and achieving major economies of scale through building larger plants.

The N13 Motorway PVP was built as the country's first full scale pilot installation with a peak power of 100kW and an estimated annual production of 117,000kWh. In the first 18 months of operation, it has contributed over 150,000kWh of electrical energy to the Swiss National Grid — enough to power a small village of group of commercial users.

Detailed information about the performance of each of the 92 arrays of 24 solar modules in the PVP is acquired by a series of CR10 Measurement and Control Modules supplied by Leicestershire-based Campbell Scientific Limited, which specialises in data acquisition equipment used for applications ranging from eteorology to agricultural research. The CR10 Measurement and Control Modules also collect data on environmental conditions at the PVP and all the data is transmitted every fortnight via modem to TNC Consulting AG for further processing.



BATAK

A sport combining electronics and agility could be the start of a series of games to tone muscles in the 21st century.

The equipment, called BATAK, is aimed at the professional sport and fitness market and is currently being developed into a three dimensional training platform. The interest from an electronic viewpoint lies in the fact that it is probably the largest physically interactive computer game in the world and has also been dubbed a 'Digital Sport'. Games and routines are played by way of a memory cartridge and a synthesised voice is incorporated together with sound effects during play.

At the present time there are two machines being play tested, one at the prestigious Surrey Tennis Centre, Nr Croydon and the other in Japan. Dr Craig Sharp of the Olympic Fitness Centre has endorsed and approved the fitness and reaction benefits of the machine for all levels of athletes in every type of sport.

Two of the National Sports Centres, Bisham Abbey and Crystal Palace, are due to take delivery of machines later in September with Lilleshall following shortly. The equipment is suitable for many types of venue including leisure centres, all types of fitness clubs, bowling alleys and fire stations, theme parks, schools, police, military and ocean liners.

For further information contact: Quotronics, Tel: 0293 785132.

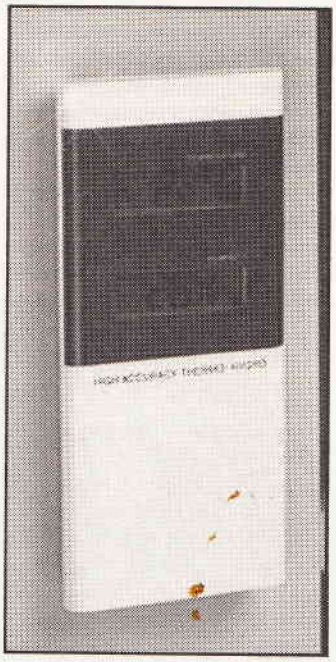
NEW LOW COST TEMPERATURE/HUMIDITY METER

Industry, horticulture, laboratories and education will all find applications for this low cost high performance digital Temperature/Humidity meter.

Priced at £19.60, the SE2000 provides simultaneous display of temperature (0°C or 0°F) and %RH. The instrument has a one year battery life, has integral temperature and humidity sensors and may be wall mounted.

Temperature ranges is 0°C to 50°C with 1°C accuracy from 0-40°C. The relative humidity range is 25% to 95% RH with 5% RH accuracy between 40%RH and 80%RH.

For further information contact Solexpress, Tel: (0455) 283486.



LCDs — THE NEXT GENERATION

The Hirst Research Centre, a division of GEC-Marconi, will be demonstrating liquid crystal displays and devices of the future within a special feature area at the Electronic Displays Exhibition (November 19-21, 1991).

Entitled 'LCDs — The Next Generation', the area will concentrate on polysilicon active matrix liquid crystal displays and show examples of integrated driver technology.

Demonstrations will include Fault Tolerant Active Matrix LCDs; Polysilicon Integrated Driver Circuitry; Ferroelectric LCDs; and Supertwist LCDs.

Dr Alan Mosley, Chief Scientist (Displays), Hirst's Display and Optical Research Laboratory, said: "Polysilicon is regarded as the material of the future for active matrix LCDs, mainly because its semiconductor qualities are better than those of the presently used amorphous silicon.

"This improvement will allow the use of smaller transistors in the active matrix array, thus providing a brighter display as the transistors are opaque.

"More significantly, the use of polysilicon enables the fabrication of the electronic drivers for the display to be carried out at the same time as the fabrication of the active matrix array — dramatically reducing the cost of the final display module.'

The Electronic Displays Exhibition (Wembley Conference and Exhibition Centre, London), will feature over 60 leading manufacturers and distributors from all areas of the display spectrum — from basic display components to complete display systems.

Further information, contact Penny Hanson at The Hanson Organisation, Tel: 081-843 1188.

ENGINEERING INDUSTRY TO BENEFIT FROM CAREERS INITIATIVE

The Engineering Training Authority has commissioned a major survey into the careers information needs of the engineering industry and the attitudes of employers, school teachers, careers officers and young people towards the material and services currently available.

The nationwide survey, by the Institute of Manpower Studies, comes at a time when research shows that the number of young people applying to study engineering has fallen by 14% between 1986-1988 and less than half the country's 'A' level students think engineering presents a positive image to young people.

EnTra's careers service, ECIS, will use the findings of the survey to support the development of a new initiative — The Network Initiative — which aims to help reverse this trend.

The initiative is a co-ordinated approach to the provision of careers information at the local level. It will ensure a more unified and proactive approach to the promotion of engineering as a career through the establishment of a network of local organisations which will act as the focus for the delivery of careers information and activities.

Each organisation will consist of a group of representatives from local companies and other establishments who share an interest in promoting engineering and the career opportunities within it.

There are a number of organisations, including TECs and LECs, introducing similar services, but they vary in their approach and effectiveness. By identifying and developing 'models of good practice' Entra is ensuring the promotion of a consistent image and common standards.

ETI NEWS

stateside

New Uses For Perovskites

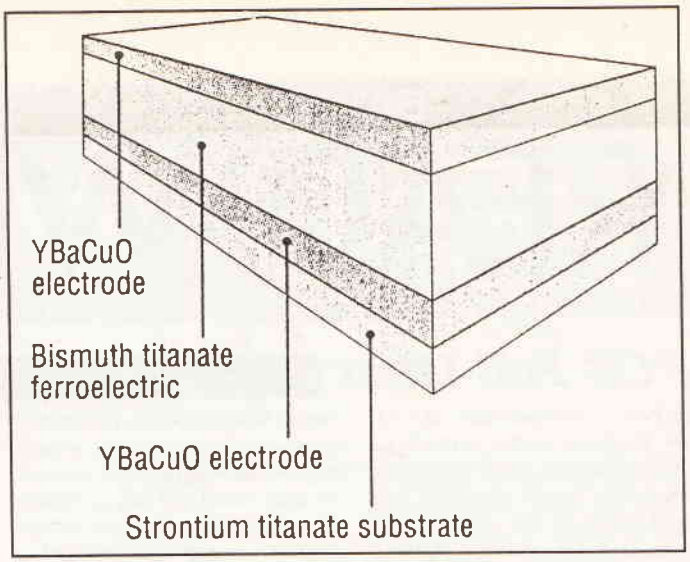
Researchers are finding new, nonsuperconducting room temperature applications for rare earth perovskites. One such application area may be nonvolatile memory chips.

A project has produced a superior ferroelectric RAM cell using yttrium barium copper oxide (YBa-CuO) as the outer electrodes and a related ferroelectric perovskite as the switching layer. A compound such as bismuth titanate has a perovskite crystal structure close to that of YBaCuO and similar chemistry, making the two compounds very easy to match.

Instead of polycrystalline deposition, the new perovskite compounds allow highly refined single crystalline epitaxial films to be grown on top of one another, eliminating the problems of conventional ferroelectric technology. There is a lattice mismatch between YBaCuO and bismuth-titanate of only 0.5% far better than most compound lattice systems, and that allows superior heterostructures to be built.

Single crystal strontium titanate is used as a substrate on which to build an epitaxial ferroelectric sandwich. A pulsed excimer laser is directed at a sample of material, which ablates the surface. As a result of the laser ablation, a plume evaporates from the material and is caught on the heated substrate, forming a single crystalline layer that grows at the rate of one angstrom per second. Up to four targets are mounted on a rotating carousel so successive layers can be formed in a continuous operation. A YBaCuO film forms the bottom electrode, after which a layer of a ferroelectric such as bismuth titanate is deposited. The cell is finished by depositing another YBaCuO film.

The work is being carried out by Bellcore Corp., of Redbank, New Jersey.



Storing Holograms

Researches at Northrop Corp.'s Technology Centre have succeeded in storing a record 500 holograms in a single crystal of lithium niobate through a technique called angle multiplexing.

The technique has allowed Northrop engineers to record and play back holographic interference patterns in a random-access mode.

A hologram is formed by interfering with coherent light reflected from an image with a reference beam. Since an identical reference beam is required to reproduce the image, different holograms can be 'keyed' by recording them at different angles.

Angle multiplexing was shown to have nearly ideal crosstalk characteristics. Previous methods for storing multiple holograms have suffered from interference effects produced by the partial recall of nearby images.

Millimetre Wave Radar System

Scientists at TRW Inc.'s Electronics & Technology Division have fabricated the first millimetre-wave radar system on a single indium gallium arsenide substrate.

Measuring 4.35 x 7 millimetres, it is also the largest multifunction millimetre-wave chip yet made, according to TRW. Monolithic microwave ICs such as this one are smaller, lighter and less costly than radars created using hybrid techniques, the company said.

The transceiver exploits TRW's 0.25-micron InGaAs high electron mobility transistor technology to pack seven active microcells on a single chip. These functions include a voltage-controlled oscillator, buffer amplifier, mixer, voltage-controlled phase shifter, and attenuator.

The chip implements an analogue diplexer comprising back-to-back Lange couplers. Besides the process advancement, the most significant factor contributing to this level of integration was the development of a CAD tool for the job. The entire chip, with all seven active functions, could be simulated through this tool. Consequently, trade-offs and adjustments could be made to obtain optimum performance.

While the transmitter section of the radar operates in the 37-40GHz frequency range, the receiver portion converts the signals in the same range to an intermediate frequency of 10-100MHz. The conversion loss in the receiver is 0dB at 38GHz. When integrated with an antenna, the chip is a fully functional FM-CW radar that can detect the Doppler frequency shift from reflected objects.

New epoxy compounds

Materials scientists from Cornell University and IBM Corp.'s Systems Technology division have created several epoxy compounds that expand and contract very little with temperature, and are also very stable at high temperatures.

The new materials tend to be more immune to heat stress, and could be suitable for printed-circuit boards and electronic packaging. They could also be used for making optoelectronic waveguides.

While experimenting with a new class of materials called liquid crystalline epoxy networks, the team discovered that if, during formation, the individual molecules are heated under intense magnetic fields, the polymer chains tend to align themselves in the magnetic field, producing a more ordered network with the unique physical properties described above.

Traditional polymers tend to be in the 100 parts per million per degree Celsius range. Silicon's coefficient of thermal expansion is 2 ppm/°C. The new material, which is based on 4.4'-dihydroxy-alpha-methylstilbene has a coefficient of 10 ppm/°C, but only in the longitudinal direction of the molecules. In the transverse direction, the coefficient rises to 80 ppm/°C, a problem the researchers are now working to solve.

READ\WRITE

ETI LETTERS

PCB Foil Offer

Your correspondent A. D. Carstens, writing in the September edition of ETI raises an interesting point regarding the production of film negatives of positives from prototype PCBs.

There are, as your reply points out, two separate issues here. One is that he requires positives from his own CAD system, the other is the availability of 'films' for your projects as published in ETI.

It had not struck me before that readers would be interested in either of these services but they are both easily provided by our own in-house facilities. Unhappily for reader Carsten there is no way of getting thoughts of his computer onto metal without considerable capital expenditure on either plotters or cameras, a problem for which we propose the following solution:

We will provide negatives from 2 × scale artwork, or dot matrix printer output, from originals no larger than 13in × 19in for only £8.75. If required positives can be made from the negative for only £1.50. All work will be serviced on an 'in by Wednesday, back by Friday' turnaround.

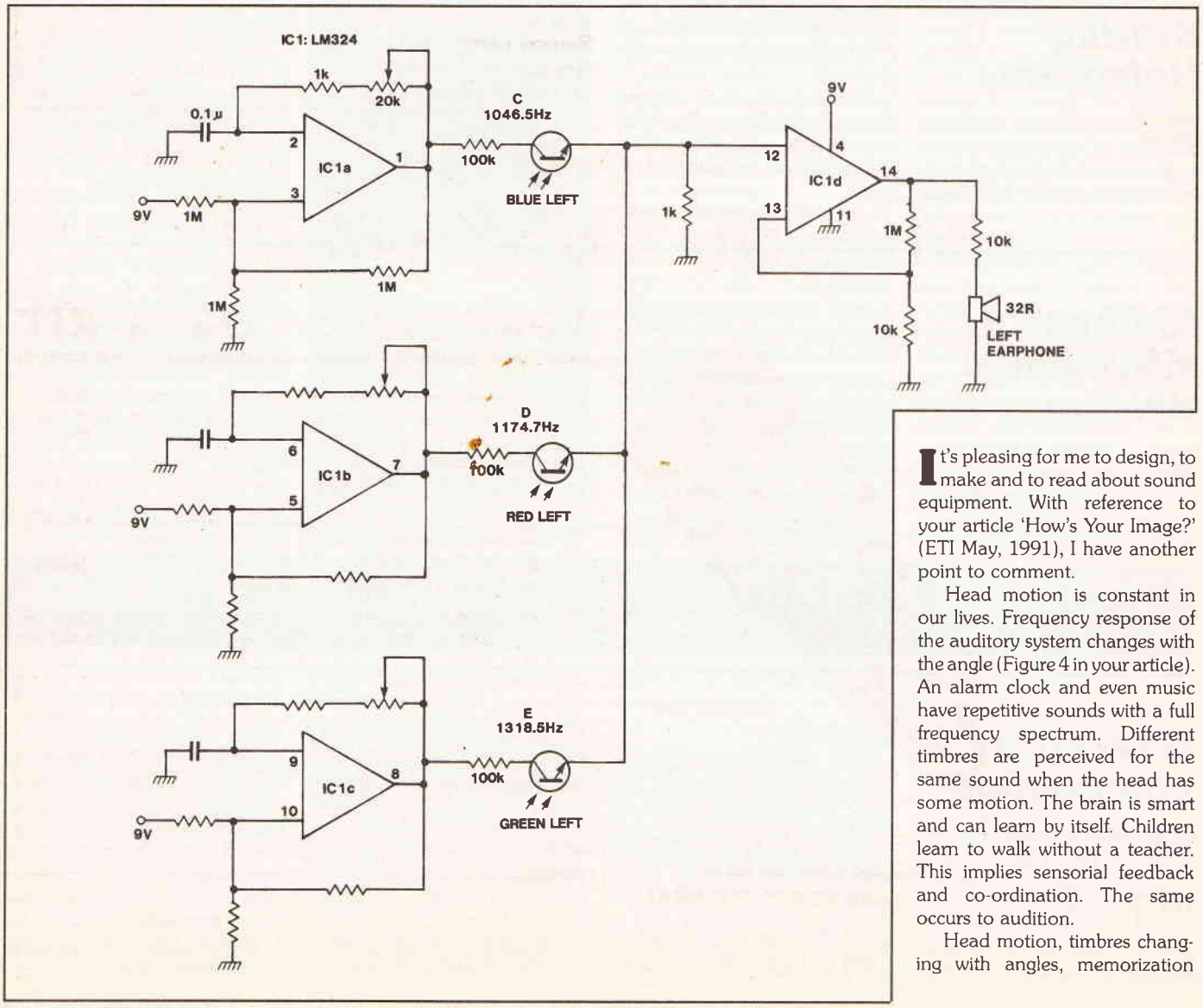
I must confess that without thinking about it I had not imagined that your foil patterns, as published, are less than useful to the reader wishing to make his own boards. The normal 'spray with transparentiser and expose to ultra violet light' being precluded because there is other printed matter on the other side of the paper. There is also the problem, looking at your current issue, that even a professional process house could not get a usable negative from most of the designs given because ink spread has joined up many of the copper lands.

If you are interested we will also be quite happy to supply film positives as a service to your readers for £1.50 each.

Tony Milligan,
Hart Electronic Kits Ltd.

Readers may be interested to know that our January issue will contain a free foil to experiment with. — Ed

Colour To Sound Conversion



It's pleasing for me to design, to make and to read about sound equipment. With reference to your article 'How's Your Image?' (ETI May, 1991), I have another point to comment.

Head motion is constant in our lives. Frequency response of the auditory system changes with the angle (Figure 4 in your article). An alarm clock and even music have repetitive sounds with a full frequency spectrum. Different timbres are perceived for the same sound when the head has some motion. The brain is smart and can learn by itself. Children learn to walk without a teacher. This implies sensorial feedback and co-ordination. The same occurs to audition.

Head motion, timbres changing with angles, memorization

and learning allows us to locate sound sources with one ear. This system will work all together as described in your article.

Based on head motion and memorization, I am sending my design for the blind.

This low cost design for the blind is one electronic circuit that translates light into musical notes. Three very directional light sensors by the side detect blue, red and green through very narrow windows joined to a pair of glasses. Head motion and memorization are necessary.

I believe human memory is smart, fast and learns by itself, and matches perfectly for this job.

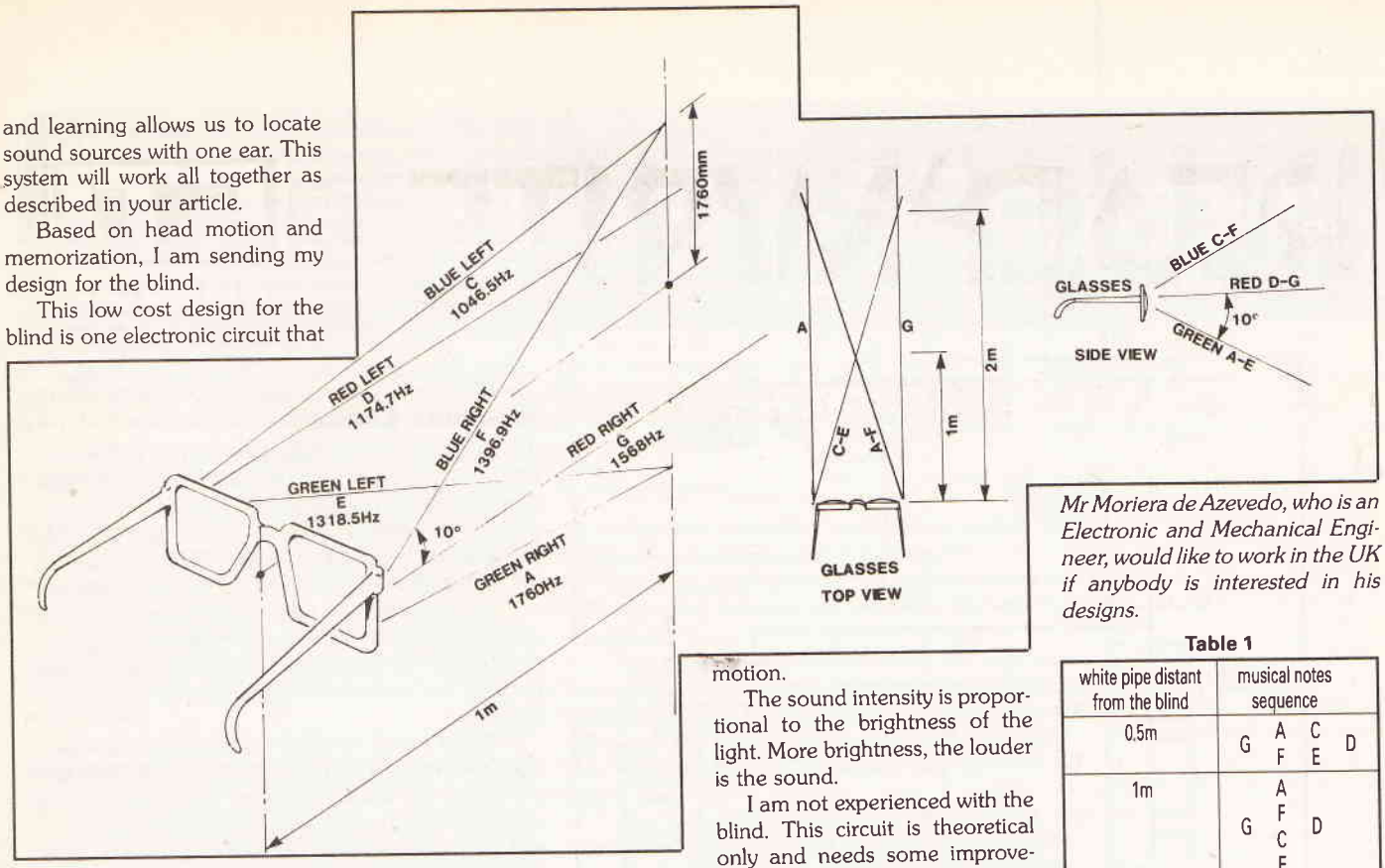
When one vertical pipe is in front of the blind the horizontal head motion (spin) from left to right results in the musical notes on the Table 1. Colours can be perceived with vertical head motion.

The sound intensity is proportional to the brightness of the light. More brightness, the louder is the sound.

I am not experienced with the blind. This circuit is theoretical only and needs some improvement. It would be made by my enterprise but it is out of the business (closed the doors).

I think these circuits have some use for robotics research.

Renato Laurentino Moreira de Azevedo, Sao Paulo, Brazil



Mr Moriera de Azevedo, who is an Electronic and Mechanical Engineer, would like to work in the UK if anybody is interested in his designs.

Table 1

white pipe distant from the blind	musical notes sequence
0.5m	G A F C E D
1m	G A F C E D
1.5m	G C E A F D
2m	G C E A F D
2.5m	C E G D A F

DREMEL® USA *Christmas Reader Offer!*

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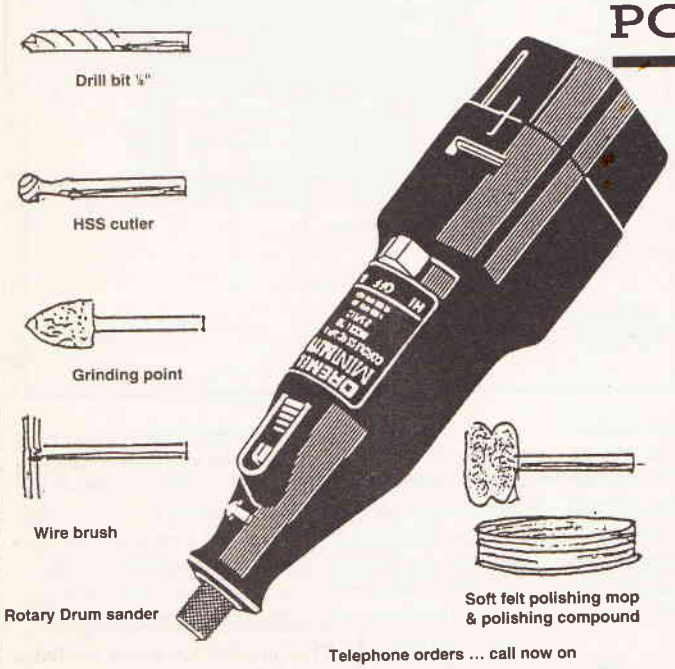

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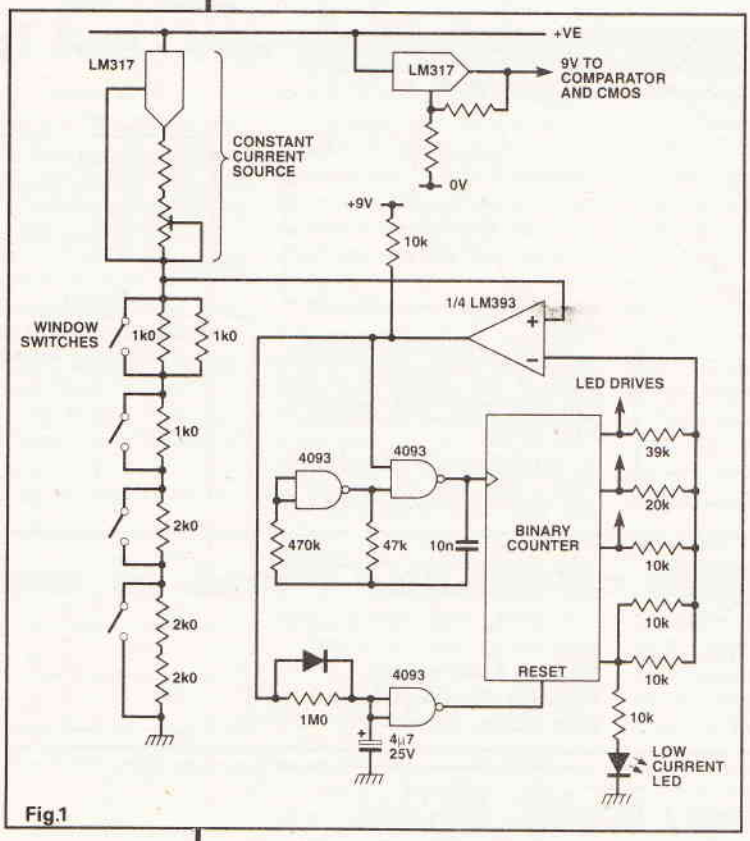

Fig.1

A few weeks ago I attended a literary weekend with some friends, and happened to fall into conversation with our guest speaker, a well-known author. You know what they say about doctors at parties; well, it happens to us as well. As soon as he found out that I was an electronics engineer, his face lit up. He is also an electronics hobbyist. He had a little problem, and he wondered...

It went like this. His wife had asked him if he could devise a means to check any of the windows in his several greenhouses were open without leaving the house. He had rashly given his opinion that not only could he detect which window was open, out of all the windows available, but he could do it with a single wire looped round all the buildings. He later had cause to repent his words, for the solution eluded him. I went ahead and suggested a means of doing it – but when I looked at it again in the cold light of another day, I had cause to repent my words, for my idea did not seem such a good one after all. So I sat down to think about it again.

Let's look at my first idea. The principle I used was to have a series of binary-weighted resistors in parallel with magnetically operated switches. Each window has a magnet, and each frame a switch, so that the switches are all ON when the windows are closed.

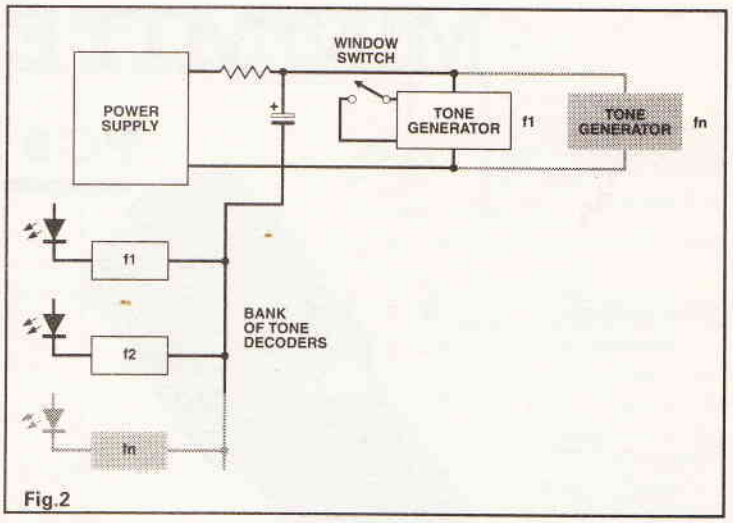

Fig.2

Resistor Chain

If a constant current is passed through the series chain of resistors (Figure 1), with their shorting switches, there will be one unique output voltage for each combination of switches. Each switch will add a certain increment to the output voltage, and that increment will not be affected by the state of the other switches.

Assuming that the resistors are accurate, and the current source is stable, then if the output voltage from this chain is fed to an analogue to digital converter, one bit of the A/D converter will switch on for every switch that is off.

This is fine in principle, but if resistors are binary-weighted in this way, one quickly runs into the problem that either the lowest resistance is too close to the resistance of the wiring, or the highest resistance is so high as to give problems with noise immunity. In addition, in order to make the bits of the A/D converter match with the individual switch positions, the reference voltage of the A/D converter must be the same as the maximum output voltage of the resistor chain, when all switches are off.

This is therefore not such a good idea, and is probably only suitable for use with up to four switches. A possible scheme to implement this idea cheaply is shown in Figure 1: not all the details are shown here, but the constructor should be able to fill in the details with the use of a CMOS data book and a proper calculator.

In this design a binary counter with its output connected to binary-weighted resistors is used as a simple digital to analogue converter. The output of this D/A converter is fed to a comparator which switches when the output from the D/A exceeds the output from the resistor chain. This stops the clock generator and starts a time delay after which the counter is briefly reset so that it starts counting up again. The reset pulse is brief, and delay is long, and the count period is short. Therefore, for most of the time, the outputs of the counter represent the states of the switches, and these outputs may be used to drive low-current LEDs. To make all this work, the ICs must be powered from a voltage

equal to the maximum output voltage of the resistor chain. Probably the best approach would be to run the ICs at 9V, while powering the constant current generator from an unregulated supply between 12 and 15V nominal. The constant current generator can then be adjusted to provide 1.2mA, which will make the resistor chain output voltage match the D/A converter voltages. While this design may be the cheapest and simplest way to detect the individual positions of up to four windows, if it is necessary to detect many more, the principle embodied in Figure 1 becomes impractical, and a new approach is needed.

If a single loop wiring scheme is to be used, it is inevitable that compromises will be necessary. If all detector circuits are wired in parallel, then the current drawn by each must be limited in order to keep the overall consumption reasonable. If on the other hand they are connected in series, then the voltage drop in each detector must be limited.

So, instead of relying on current or voltage measurements to detect which window switches are open, I decided to use AC signals superimposed on the power supply line.

The principle of this is shown in the block diagram of Figure 2. In this design, a series of tone generators, connected in parallel, are powered via a resistor. The tone generators are designed so that they draw a sinusoidal current from the supply at their tone frequency, in addition to the operating current of the generator. These sinusoidal signals are detected by the tone decoders and used to drive LED indicators.

Tone Generator

The design of a suitable tone generator is shown in Figure 3. It employs a Wien bridge oscillator with a

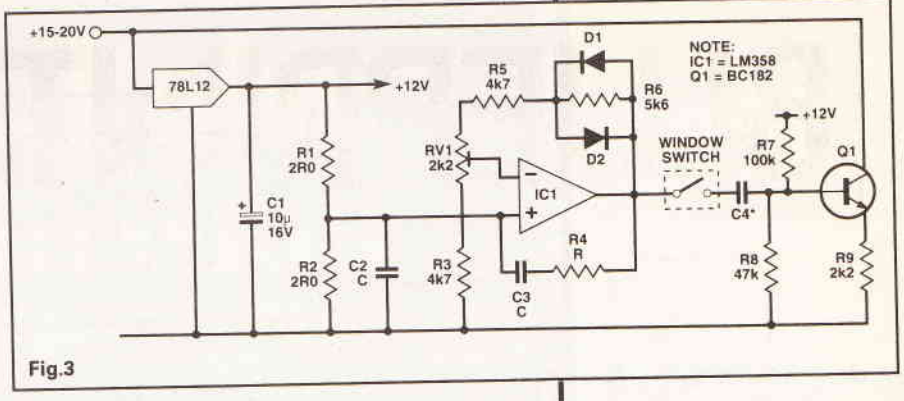

Fig.3

duct. This will reduce the gain and so prevent the amplitude of oscillation rising further.

When the window switch is closed, the sinusoidal waveform is AC-coupled to a transistor. This will draw a sinusoidal current from the main supply.

Power for IC1 is provided via a 12V regulator, because the power supply rejection ratio of op-amps declines rapidly as frequency decreases. If the supply is not regulated, then power supply modulation from one tone generator could affect the operation of another.

The value of C4 should be chosen to be big enough not to significantly attenuate the oscillator frequency when fed into a load of about 33k (R7 and R8 in parallel). In most cases it will be convenient to use a 100n capacitor, but if a very low frequency is used, a larger capacitor value may be required.

Tone Decoder

The circuit of the tone decoder is shown in Figure 4, as are the design formulae. The design is shown using fixed components, but if it is necessary to use a large number of tone generators and decoders, then it may be necessary to set a narrow bandwidth for the tone decoder, in which case R1 should consist of a fixed resistor and a preset potentiometer to adjust the tone decoder's centre frequency to match the frequency of the tone generator.

If a number of window detectors are needed, then the frequencies must be chosen with care. First of all, one should avoid the lower harmonics of the mains, and secondly no two tones should be harmonically related if possible. It may be unavoidable to have a harmonic relation between pairs of tones, in which case one should avoid the second, third and fifth harmonics.

Though the tone generator circuit is designed to produce a clean sine wave,and not to interact with other tone generators, beat generation is not impossible. Therefore, it is also strongly advisable to avoid having a difference in frequency between two tones equal to the frequency of a third. Otherwise, the first two tones could beat together to give a false indication of a third tone being present.

Because of the good linearity of the circuitry, the problems with harmonics and beats may not turn out to be serious in practice: this is an aspect of the design with which the constructor needs to experiment.

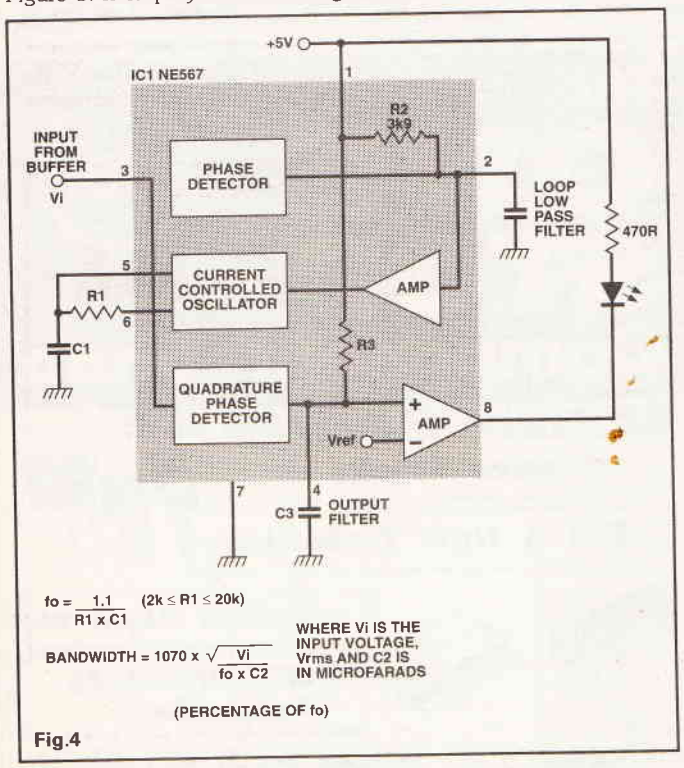

Fig.4

form of level stabilisation that will cause some distortion but not enough to give problems. The output of the oscillator op-amp is a fairly good sine wave, at a stable frequency.

This particular embodiment of the Wien bridge circuit has an attenuation of 3 in the positive feedback loop, so that a gain of just over 3 is required to guarantee oscillation. The pot, RV1, should be adjusted until oscillation just takes place. As the oscillation builds up it will reach the point at which D1 and D2 begin to con-

Power Supply and Buffer

To complete the design we need a power supply. Figure 5 shows a suitable circuit. This shows the equipment running from the mains, but if desired it would be

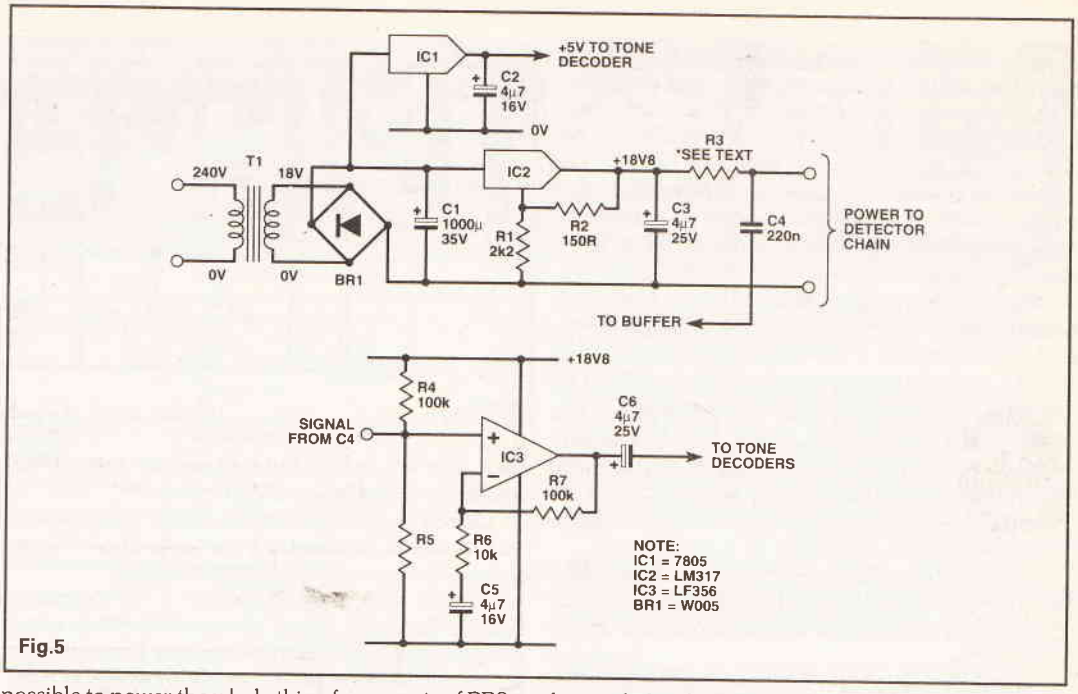

Fig.5

possible to power the whole thing from a pair of PP9s in series. In this case, IC2 would not be required, and IC1 would be powered from the 18V supply. A battery-powered design could not operate continuously, so one would also incorporate a push-to-read switch.

The value of R3 must be chosen so that the voltage fed to the detector chain is between 15 and 16V. The sinusoidal AC voltages imposed on this resistor will be in the mV range, and must be amplified in order to operate the tone decoders. An AC-coupled buffer amplifier is shown as part of this diagram. It is shown set to give an AC gain of 11, but some experiment may be needed to find the optimum level of gain. Because quite a high gain at a high frequency may be required from this buffer amplifier, a high gain-bandwidth op-amp is specified. The constructor may substitute any other op-amp capable of working on the supply voltage, and having a high gain-bandwidth product.

In blueprint tradition, these circuits have been designed carefully but have not been prototyped. They may work as drawn, or with minor modifications. The building of blueprint circuits is not recommended for completely inexperienced constructors.

Andrew Armstrong

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Digital, Pulse Transmission

An introductory survey by Bryan Hart

Stand two dominoes one behind the other, in an upright position, a short distance apart on a table. Observe that if you brush one domino with a finger so that it falls on its neighbour then both fall down together.

Instead of just two dominoes, erect a large number, e.g., several hundred, one behind the other a short distance apart so they appear like soldiers standing to attention on a parade ground.

Observe, now, that if you brush the first domino so that it falls on its neighbour then all the pieces do not fall down together. There is a progressive disturbance as they fall down in sequence. 'Domino-toppling' as this activity is known, is one of those pursuits carried out world-wide by groups of people, often students, wishing to establish records. According to one source (1) it takes about 13 minutes for a parade of some 280,000 dominoes to fall down.

The first case, of two dominoes, is analogous to the transient behaviour of a conventional 'lumped-parameter' (or just 'lumped') electrical circuit, for example, an elementary resistive potential-divider. The second case, of many dominoes, is analogous to the transient behaviour of a 'distributed-parameter' (or just 'distributed') electrical circuit e.g., a transmission line used for the distribution of digital logic pulses.

The practical characterization of these cases is considered first, in this introductory survey, and is followed by a discussion of the properties and use of the popular twisted-pair line widely used in digital systems.

Lumped and distributed circuits

Consider the circuit of Figure 1a comprising two resistors R_G, R_1 connected to form a simple resistive potential-divider network. The input waveform V_G (Fig 1b) is a pulse edge having a transition time t_c and an amplitude $\Delta V = (V_{OH} - V_{OL})$, corresponding to logic voltage levels V_{OH}, V_{OL}. The output waveform, V_I, is shown in Figure 1c.

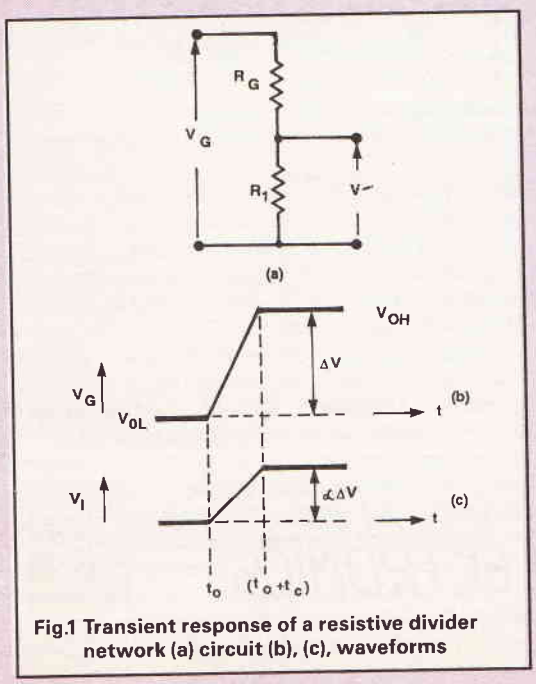


Fig.1 Transient response of a resistive divider network (a) circuit (b), (c), waveforms

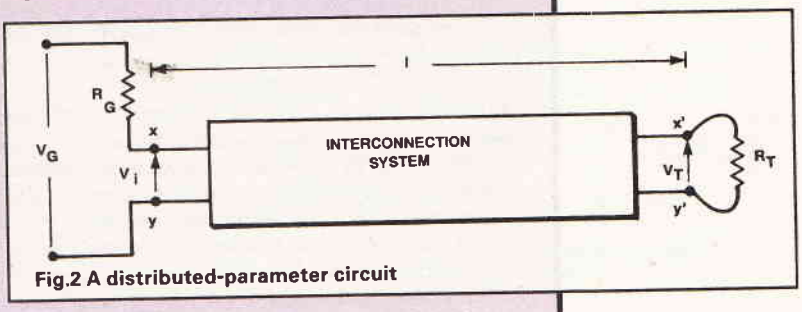


Fig.2 A distributed-parameter circuit

Note the following characteristics: there is *no delay* between the start of V_I and the start of V_G. V_I is a scaled replica of V_G, as $V_I = \alpha V_G$ where the scale factor α (a pure number) $= R_1/(R_1 + R_G)$.

This state of affairs exists because of the 'small' physical dimensions of practical resistors. All electrical signals are transmitted via electromagnetic disturbances, which travel with speeds approaching that of the velocity of light in air (3×10^{10} cms/sec). Thus a voltage change at one end of a resistor 1.5cm long shows itself about 0.05ns later at the other end.

This is a negligible time delay even for ECL logic pulses having $t_c \simeq 2$ns.

We have ignored circuit capacitances in this discussion but the result is still valid, with certain provisos, if they are included. Suppose R_G, R_1 have end-to-end capacitances C_G, C_1 respectively. Provided $C_G R_G = C_1 R_1$ the waveforms of Figure 1b, Figure 1c still apply. We can guarantee that this condition is satisfied by connecting a small padder capacitor across R_1 and making suitable adjustment of a trimmer capacitor connected in parallel with R_G.

Consider, now, the arrangement of Figure 2 in which the resistor R_1 of Figure 1 is replaced by a load resistor R_T located a distance l metres away. For $l = 3$m, an electromagnetic disturbance occurring between the terminals xy cannot be felt between the terminals x^1y^1 till at least 10ns later. This is the delay between the start of the waveform, V_I, at the drive (sending, or source) end and the commencement of the resulting waveform, V_T, at the load (or receive) end and is obviously not negligible for a pulse edge 2ns in duration.

Since it is a limitation of nature, there is little we can do about delay, except perhaps 'equalize' it when appropriate. What we can do something about is transmitted pulse shape. Serious pulse edge distortion can result if the inter-connection system does not satisfy a basic practical requirement, meaning that its electrical characteristics are uniform throughout its length. This condition is encouraged by geometrical symmetry. The transmission path of Figure 3, showing ordinary 'hook-up' wire laid out in a random way between xy and x^1y^1, is thus completely unsatisfactory for fast digital pulses.

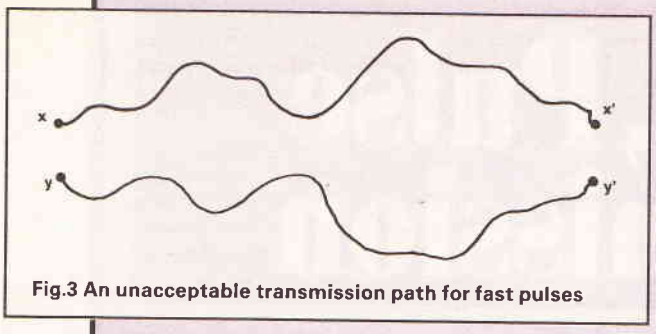


Fig.3 An unacceptable transmission path for fast pulses

Line Characteristics

An ideal transmission path, offering the possibility of distortionless transmission and predictable delay, can be completely specified by a uniform unit capacitance C_o(pF/m) and a uniform unit inductance L_o(nH/m). The parameters that then describe the path for digital pulse applications, are the unit time delay, t_u, and the characteristic resistance, R_o.

$t_u = \sqrt{L_oC_o}$ and is usually expressed in ns/m or ns/ft (e.g., 1.5ns/ft). For a line of physical length l the 'electrical length' or one-way delay time is t_d ($= lt_u$).

Physically, R_o is the ratio (change in line voltage: change in line current) for a disturbance on the line.

$R_o = \sqrt{L_o/C_o}$, and is expressed on Ohms.

A practical approximation to this ideal is the coaxial cable shown in Figure 4a. However, a coax suffers from the disadvantages of requiring special plugs and sockets and being unsuitable for differential drive which we will discuss later.

A low-cost alternative that is only slightly inferior in performance to the coax is the twisted-pair line (TPL).

Figure 4b shows the physical construction of TPL, whereas Figure 4c shows a schematic representation that eases the drawing of system diagrams.

At its simplest, TPL comprises two insulated conductors twisted together in a regular way. In fact, it lends itself to a DIY approach for short lengths of transmission path. However, for longer lengths and in professional applications, it is more often purchased as a standard catalogue item from an electronic component distributor.

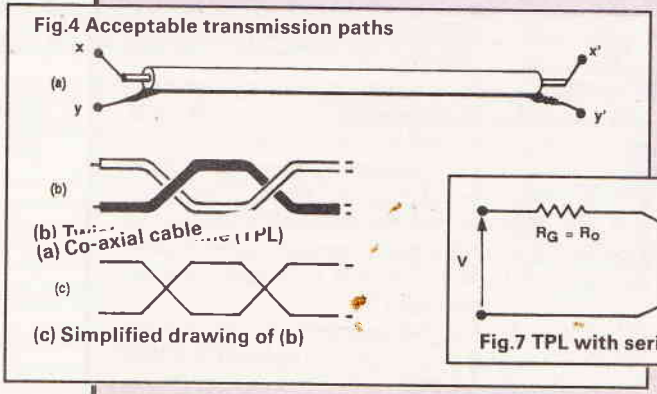


Fig.4 Acceptable transmission paths
(a) Co-axial cable
(b) Twisted pair (TPL)
(c) Simplified drawing of (b)

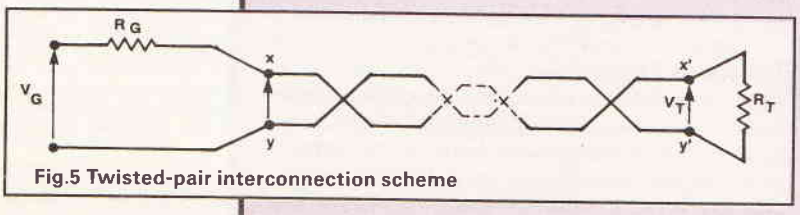


Fig.5 Twisted-pair interconnection scheme

The advantages of TPL over coax are that it requires no special plugs and sockets, is mechanically more flexible and is suitable for balanced drive. Figure 5 results when the interconnection system of Figure 2 is a TPL. A pulse edge launched on to the line at $t = t_o$ sees at terminals xy an effective resistance R_o. When the edge reaches x^1y^1 it is completely absorbed if $R_1 = R_o$. For this special case the line is said to be correctly matched or correctly terminated at the receive end and $V_1 = \lambda V_G$, where $\lambda = R_o/(R_o+R_G)$. See Figure 6.

V_1 is a non-delayed, scaled, replica of V_G whereas V_T is a replica of V_1 delayed by a time interval t_d. If $R_T \neq R_o$ all the energy in a pulse edge is not absorbed by R_T. The energy that is not absorbed is responsible for the generation of a reflected pulse edge, positive-going for $R_T > R_o$ and negative-going for $R_T < R_o$, that is sent back along the line to the drive end. What happens

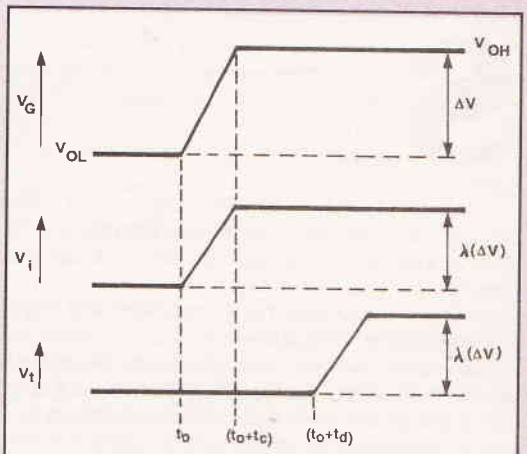


Fig.6 Waveforms for Figure 5 V_G, V_1, V_T for $t_d(=lt_u) > t_c$ and special case $R_T = R_o$ (parallel matching)

when it reaches R_G depends on the magnitude of (R_G/R_o). There is a reflected edge at xy unless (R_G/R_o) = 1.

Reflections can lead to the generation of false pulses, if logic gate threshold-voltage levels are temporarily crossed, and the possibility of voltage-overstressing of gates connected to the line. Both these effects are undesirable so some form of matching is often employed. For fast bus systems matching is essential.

Figure 5, with $R_T = R_o$, illustrates 'load' or 'parallel' matching. A disadvantage of this arrangement is the high DC loading that R_T presents to the drive end, when there is a '1' there, with the associated power waste in R_T. An alternative form of matching, known as 'source' or 'series' matching, that avoids power waste and depends for its operation on the existence of a single controlled reflection from the load end is shown in Figure 7. This is a version of Figure 5 for the particular conditions $R_T = \infty$, $R_G = R_o$. Relevant waveforms are shown in Figure 8. For the rising pulse edge the line appears as a resistor R_o. As $R_G = R_o$ the amplitude of the pulse launched on to the line at xy is $\Delta V/2$. The pulse edge travels down the line towards the load end and, on meeting an open circuit, is completely reflected. The reflected edge travels back along the line to the drive end and is completely absorbed there. V_T is a delayed replica of V but V_1 is *not* a copy of V_G.

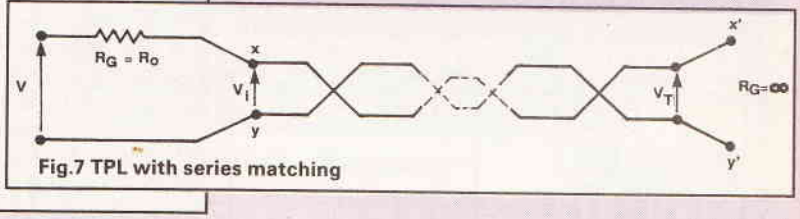


Fig.7 TPL with series matching

Series matching is useful for inter-board wiring because small reflections that result from minor discontinuities in the transmission path are absorbed at the drive end.

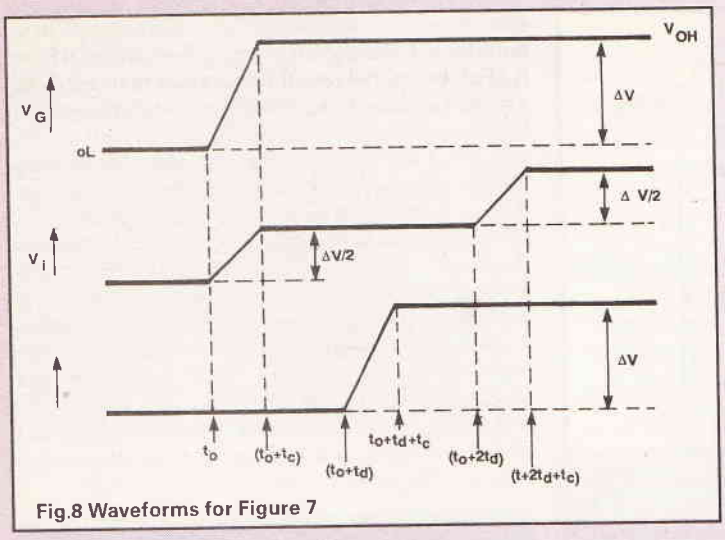


Fig.8 Waveforms for Figure 7

A disadvantage of series matching is that there is a time interval $2t_d$, at the drive end, during which the logic signal swing has reached only half its maximum value. This precludes the direct connection of a logic gate input to the terminals xy.

Referring back to Figure 2, the two-way delay time $2t_d$ ($= 2l$ tu) is a convenient yardstick for classifying a system as either lumped or distributed. If $t_c > 2t_d$, i.e. the pulse edge transition time is greater than twice the electrical length of the line, the drive circuit is loaded by R_T while V_G is changing. In this case the physical dimensions of the transmission path can be ignored and the system can be regarded as lumped. Conventional circuit analysis can be used.

If $t_c < 2t_d$ the effect of R_T is only felt by the drive circuit after V_G has completed its transition between '0' and '1' states. The physical dimensions of the interconnection path cannot be ignored. The system is distributed and transmission line circuit techniques are necessary.

We have assumed, so far, that the TPL is ideal. In practice it has series and shunt losses. As indicated in Figure 9 the overall effect of these is to cause: rounding of waveform corners; degradation of transition times; reduction in pulse amplitudes. The extent to which these effects present problems depends on the length of line used. It is worth noting, however, that ECL has operated successfully with 1000ft of TPL using appropriate drive and receive units.

Unbalanced And Balanced Transmission

An example of an unbalanced transmission path using TPL is shown in Figure 10. The input is single-ended

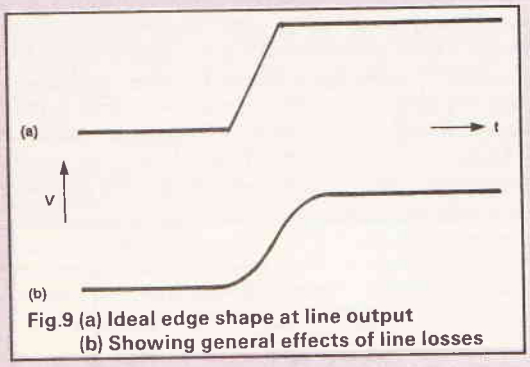


Fig.9 (a) Ideal edge shape at line output
(b) Showing general effects of line losses

and so is the output. One conductor of the TPL is earthed at both the input (y) and at the output (y^1). As mentioned above, a pulse edge can be transmitted from xy to x^1y^1 with minimal distortion if $R_T = R_o$. However, the existence of a current in, and the finite resistance of, the ground return path causes two effects, both undesirable: a potential difference, V_e, and unbalanced fields in the vicinity of the line.

The PD, V_e, between the 'earths' at the input and output can erode, and in the worst case exceed, the noise margins at the receive end. The fields in the space around the conductors can lead to pulses in the line being coupled to a neighbouring TPL (Crosstalk).

These disadvantages are overcome in balanced transmission, an example of which is shown in Figure 11. In this, differential (or, double-ended) drive is employed. The waveforms at x and y are complementary, which means that when

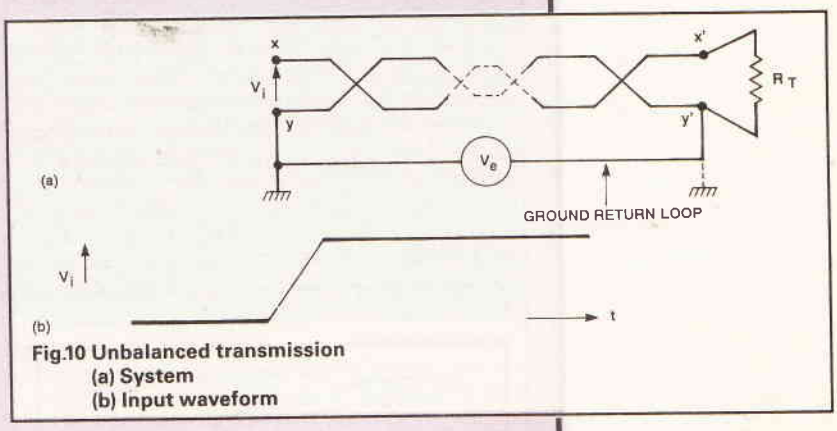


Fig.10 Unbalanced transmission
(a) System
(b) Input waveform

one is at '0' the other is at '1' and vice-versa. The output is the difference between the signals at x^1 and y^1 and is not dependent on any difference in earth levels at the drive and receive ends, provided this difference falls within acceptable limits. The balanced system minimizes crosstalk. Furthermore, the doubling of signal swing that results from differential drive means that a greater line length can be employed for a given attenuation in logic pulse amplitude.

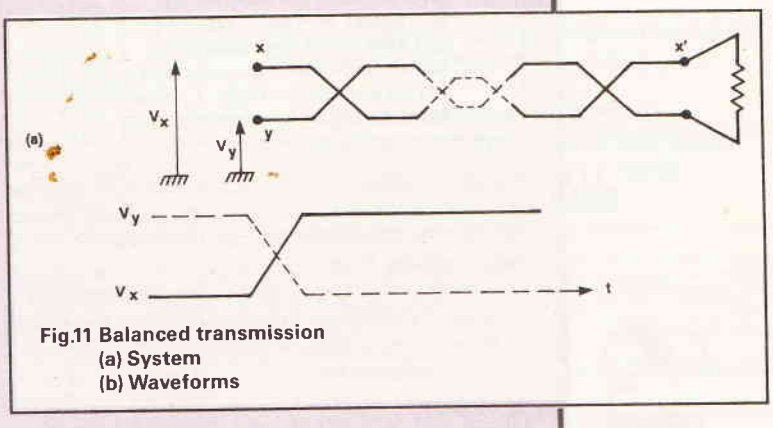
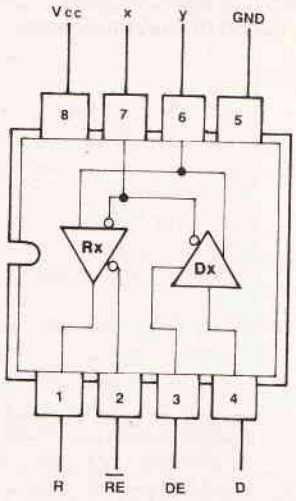


Fig.11 Balanced transmission
(a) System
(b) Waveforms

Practical Line Drive

For 'short' lengths of TPL — a few metres, say — it is possible to use standard logic gates for drive and receive stages. Used with ECL and fast CMOS, TPL can be correctly terminated at the receive end because both these types of logic gate have input resistances high compared with practical values of R_o (100R). Both types of gate also have output resistances low enough to make series matching possible.

Care is required using TPL and TTL. Correct termination at the receive end is not possible because of



D	ENABLE DE	OUTPUTS y	x
H	H	H	L
L	H	L	H
X	L	Z	Z

(b)

DIFFERENTIAL INPUT (y-x)	ENABLE $\overline{RE}$	OUTPUT R
>0.2V	L	H
<-0.2V	L	L
X	H	Z

(c)

Fig.12 (a) SN75176A bus transceiver schematic with package pin numbering.
D_x = Driver, R_x = Receiver
(b) Drive-mode characteristics
(c) Receive-mode characteristics
For (b) and (c): H = High; L = Low; X = Don't care; Z = High impedance output

the limited drive capability of standard TTL and the grossly non-linear nature of its input characteristic. Voltage overstressing at the input is minimized by in-built clamping diodes.

Series matching is not completely satisfactory because of the different output resistance in the '1' and '0' states. Long lengths of TPL are used in digital systems for interconnecting Data Transmitting Equipment (DTE) and Data Communications Equipment (DCE). The transmission path, comprising the interface, normally meets a recommended standard (RS) set up by a national body such as the American Electronic Industries Association (ETA) or endorsed by an international body, e.g., CCITT (Comité Consultatif Internationale de Télégraphie et Téléphonie).

These standards specify limits required of pulse '0' and '1' levels, cable length, transmission rate (in Bits/sec), etc. Thus the RS422 applies to balanced drive and includes the following specification: maximum path length 1200m; maximum data rate 10MB/s; driver load 100R.

Driver and receiver IC chips are widely available commercially to meet these requirements. Some chips combine the function of transmitter (i.e. driver) and receiver in a transceiver. Popular among these is the transceiver type SN75176A (Texas Instruments) whose schematic and operating characteristics are shown in Figure 12.

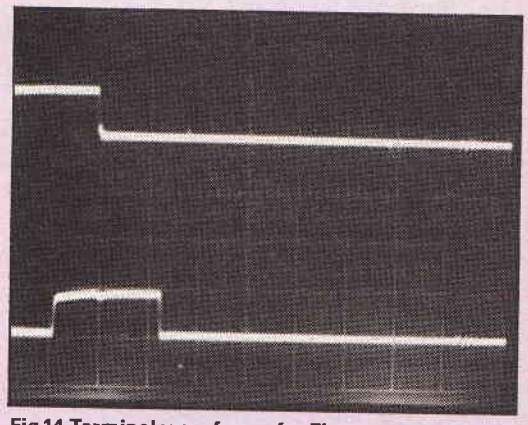


Fig.14 Terminal waveforms for Figure 13
Upper trace: Input to driver of chip A
Lower trace: Output of receiver of chip B
Scales (both traces): Vertical, 5V/cm; Horizontal, 0.5µs/cm

Figure 13 shows a convenient set-up, using the SN75176A, for demonstrating that short duration pulses with fast edges can be transmitted successfully over long lengths of TPL.

Pulses from a generator having TTL-compatible output levels feed into the data input terminal of chip A, which is configured as a driver and connected to one end of a 100m reel of TPL (unscreened TPL type 1, RS Components Ltd). The other end of the reel is connected to transceiver chip B configured as a receiver.

The TPL is made up of a pair of colour-coded polythene-insulated 22 swg conductors in a PVC outer sheath and has a specified R_o of 110R (nominal).

To obtain a correct termination at the load end two 220R resistors are connected in parallel at the input of chip B.

Observed waveforms, obtained using x 10 oscilloscope probes, are shown in Figures 14, 15, 16.

The upper trace of Figure 14 shows a pulse of approximately 1µs duration at the input to chip A and the lower trace shows the output of chip B. Leading edge pulse delay is about 0.6µs. Neglecting small delays in the driver and receiver this gives, for the line,

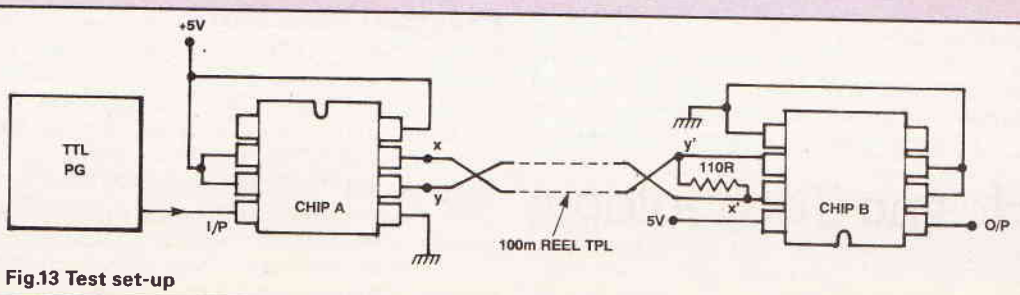


Fig.13 Test set-up

SIGNALS

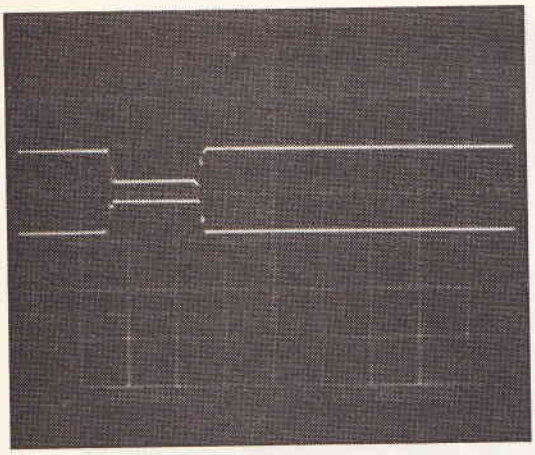


Fig.15 Line input waveforms
Upper trace: waveform at x
Lower trace: waveform at y
Scales as for Figure 14.

$t_u \simeq 6ns/m$.

The upper and lower traces of Figure 15 show the line input pulses respectively at x and y. These operate between the same logic levels but are shown with a vertical separation between them in order to avoid confusion in viewing the display. y is a non-inverted version of the input pulse but x is an inverted version of it.

The upper and lower traces of Figure 16, which illustrate for comparison the line output pulses respectively at x^1 and y^1, show some expected deterioration in pulse shape and amplitude.

However, the magnitude of the differential signal at the line output far exceeds the specified 200mV (minimum) required to switch the receiver output between '0' and '1' logic states so it is clear that 100m of TPL (chosen because of its ready availability in reel form) does not represent the maximum length of TPL possible with the SN75176A transceiver.

Conclusion

This article has set out to introduce the subject of logic pulse transmission on twisted-pair line. Interested readers will find an extended coverage of the subject in Reference 2.

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2. Digital Signal Transmission: Line Circuit Technology. B. L. Hart. Van Nostrand (UK) 1988.

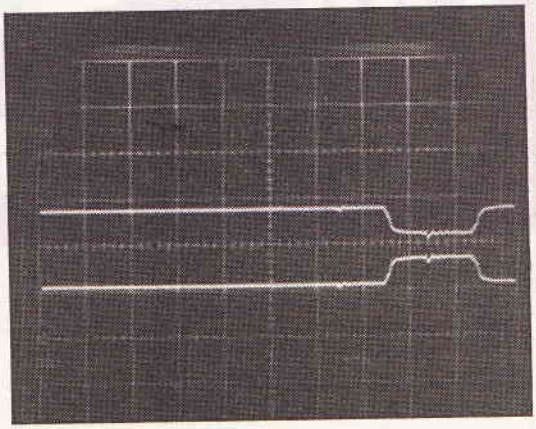

Fig.16 Line output waveforms
Upper trace: waveform at x^1
Lower trace: waveform at y^1
Scales as for Figure 14

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The Nightfighter

3

Mike Meechan provides constructional details for the master controller and dimmer.

This is the penultimate part of the Nightfighter series of articles and presents those overlays held over from Part 1 due to space restrictions, as well as offering some hints and suggestions on individual board construction and faultfinding (should this prove necessary).

If you've been following the preceeding chapters of the Nightfighter saga and perhaps raided the components bins of your local shop, the final information required to build the Master Controller is contained in these very pages. Parts 1 and 2 deluged you with the technical information of the system and a plethora of circuit diagrams – these will be kept to a minimum in Part 3 and emphasis placed firmly on practical and get-you-going advice. Now, without further ado, let's get building.

The simplest and most logical board to begin construction with is of course the Master Controller Power Supply. First of all, fit all resistors and link LK1, then the diode, bridge rectifiers, fuseholders and LED's, taking care with the polarity sensitive components and remembering that LED3 ANODE is connected to ground. The presets and PCB connector strip are mounted next, followed closely by all of the capacitors, the electrolytics being mounted last.

The most troublesome component to mount is the plastic-encapsulated transformer mainly because

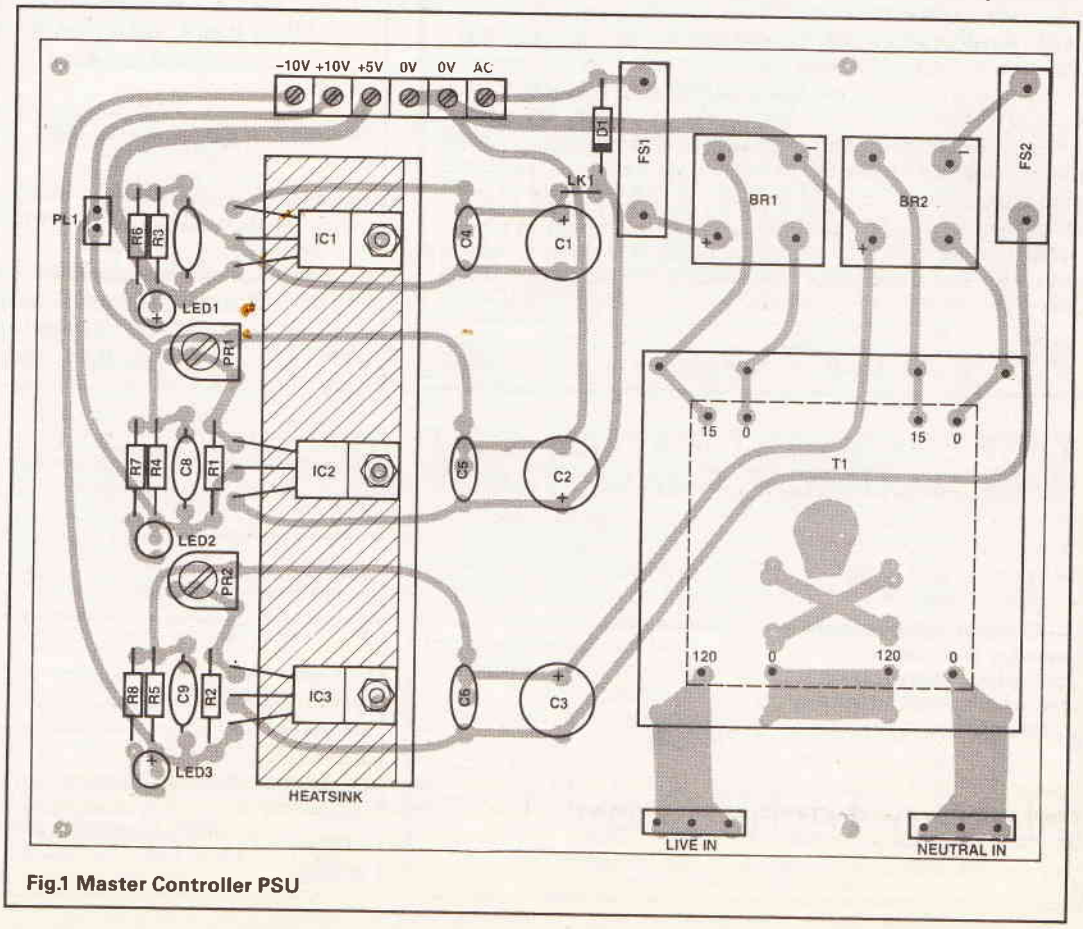

Fig.1 Master Controller PSU

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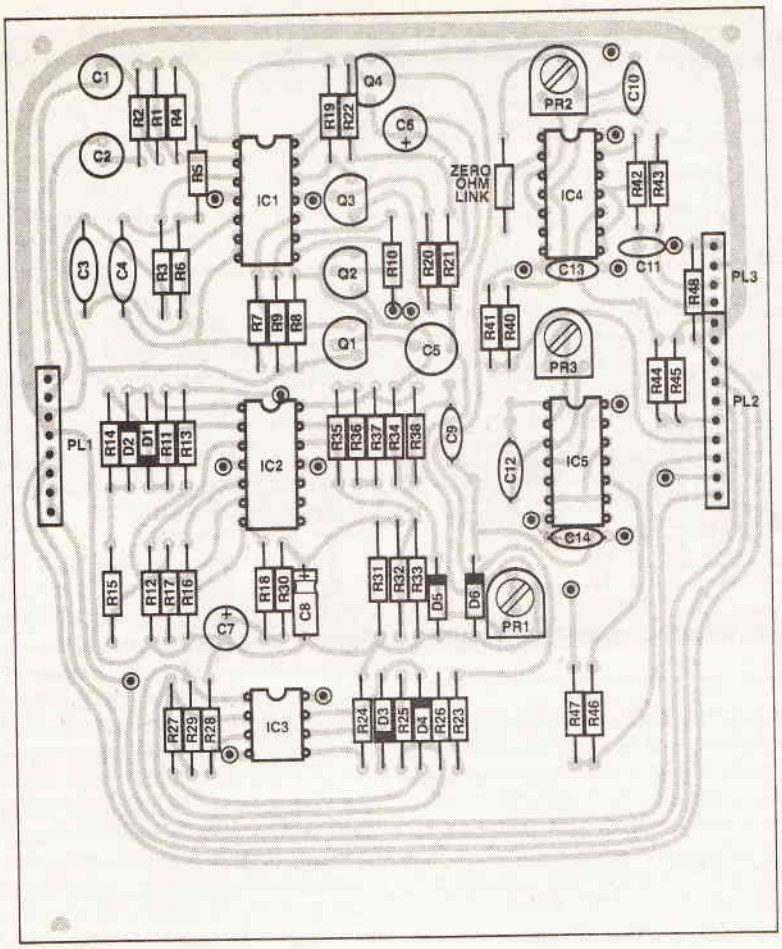

Fig.2 Bass beat trigger overlay

it has eight easily-broken pins which are all but hidden as the transformer is placed onto the board. The best way is to drill out the relevant mounting holes on the PCB to a diameter of 1.5 to 2.0mm and gradually work round pin by pin until the item drops safely into place.

The drilled and painted piece of angle aluminium (which in the best traditions of Blue Peter, you had prepared earlier) is now required for use as a heatsink. It should be placed in the correct position on the board, with IC1 in place on top of it. Mark on the legs of the IC where they should be bent such that they will fit into the component mounting holes with the heatsink-mounting tab hole still perfectly aligned on the heatsink. Bend the legs of the IC carefully, mount it onto the heatsink using a mica washer, insulating bush, M3 nut, bolt and washer and some silicon paste and solder in place. Repeat for IC's 2 and 3. Finally, insert both fuses. The unit is now ready to be tested.

The constructor might like to note that since the inception of the original design, it was latterly found s at when the master Controller was operated in high ambient temperatures, ie with the lids of the casing on, all LED's lit and with high summer temperatures, the original area of heatsink proved inadequate and the regulator IC's overheated with consequent strange occurences, namely unregulated DC being fed to all circuits. An improved design of heatsink is thus offered for any of you who experience similar problems.

Double check everything. Place the board on an insulating surface, set each of the presets to their mid positions and then construct a mains plug to flying lead assembly which should be connected to the PCB constrip at the rear of the transformer. Apply power whereupon each of the LED's should be glowing happily. With a multimeter, check for the presence of three different voltages on the low voltage terminal strip. If there are none, the fault lies in one of three areas: Diodes or bridge rectifiers inserted incorrectly, fuses blown, or IC's or electrolytics incorrectly inserted.

If all of the voltages are present but one or more of the LED's are out, check that they've been soldered in the right way round. When all of the above check out, monitor the +10V terminal and adjust PR1 for +10.5V then monitor the −10V terminal and adjust PR2 for −10.5V. Now switch it off and put it to one side.

The next board to be built is the Bass Beat Trigger board. This is a straightforward board to construct with IC sockets, resistors, through-board pins and diodes being mounted first, then transistors, capacitors and lastly the Minicon plugs. Remember that IC's 4 and 5 are CMOS. From now on, assume that all IC's belong to the CMOS family of devices and adopt the correct handling precautions.

To test the unit, SK1 and SK2 socket-lead assemblies must first be made, these being fabricated from 25cm long pieces of stranded wire, green, red, brown and black in colour, these colours referring to 0V, +5V, +10V and −10V respectively. This colour code should be adopted in all of the wiring. A 400mm long piece of stereo screened lead is also required for connection to the ¼" stereo jack socket which comprises the Audio Input. The two cores of the screened lead are connected to pins 1 and 2, the screen to pin 3, green to pin 4, red to 5, brown to 6 and black to pin 7. Connect each of the wires to the respective terminal on the PSU connector strip and the screened lead to a switched stereo jack socket. Solder a piece of tinned wire across the

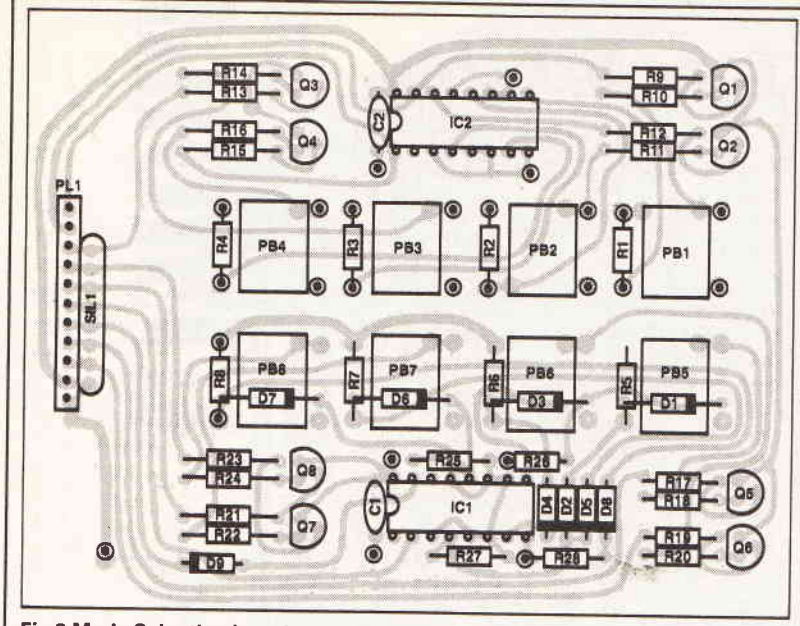

Fig.3 Mode Selection board overlay
Note SIL1 and R25-28 are additional pull down resistors not mentioned in text and inserted if required

unused pins of the socket – this ensures that the audio input is grounded when no music source is connected.

Now cut a piece of four core ribbon wire about 500mm long and connect to the switched pot RV1, ensuring that pins 1 and 2 connect to the switched part and 3 and 4 to the resistive element.

Set RV1, PR2 and PR3 to their mid positions and switch on. Should all of the PSU monitor LED's remain lit, check for the presence of square waves on pin 4 and pin 10 of IC4. If there are none check for +10.5v on pin 14 of this IC. Failing this, remove the power and try another IC.

Now connect an audio source of level 80mV to 2.5V to the audio input. An oscilloscope is really required at this stage. Cursory checks should include checking IC1 pin 1 for wideband audio, IC1 pin 14 for gain-controlled audio, IC1 pin 7 for low pass filtered audio and IC1 pin 8 for a gain-controlled version of this. IC2 pin 7 should have rectified bass, IC3 pin 7 rectified audio and IC2 pin 12 should have a DC level rising to about +2v on the bass notes.

Faultfinding is basically confined to verifying the presence or otherwise of these signals and looking to where on the board they can have disappeared.

If all is well, adjust PR1 for +2.5V on pin 13 of IC2. Pin 8 of IC5 should have a bass-derived input clock. This board is now fully set up and operational. It should be noted that the AGC time-constant capacitors, C6 and C7, are electrolytics and have tolerances of −50%/+100% and so, depending on the exact value of these, the already long time constant may be stretched further. This means that the unit may take a minute or so to adjust the gain of the circuits for satisfactory response.

The next two boards to be constructed are the Mode Selection Board and the Seq. Select/Output Mode Board. You may notice from the component overlays that there are resistors and resistor arrays not shown in the circuit diagrams or mentioned in the text. These will be discussed later.

On both boards, all of the through-board pins should be soldered first as some later-mounted components, notably resistors and diodes, then obscure these roundels. Also ensure that any components which require it, are soldered on both sides of the board. Components mounted on the foil side are fitted next (these are shown dotted on the overlays), followed by IC sockets, resistors, diodes, and capacitors. The switches are the final items to be mounted. Before this can be done, each should be fitted with an LED. Ensure that the LED's purchased for the task have long enough legs (no whistling at the back) so that after bending, enough lead protrudes through the switch housing for a good solder joint to be made. All switches should be wriggled into place and aligned with respect to one another until all are straight. Only now can they be soldered to the board.

To test these boards, a twelve-way Minicon socket to flying lead assembly needs to be constructed. This has no other purpose but to test the boards and will not be required in the finished unit – it can, however, be used to test other boards.

With the test lead plugged into the Mode Selection Board, connect pins 1 and 2 to 0V and pins 3, 4, 5, 8, 9 and 10 to +5V on the PSU. Apply power and if all is well, all of the LED's except 2 and 4 should be lit. Pressing PB2 and PB4 should cause these LED's to light. With reference to the circuit diagram, check that each button toggles its respective flip-flop and that PB5 to PB8 generate their own unique 2-bit binary code on pins 6 and 7, Q0 and Q1. Switch off and now connect pins 4, 5, 8, 9 and 10 to 0V. Switch on and only LED 1 should be on. Faults on this board are generally the result of unsoldered or un-inserted Veropins or wrongly inserted diodes or LED's. Should an LED not function, check the associated drive transistor before embarking on the troublesome task of desoldering the little critter.

Now depower and transfer the lead to the Sequence Select/Output Mode board. Connect pins 1 and 2 to 0V and pins 3, 5, 6 and 10 to +5V. Apply power and if all is well, LED1, 2 and 5 should be on. Pressing PB3 should flash LED3, pressing PB4 should light LED 4 and pressing PB6 should light LED6 whilst causing LED4 to extinguish. Press PB3 again and check for a low-to-high transition on PL1 pin 9. Depower and connect pins 5, 6 and 10 to 0V where-

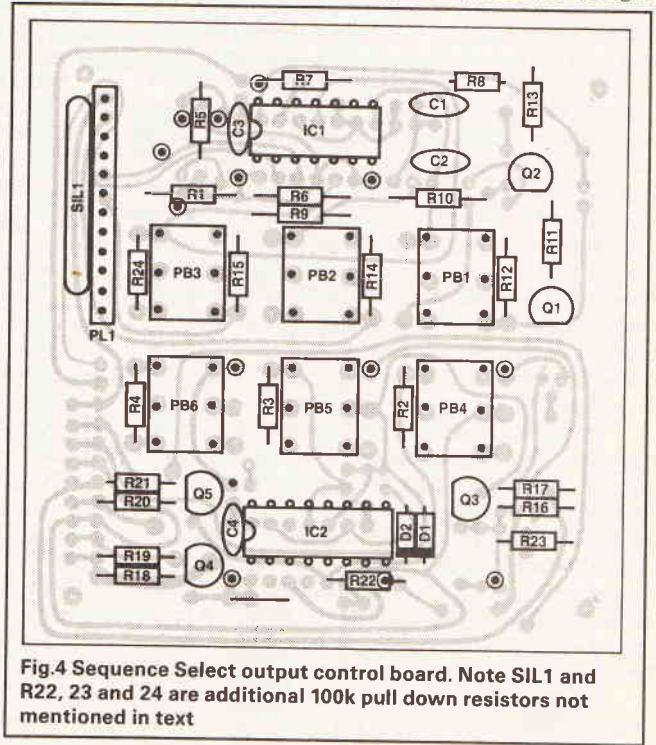

Fig.4 Sequence Select output control board. Note SIL1 and R22, 23 and 24 are additional 100k pull down resistors not mentioned in text

PROJECT

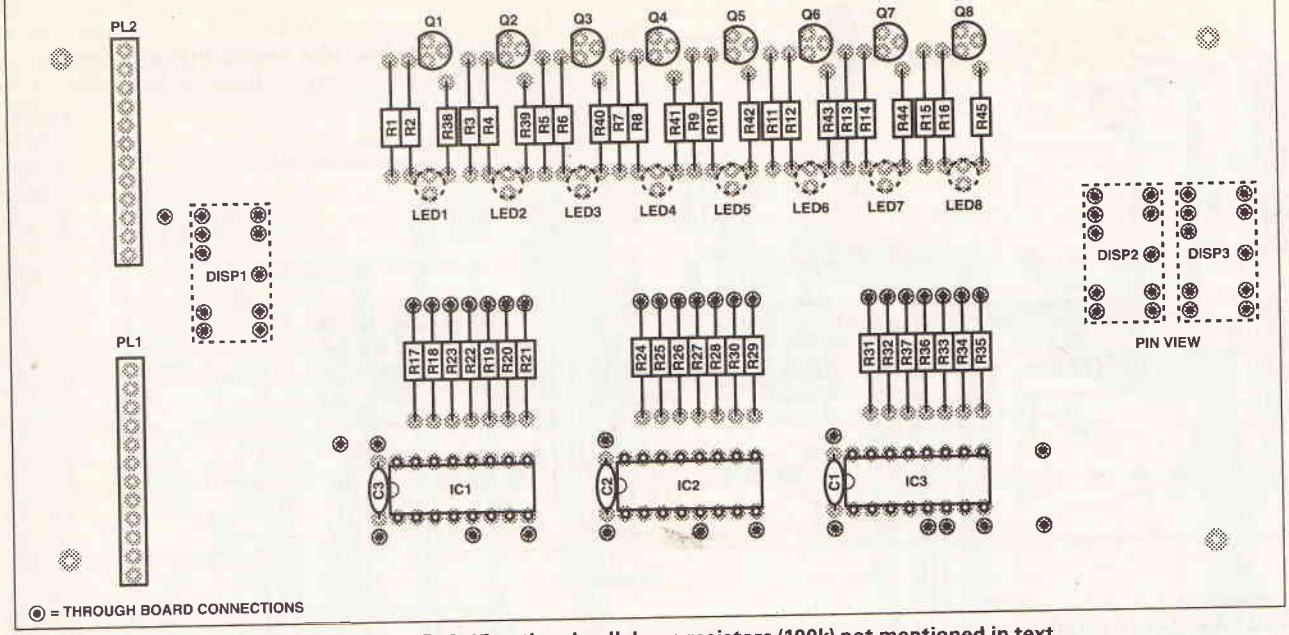

Fig.5 Channel monitor and display board. R38-45 optional pull down resistors (100k) not mentioned in text

upon LED's 1, 2 and 5 should be off. Finally, check that pressing PB4, 5 and 6 toggles Strobe pin 11 and Standby/Go pin 12. Faultfinding is as the previous board.

The Channel Monitor and Display board is constructed next. All resistors and through-board pins and IC sockets are mounted first, noting that display resistors R17-38 are soldered on both sides of the board. Turn the board over and mount the seven-segment displays next and then on the component side again, mount the resistors, capacitors and plugs PL1 and PL2. Finally, LED's 1 to 8 should be soldered in place. To do this, first cut a piece of card about 5 x 80mm long and use this as a temporary spacer to ensure that all of

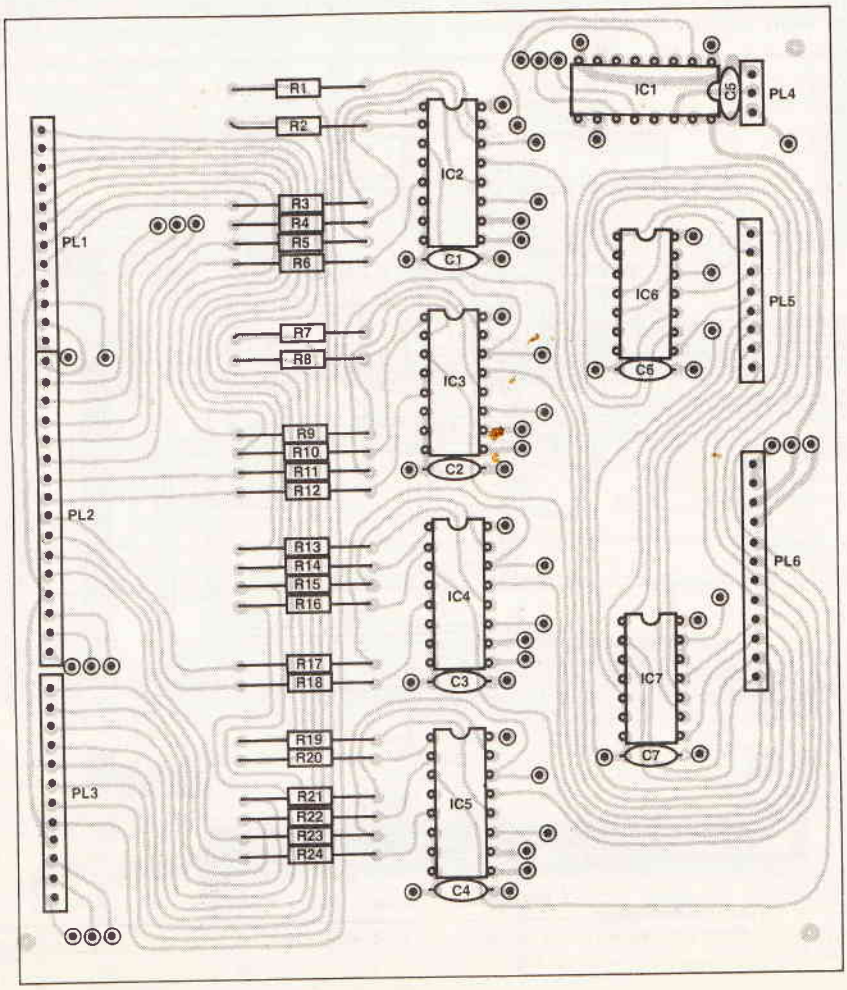

Fig.6 Output switch overlay

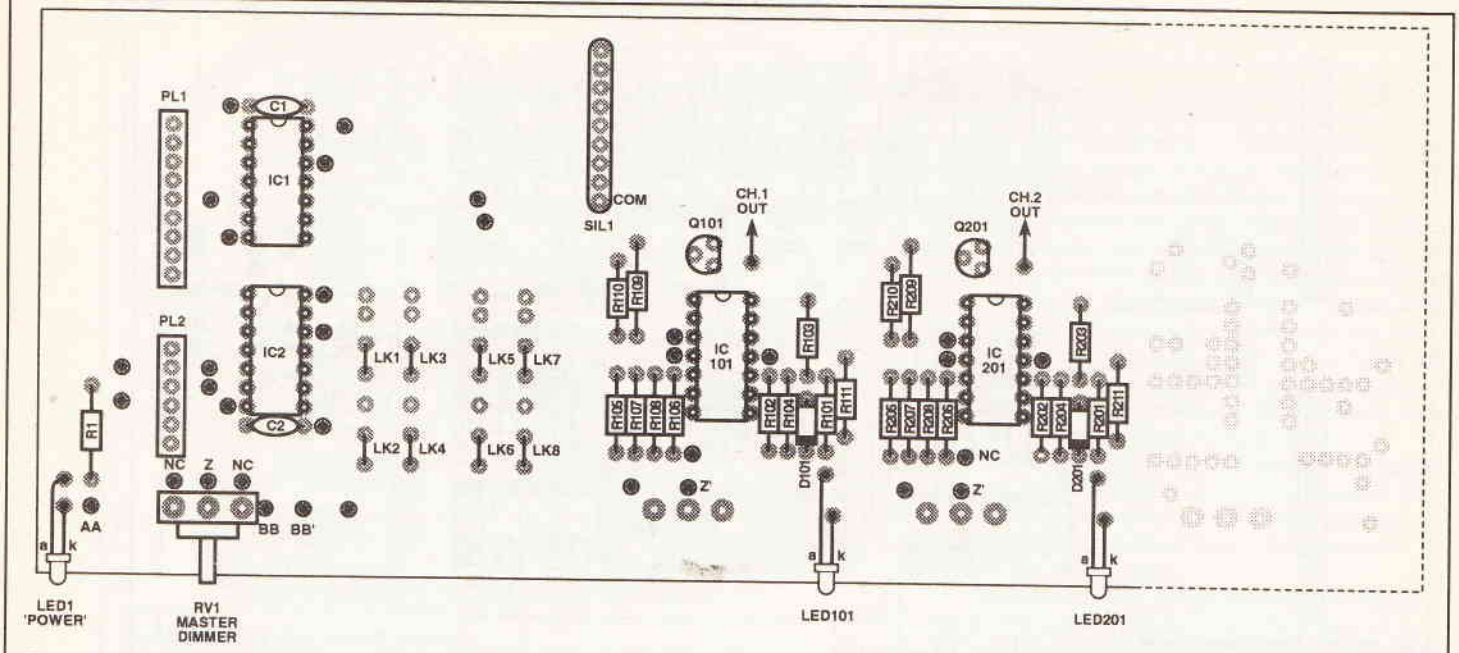

Fig.7 Limited Interface board overlay

the LED's are at an equal height above the PCB. Also ensure that they are mounted correctly with respect to polarity as, being soldered on both sides of the board, the LED's are the devil themselves when it comes to desoldering.

To test, insert the 12-way socket assembly into PL2 and connect pins 1-3 to 0V and pins 4-12 to +10V on the PSU. Apply power and LED's 1 to 8 should be glowing. Depower and connect pins 5-12 to 0V. LED's 1-8 should now be off. IC's 1 to 3 and their associated displays can't easily be tested without constructing another ultimately redundant lead assembly and unless problems persist when the board is connected to the Main Processor board, it can't really be justified. Fault-finding is confined mainly to checking for shorts and for incorrectly inserted LED's.

Finally, we can construct the Main Processor board and the Output Switch board. Although they are the most complicated boards electrically, these are the two easiest to construct, fabrication consisting in the main of repetitive soldering of IC sockets, through board pins and resistors. As there are so many linking

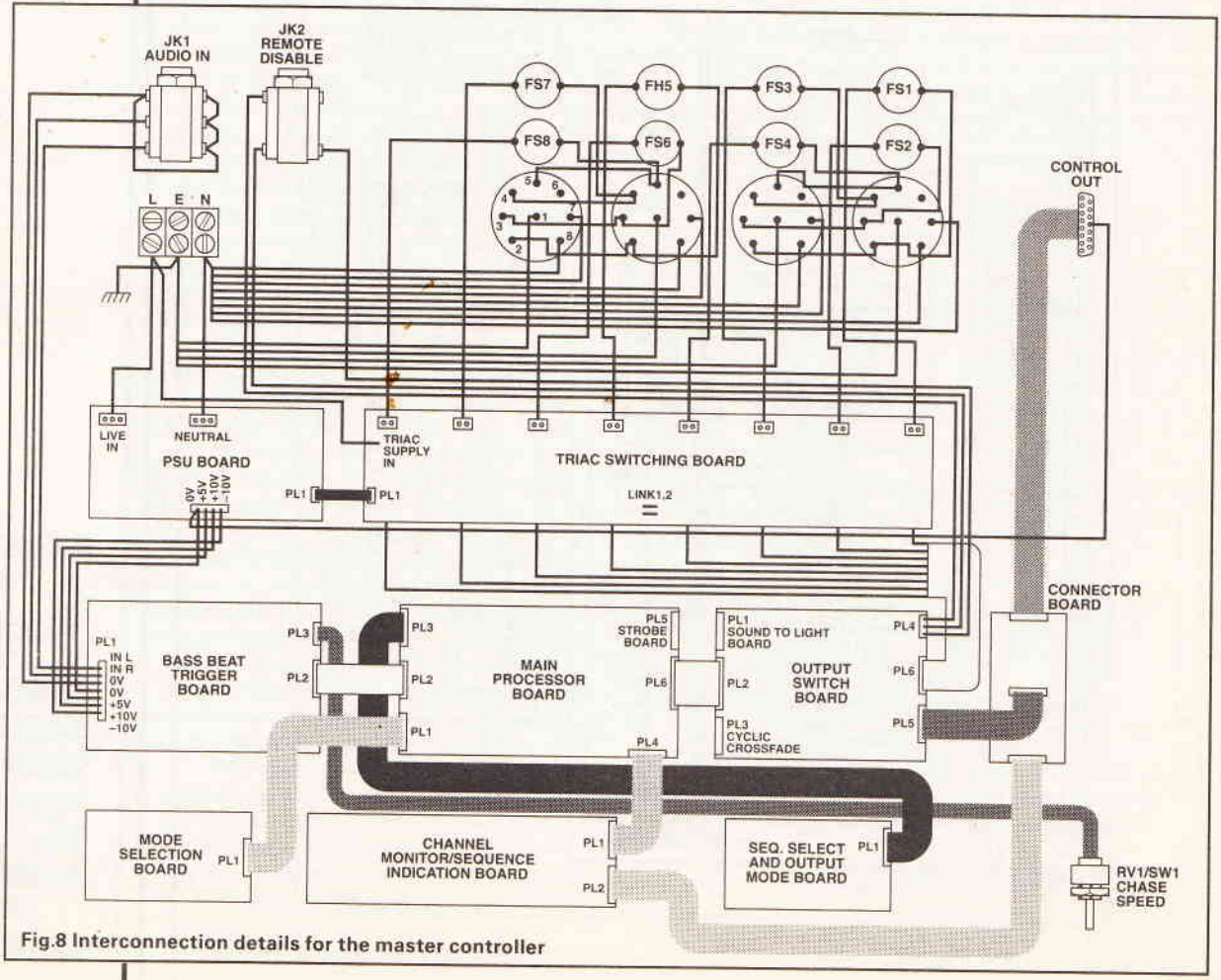

Fig.8 Interconnection details for the master controller

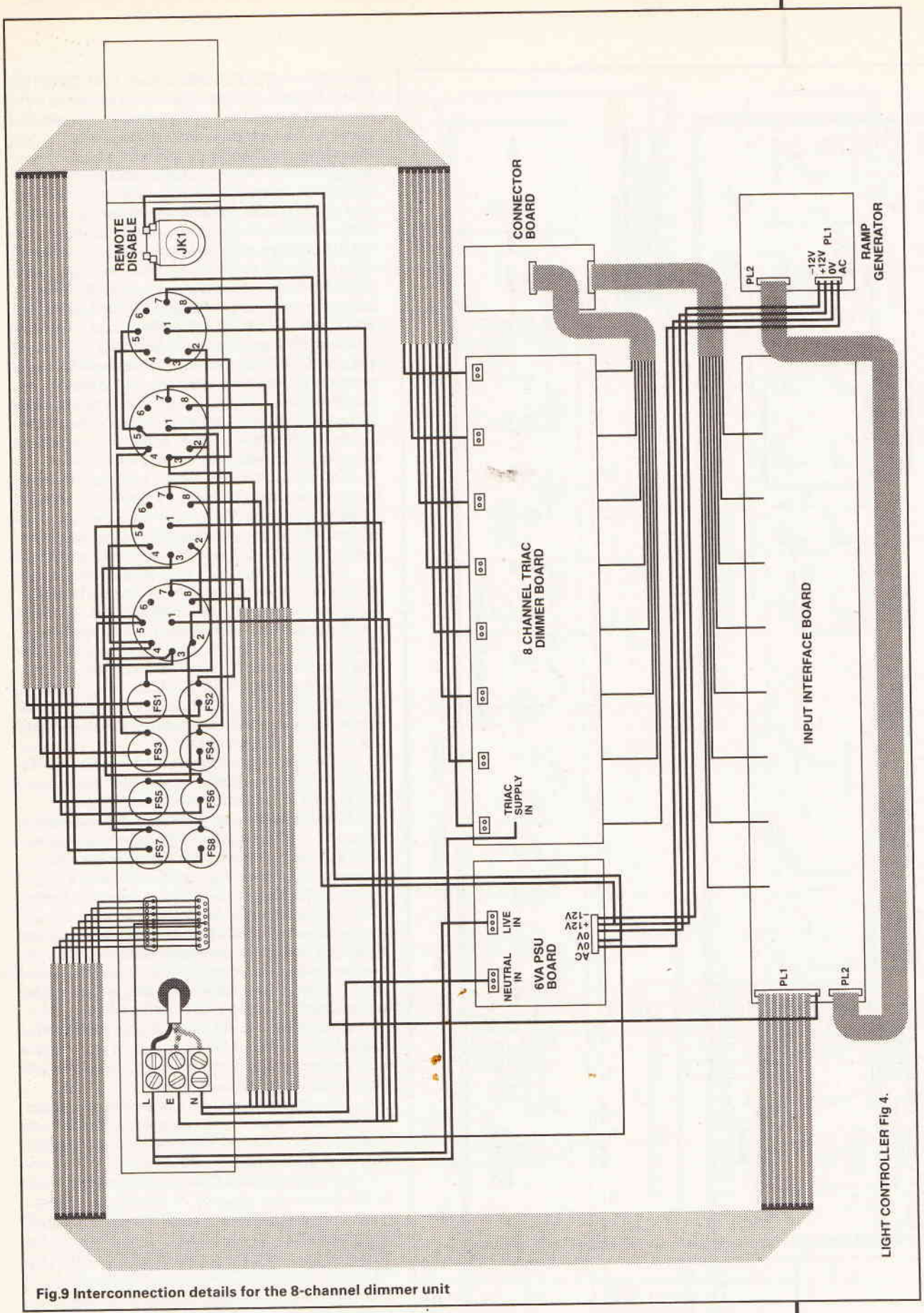

Fig.9 Interconnection details for the 8-channel dimmer unit

pins, it may be found useful to adopt the following method.

Firstly, count the number of pins on the overlay. Now insert the pins, counting them off until the two numbers reconcile. Then count off as each pin is firstly soldered on the foil side and finally on the component side, again verifying that all pins have been soldered. This workman-like approach may save much heartbreak at a later stage as most faults at the prototype stage were traced to unsoldered or un-inserted pins causing IC's to be powered by their gates or signals to disappear into an electronic limbo between foil and component side.

Mount the sockets, capacitors and finally the plugs. Now comes the really tedious part, namely the fabrication of the various Minicon socket to socket

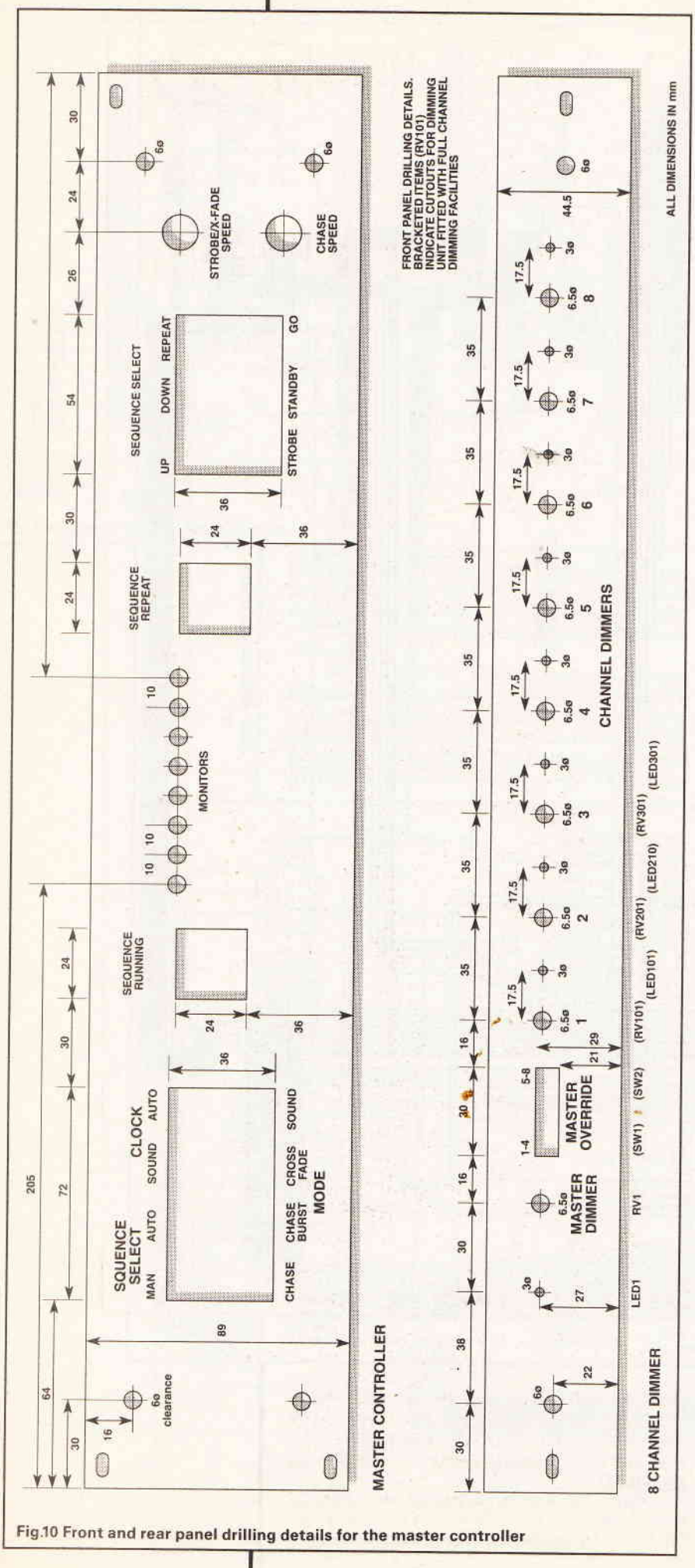

Fig.10 Front and rear panel drilling details for the master controller

assemblies required to interconnect between the six PCB's. Firstly, lay the six boards in a rectangle three boards wide and two high arranged in a clockwise fashion from top left as follows: Bass Beat Trigger, Main Processor, Output Switch, Seq. Select/Output Mode, Channel Monitor/Display and Mode Select. The boards should butt against one another. Now load all of the PCB mounted plugs with the empty Minicon shells. Referring to the circuit diagrams, mark what end of the plug is pin 1 and then cut pieces of 12 way ribbon wire to interconnect between appropriate plugs. Most assemblies are simply 'straight through' but one or two require what best can be described as 'kinks'. Solder pin 1 first as the reference pin. This simplifies the making of further connections. The socket assembly for PL7 on the output switch board is made using stereo screened lead, the screen being connected to the 0V pin, pin 2 connecting to the make contact of a mono ¼" jack socket and the break contact being connected to pin 3. A 100k resistor should be connected between the make contact and 0V.

Once these leads have been made and tested to the reader's satisfaction, the PCB's should then be plugged together in the correct manner and power applied. All should be well and the functional checks detailed in Part 1 can be carried out. If not, read on.

First, check that the LED's on the PSU are still alight. If not, unplug the lead connecting the Bass Beat Trigger to the Main Processor. Should the PSU now resume normal operation, unplug all of the peripheral boards from the Main Processor and reconnect the Bass Beat Trigger to it. This will eliminate or otherwise the Main Processor PCB. Gradually plug all of the other boards back into the Processor until the fault reoccurs. The power fault must lie in this interconnecting link which should be checked.

If the PSU does not spring back into life with the processor board unplugged, check the connections between the PSU and the Bass Beat Trigger.

Should all of the supply rails remain intact but the functional checks reveal the unit to be malfunctioning, verify that all boards are correctly powered with the appropriate voltages, then check individual IC's for power, the presence of clocks were relevant, whether AND and transmission gates are passing the correct logic levels when enabled, and whether bistables are toggling. These checks should reveal the fault to lie in one particular area. It was for this reason that each individual board was proved separately. A logic probe will be found to be invaluable for fault-finding.

When the unit works, the lead assemblies for the Control Out D-type socket can be made and also the lead for connection 0 between the Output Switch Board and the Triac Board (if fitted).

Any optional boards the reader may require can now be built. Constructional hints detailed previously should be followed as none of these boards differ radically from those already mentioned.

Faultfinding on the Crossfade board is confined to the presence or absence of supply rails, triangle wave, clock and the correct operation of the counters and multiplexers. On the Sound to Light, look first for an output from each buffer amp (IC1a-IC1d), then for an output from each filter section and finally, check that there is an output from the diode/capacitor combination. On the Strobe Board check for supply rails, the presence of a square wave from the oscillator and of the Strobe Enable line being low.

Construction, Input Interface Triac Board and Ramp Generator

Decide at this stage whether the switch pack is to be the zero-switched option, the limited facility dimmer or the

full facility dimmer. This choice will, of course, dictate what components need to be bought. Part 2 gives listings of the boards required for each option. Again note that if the Triac board is configured as a Zero Switch board, the channel monitor LED's sited adjacent to the opto-triacs should be mounted at right-angles to the PCB so that they are able to protrude through the front panel metalwork. Also note that points X, Y either side of the chokes shown on the circuit diagram are jointed by insulated wire links and that the left-hand side of the triac board nearest the PSU has a 2-way Minicon plug feeding the /V and 12V to the board. A two-way Minicon socket-socket assembly will need to be constructed. The Connector board, Control In socket, PSU (if fitted) and the Triac board are interconnected to create a Switch pack.

For both of the dimmer options, a PSU needs to be constructed. This is a simpler affair than the variable voltage unit used in the Master Controller and generates only plus and minus 12V and an unsmoothed but fullwave rectified AC output for the Ramp Generator. Construction is identical in most aspects to those of the Master PSU and no new points need be raised. Build this first and test it in accordance with the instructions given previously. Owing to space limitations, the component overlay and circuit will be presented next month.

Now construct a 4-way socket to flying lead assembly using the following code for the cableform: 0V – Green; +12V – Brown; −12V – Black; AC – Violet.

The assembly should be about 18" in length. Connect this to the PSU and set about making the Ramp Generator. Then fabricate another Minicon assembly, this time a 6-way socket to socket. Use the colour code specified above, adding White for the +10V and Grey for the −10V connections. Refer to the relevant circuit diagram for the correct pinout.

These remaining boards should not present any major problems if the reader has progressed so far, the only noteworthy points being:-

The mounting of the LED's on the Interface PCB which should have their legs bent at right-angles before being soldered to Veropins on the PCB.

The use of a suitably powerful soldering iron when soldering each of the 2.5mm triac supply links.

Great care should be taken when constructing the triac board as any mistakes made may be both expensive and dangerous. All components are mounted, as before, in order of ascending size. The triacs should have each leg insulated with silicon or similar sleeving before being mounted on the board/heatsink using M3 hardware, mica washers and insulating bushes.

Once the Interface board has been constructed, check and double-check that only the correct through-board pins have been inserted as supplementing the pins required for the limited facility board with those required for the full facility option or vice versa will result in damage to the trackwork and dimmer pots.

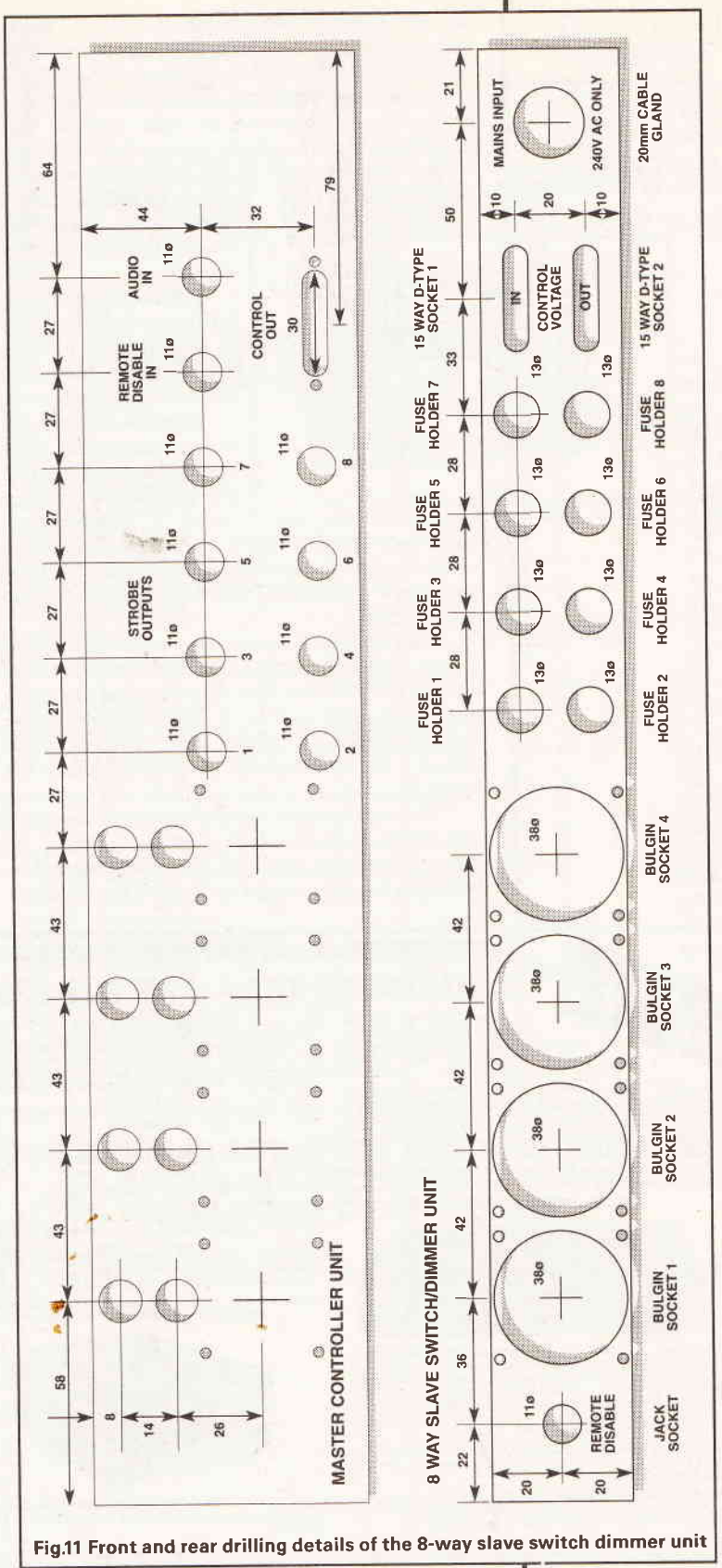

Fig.11 Front and rear drilling details of the 8-way slave switch dimmer unit

Testing and Faultfinding

Connect the PSU to PL1 on the Ramp Generator and apply power. Should all remain well, switch off and purloin a dual trace 'scope from somewhere. Trigger the 'scope with the 240V mains input waveform and connect channel 2 to Q4 collector. Gingerly, re-apply power and if there are no bangs or flashes at this juncture and two traces on the 'scope, adjust PR1 until the positive-going pulses are coincident with the zero crossings and as narrow as possible. Over adjustment will cause the pulse to reduce in amplitude and then disappear. Transfer Channel 2 probe to IC1 pin 1 and adjust PR2 for a linear sawtooth of final amplitude +10V. Finally, adjust PR4 for +10V on IC2 pin 2 and PR5 for -10V on IC3 pin 3. Should no 'scope be readily available, adjust PR1 for a voltage of 3.5V on Q1 base. This is a slightly inaccurate method as, ideally, the waveform needs to be viewed and compensation made for the slight phase lag of the transformer. It is for this reason that we look at the mains primary waveform and not the secondary and set up the circuit accordingly.

Now connect the Ramp Generator to the Interface board and referring to Part 2, undertake the functional tests detailed. Should the unit fail any of these

tests, unplug all of the IC's except IC's 1, 2 and 101 to ascertain whether or not the problem is common to all channels or is confined to one or more channels. Look for missing supply rails, the presence of the sawtooth, diodes inserted back-to-front, then working from IC101d backwards, check each of the op-amp outputs to see whether or not the DC voltage can be altered within its specified limits using the dimmer controls.

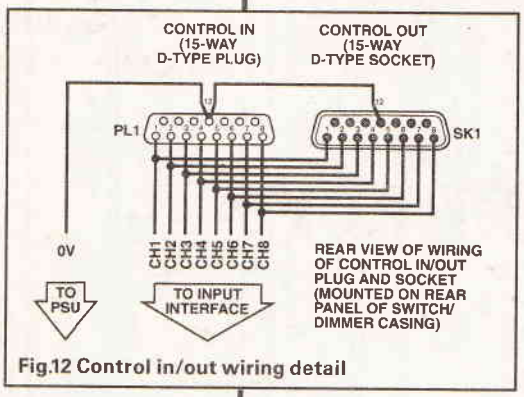

Fig.12 Control in/out wiring detail

When the Interface is fully operational, construct a 10 way socket to flying lead assembly using eight different coloured cores for the channel inputs and the central core from some screened lead for the Disable pin. Connect this to a mono ¼" switched jack socket as in the diagram. For those of you not wishing to construct the Sensor Switch, I have included a circuit using a normal SPST switch to implement the Disable function.

Connect the other cores to pins 1 to 8 of a 15 way D-type socket. This is the Control In socket. Pin 12 is connected to 0V. The Triac board is tested as per the instructions given in Part 2. Faults are almost exclusively confined to the incorrect insertion or the failure of the semiconductor devices housed on the board.

This concludes the bulk of the complex construction of the Master Controller and 8kW Dimmer. All that remains is to create the metalwork required to house the boards, measure up and drill the front panels and then neatly wire the boards to the various rear panel connectors. The final part of the series gives the presentation of the design and construction of the Sensor Switch.

One or two errors have occured in Parts 1 and 2 namely to the ramp generator board overlay and the orientation of PR1 and positioning of R1. These will be published in next month's article.

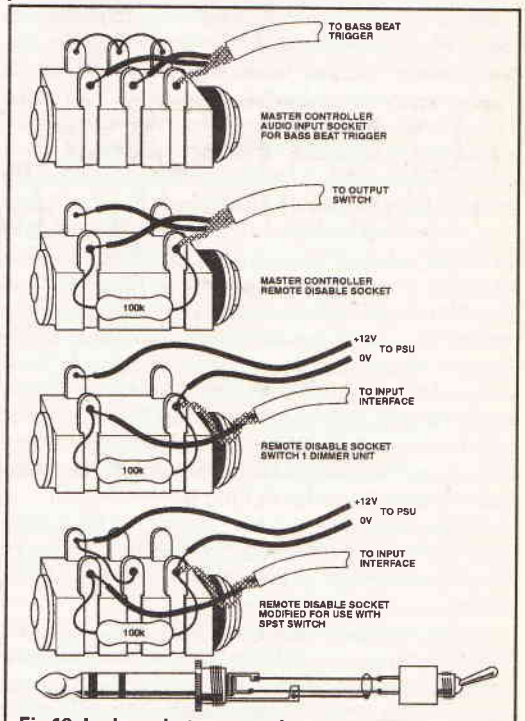

Fig.13 Jack socket connections

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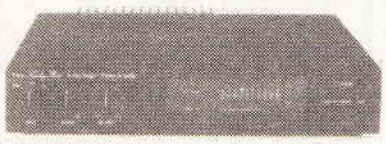

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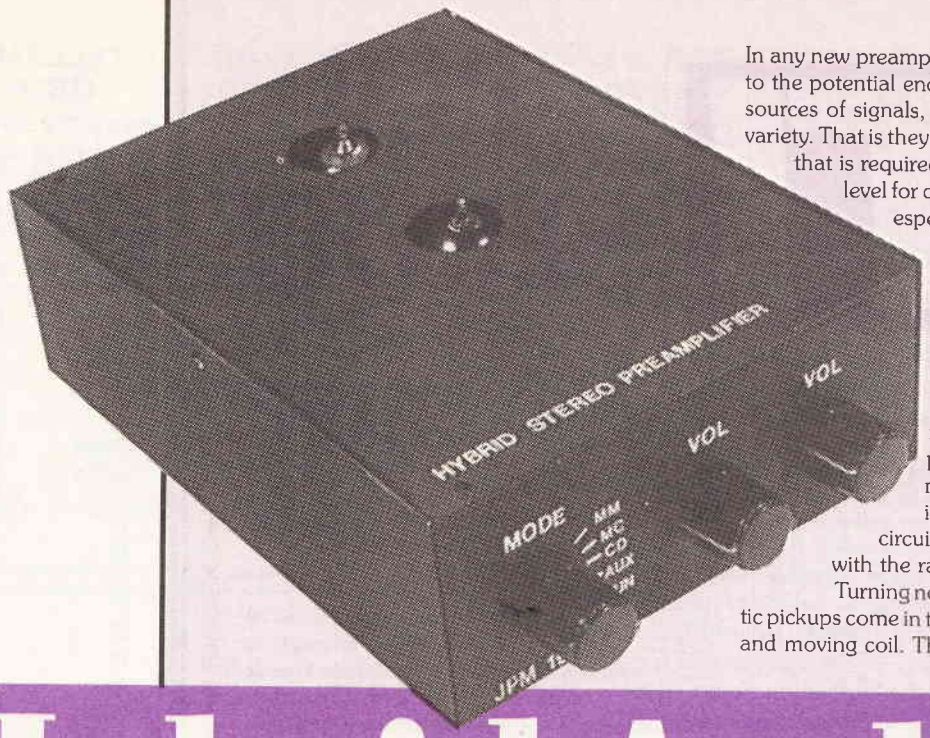


Hybrid Audio Pr

A high quality audio design using valves and transistors by Jeff Macaulay.

PROJECT

It's been a long time since my preamp circuits have featured in this magazine. Since then a great deal of electronic design has flowed under the bridge. I was rather surprised recently to receive a letter from an ETI reader in Athens asking some specific enquiries regarding these. Digging out my back issues I found to my surprise that these designs were 6 years old! The letter also coincided with trying to concoct a good preamp for my now ageing record deck.

Like many audiophiles I have been optimising my system for CD and had a pile of unused records. Also, with advancing age, I have become a far more pragmatic designer than in days of yore. My philosophy has become one of simply using the best device for the job regardless of current fashions. This reflects in this design in several ways. For example I use valves where their unique attributes give the design an edge but have eschewed these for transistors where low noise is required.

Such a hybrid approach allows one to extract the maximum potential of each device. For example one would normally need a high voltage line, several hundred volts in fact, to allow direct coupling between valves. At least if you want a sensible design. Using transistors and valves together allows a good preamp to be designed using a relatively low operating voltage with full DC coupling between stages.

Lower operating voltages allow a larger range of standard components to be used. For example, in valve terms 100µ is a large capacitance. 4700µ/100V caps can be obtained for the same price. For the input stage low noise is a natural prerequisite. Again if I were to use valves here I would need a stabilised power supply for the heaters, despite the hum level being 60dB below 5mV for an AC supply. More importantly, the main source of hum pickup would be wires carrying 6VAC around the sensitive input circuitry.

In any new preamp design, thought has to be applied to the potential end users ancilliary equipment. Most sources of signals, excluding pickups are of the 'flat' variety. That is they require no special equalisation. All that is required is to bring them up to a suitable level for driving the power amp. This applies especially for sources which have in any case a hefty output.

This brings us naturally to the problem of output level. Unfortunately standards here are very lax. Many amplifiers need only a few hundred millivolts to drive it into clipping. However this is not necessarily the case. If a preamp is to have any use at all it must be capable of driving all exist ing amplifiers. To this end I design circuits for 775mV output, when driven with the rated input signal.

Turning now to the pickup equaliser. Magnetic pickups come in two basic varieties, moving magnet and moving coil. This preamp has been designed to cater for low output moving magnets, primarily. However there is sufficient gain for high output moving coils to be used. A caution though.

Many of the newer integrated amplifiers have been designed to cater for both types of cartridges by increasing the current density in the first transistor by

means of a switch. Although this works it involves a certain amount of compromise. If you have a moving coil it usually sounds better when fed through a dedicated head amp. I hope to publish a suitable circuit soon.

Any available head amp or step up transformer can be used with the circuit as published. Unfortunately, in audio as in life generally, fashion tends to rule the roost. This is all very well but unfortunately has tended to obscure the real purpose of hi fi. That is to produce an accurate rather than 'good' sounding equipment. Now while it is true that we will never be able to produce a perfect piece of equipment with no distortion or noise this doesn't make the goal of truly accurate reproduction a nonsense.

Perfection, in the audio sense, will be achieved when all distortions and noise have been pushed below audibility. This is at least theoretically possible without the need for zero imperfections. When this has finally been achieved we will be limited by the quality of our source material.

The Phono Stage

Of all the circuits in audio the greatest challenge is probably the phono equaliser stage. Here in one circuit we need low noise, exceptional linearity and accurate equalisation. This is a difficult thing to acheive, as you may imagine. To confound matters the source impedance of the cartridge varies with frequency and is of low output. Several methods may be employed to achieve the desired response and most of them have appeared

e-amp

HOW IT WORKS

Looking at the schematic the stage works as follows. Input signals from the slider of RV1 are fed into the base of Q2 via the DC blocking capacitor, C12. This transistor is operated in the can emitter mode with plenty of local negative feedback supplied by the emitter resistor R15. The collector load comprises of R13 and R14 in series. C13 decouples the voltage at the junction of these two resistors to ground at AC. Thus removing line noise and ripple which would otherwise appear on the output. Again a valve stage is used as the business end and this is operated in the common cathode configuration. DC coupling is used between collector and grid and the bias voltage for Q2 is applied via R17.

This component along with the series connected R16 form the cathode load of the valve. R11 and R12 which provide the bias are bypassed to ground by C14 which removes unwanted feedback from the cathode at AC. R18, is the valve anode load. Output signals are taken from here via C16 to the outside world and via the feedback resistor R19 to Q2's emitter. The ratio of R19 to R15 sets the gain at 11 times.

One of the reasons for having a line stage was, as mentioned earlier to enable low impedance cables to be driven without top loss due to cable capacitance. This requires a low output impedance. The overall gain of the circuit, measured open loop is about 625. The triode has an output impedance of about 3k before feedback. With the level of negative feedback used this is reduced to less than 100R. Sufficiently low to drive several hundred metres of wire without problems.

POWER SUPPLY

Two voltages are required from the power supply. Firstly an HT voltage of some 80V and the AC voltage for the heaters. Looking at the schematic for the power supply you will see that two transformers are used. T1 produces HT from the secondary which is fed into a voltage doubler circuit D1 and D2. The raw DC is then smoothed by C17 and C18. T2 provides AC for the heaters and this is taken directly from the secondary. The preamp is turned on or off by SW1, a DPST switch. On indication is provided by LED D4. Half wave rectification of T2's secondary is provided by D3, current limiting for the LED is producedby R28.

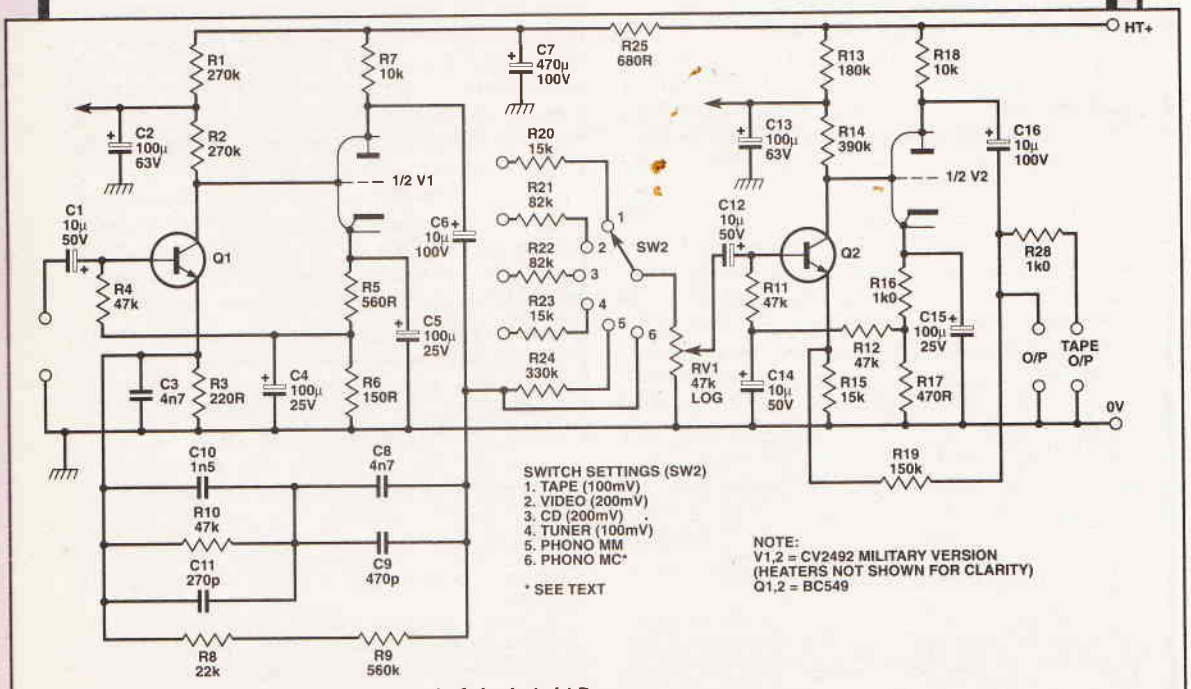


Fig.1 Circuit diagram showing one channel of the hybrid Pre-amp

in the pages of this magazine from time to time.

The circuit I have chosen is a variation on one of the most successful types, the non inverting feedback amplifier. Equalisation is achieved by varying the impedance in the feedback loop of a high gain amplifier. To explain how it works we have to refer to the schematic.

The vital front end in this design is a low noise transistor operating in the common emitter mode. Signals from the cartridge are fed into Q1 via the DC blocking capacitor C1. Because of the negative feedback applied to the emitter of Q1 the input impedance looking into Q1's base is very high and is shunted by R4 which both biases the amplifier and sets the input impedance at the required value of 47k.

In order to keep the noise level low the collector current and collector emitter voltage must be kept to a minimum. Also the open loop gain must be kept high. R2 ensures that the latter requirement is met. The current level for optimum noise can be found from the relationship:

$$Ic = (Hfe)\ 0.5/[40 \times rs] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [1]$$

Where rs = source resistance. Herein lies the rub. A moving magnet cartridge consists of a voltage generator in series with a small resistance, usually about 1k and a hefty inductance. This inductance can easily be in excess of 100mH and so the apparent source impedance is not a fixed quantity but increases with frequency. Worse still from the design point of view most cartridges don't have a linear response even after equalisation. Often you will see a recommended capacitance as well as resistance in the loading data. Not often explained is that this capacitance is used to tune with the cartridge inductance to raise the levels at the top end where the inductance would otherwise cause a loss.

The typical moving magnet will have response variations an order of a magnitude greater than that found in a well designed equalisation network. Surprisingly never mentioned by those who seek 0.1dB accuracy in that department.

If you are interested in experimenting with your cartridge you could try substituting a 1M resistor in the R4 position. Various values of loading can then be substituted by connecting resistors across the cartridge input.

Generally speaking a high value resistor will give you more treble and a low value much less than normal. Again various values of capacitance can be connected across the cartridge with varying effects. These audible changes will interest those who want their systems to sound 'good' but if you are interested in an accurate system you will follow the cartridge maker's recommendations.

In order to keep the gain of the stage high the value of R2 needs to be large. Fortunately using a high supply voltage helps considerably here. I have used an RC decoupling network to supply voltage for the stage. If you tried to use the ubiquitous 317T regulator for this duty you would find that the sound would be buried in the white noise generated by this device. Now for the second stage of the equaliser, the valve.

At first sight the use of a valve in this position might raise a few eyebrows. However it happens to be the best device for the job. It has all the right qualities. Looking into the grid the transistor 'sees' an impedance of about 100 megohms so that the stage is essentially working into an open circuit, ie the transistor is unloaded. Only a small amount of gain is required from this stage and this is just what the valve delivers. The voltage gain provided is very linear approximately 10 times more so than a transistor stage.

The valve can also be operated at a reasonably high current so as to produce a low output impedance to drive the feedback loop. Note the DC coupling between the transistor and valve, no expensive and nasty capacitors here. This results in superior transient response.

Negative feedback is applied through R4 which is connected to the junction of R5 and R6, the cathode load of V1. C5 and C4 decouple the cathode circuit to ground.

Now that we have a highly linear low noise stage all that remains is to achieve RIAA equalisation and the

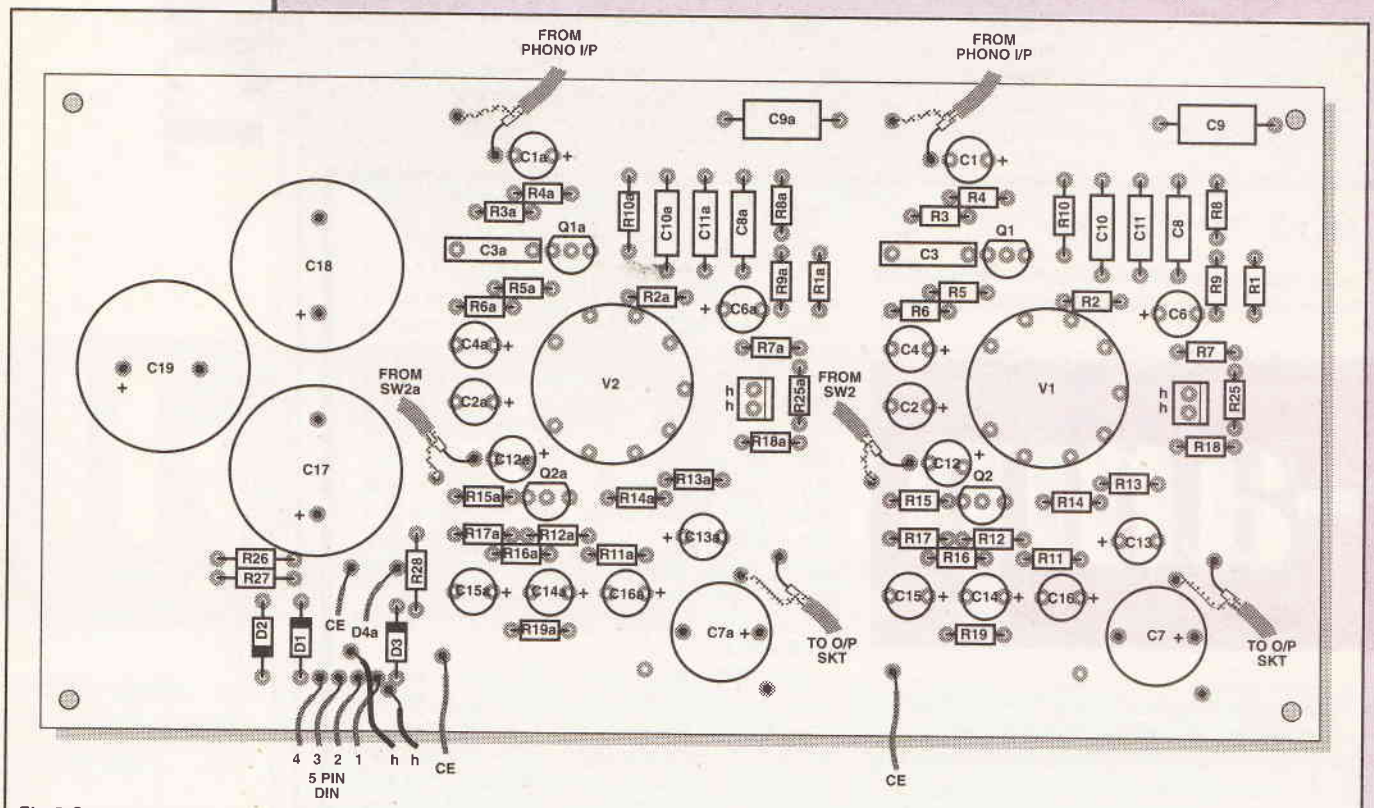


Fig.2 Component overlay of the pre-amp

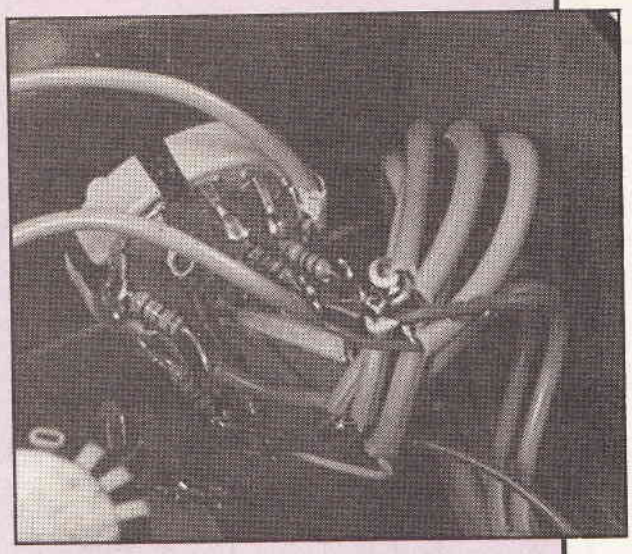
PROJECT

correct gain for the cartridge. Magnetic cartridges have an output that is proportional to groove velocity. Again different units have different outputs. As a generalisation better quality cartridges tend to have a lower output than mediocre ones. An average output is said to be 1mV/cm and the input sensitivity is based on an average groove velocity of 5cm/sec.

The gain of the circuit is dependent upon the value of R3. I have used a 220R component here to cater effectively for lower output cartridges. If your cartridge has a higher output 470R can be substituted without further circuit modification. Now to the equalisation. Naturally this needs to follow the standard RIAA curve. Despite the copious correspondence in ETI about this very subject I would suggest interested readers should also look up the reference given at the end of this article for a definitive treatment. [2]

Boiled down to it's essentials the basic circuit used posseses two reactive circuits, R8/9, C10/11 and R11, C8/9. Because of the interaction that occurs between the two networks that comprise the equaliser the time constants are not as might be expected from the break points on the standard RIAA curve.The 7-element network used here gives the correct curve to within 0.1dB between 20Hz to 20kHz, provided the 1% components are used. Don't substitute for the polystyrenes used.

Whilst on the subject of gain one of the requirements of the design was to provide a high overload ratio. There is a lot of misunderstanding about this factor in preamp design. The overload ratio is the ratio



Indeed taking matters to the extreme the perfect amplifier is one with a zero signal, why, because it has zero distortion. Of course if you were turn it off as well you'd have an even better amp, no noise level either!

Finally, a cautionary tale for prospective circuit tweakers. In the development of this circuit I have attempted all the obvious tweaks. For example I have'nt bothered to run the valve heaters from a regulated DC supply.

Why? Well the effects of tube hum when run from

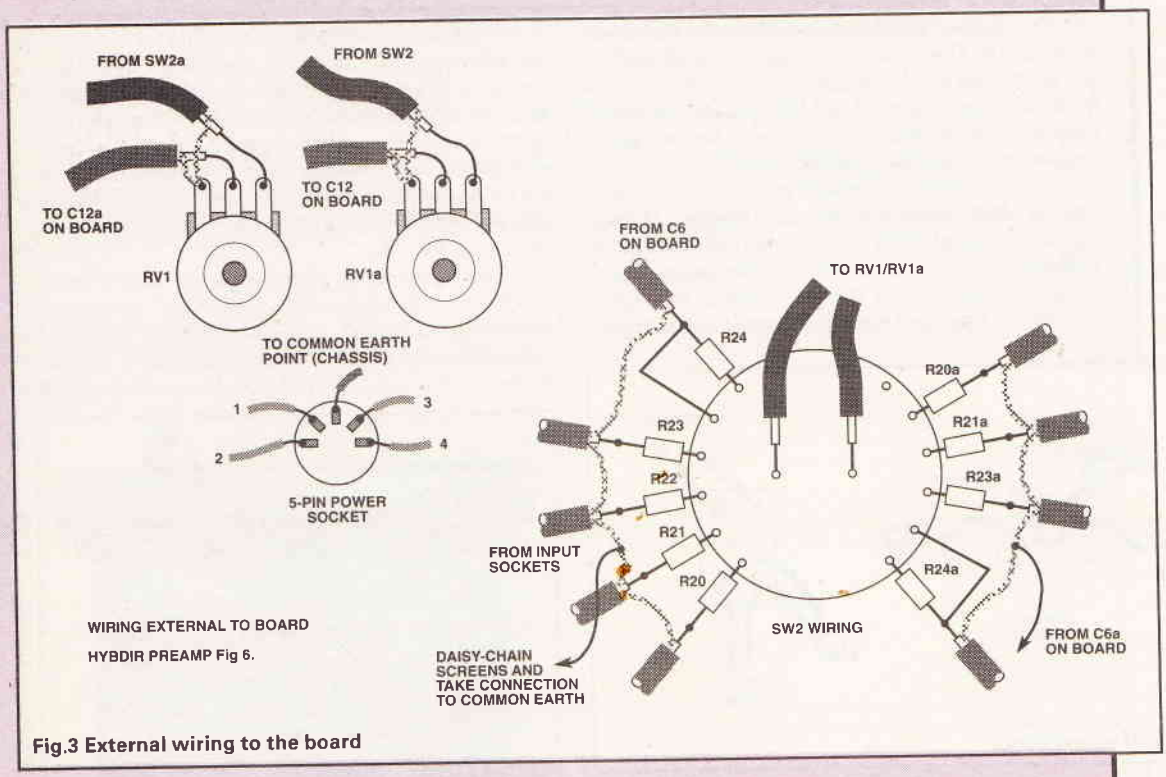


Fig.3 External wiring to the board

between the nominal input and one that would drive the stage into clipping. Records seldom contain groove velocities in excess of 25 cm/sec, even on energetic direct discs. The reason for wanting a large overload ratio is simple. In the real world we are not blessed with perfectly linear circuits. In fact it's fair to say that we aren't blessed with perfect anything, so audio hasn't been singled out for special treatment in this regard.

However, if you consider the transfer charactaristic as a nearly straight line it follows that the smaller the section of that straight line that your signal traverses the more linear the output will be. In a Class A amplifier circuit, which this is, distortion and all types of non linearity are directly proportional to output level. raw AC are greatly exagerated. The hum level from the valve is at least 60dB below a 5mV input. When used as a second stage the signal applied to the grid is roughly ten times greater giving a S/N of better than 80dB. But wait, there's more. The overall negative feedback will reduce the hum level at the output by another ten fold. Result, hum level 100dB down.

Bear in mind that the maximum S/N ratio obtainable from a pickup cartridge is determined by the natural noise generated by the resistance of the pickup coils. As this is generally in the order of 1k the ultimate S/N ratio from a cartridge is limited to −70dB, even with a noiseless preamp!

Next consider C6. This is an electrolytic, horror of

audiophile horrors. However, due to the feedback, loop it's distortion is reduced 10 fold at low frequencies and 1000 fold at 20kHz. Even if some of the highly priced eseoteric capacitors are actually better than an electrolytic they are not going to be 1000 times better. The same arguments apply to all the components used within the feedback loop.

Again I could have stabilised the supply line to the valve. When I tried this I found that the noise level of the circuit rose. An RC decoupling network worked far better.

Having dealt with the magnetic pickup stage we now come to the other, equally important part of the circuit, the line stage. The purpose of this stage is to take outputs which are already 'flat' and bring them up to the level necessary to drive the amplifier. An important feature of such designs is that they provide a low output impedance to drive long lines if required. Naturally we need to provide such a function with the least disturbance to the quality of the original signal.

As I mentioned earlier I have designed the equipment to provide standard line level, 775mV when fed from the stated input. The same logic has been applied to this stage. One exception to the rule however. CD players have a high output and require no further equalisation. This allows the signal to be fed directly to the output via a volume control. Unfortunately such 'passive preamps' tend to use 10k pots. As the output stage is invariably an op amp such a load will appear in parallel to the existing feedback loop.

Most common-or-garden op-amps are incapable of giving their best when operated in this way. The reason is simple. Op-amps are operated with a couple of milliamps of quiescent current in the output stage. When operated into a high impedance the output operates in push-pull class A. However as the impedance is lowered they revert to Class AB generating unecessary distortion.

It follows that the best way to avoid this is to feed the signal into a high impedance, ie greater than 10k. An alternative option which CD makers could consider would be to load the output stage with a constant current source of say 10mA. This would bias the last op-amp into single ended Class A. However I am not advocating violating the manufacturer's warranty. Anyone who tries such a modification does so at their own risk!

The power supply is mounted in a small separate case from the preamp. This allows complete separation of functions and prevents unecessary hum pickup by the preamp. Valves are high impedance devices and are very prone to picking up noise from nearby cables, especially when they're carrying HT. However at least I have at last found a use for multipin DIN plugs and sockets which carry the line voltage between the power supply and the preamplifier!

Construction

Since many of the parts used in this design are not available from retail or mail order outlets I have made arrangements with 'HOBTEK' to supply a complete kit of parts. The following instructions assume that the circuit is being built from this kit.

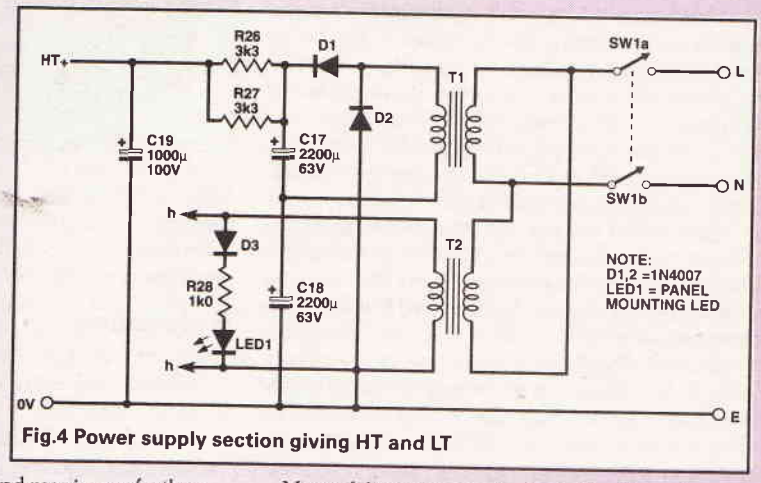


Fig.4 Power supply section giving HT and LT

Most of the components, including the valves are mounted upon the large PCB, the overlay of which is shown in Figure 2. Very little comment is required regarding this except to ensure that all the polarised components are correctly inserted. When you have assembled the board turn it over and check that their are no dry joints or unwanted solder blobs. Assuming all is well, attention can then be turned to the mechanical part of the job.

The figure shows the metalwork drilling detail and this should be adhered to. Deburr the holes before mounting the sockets, pots and switch. Note that square holes are used for the multiway phono sockets. As the cases are of 18SWG Aluminium, working them

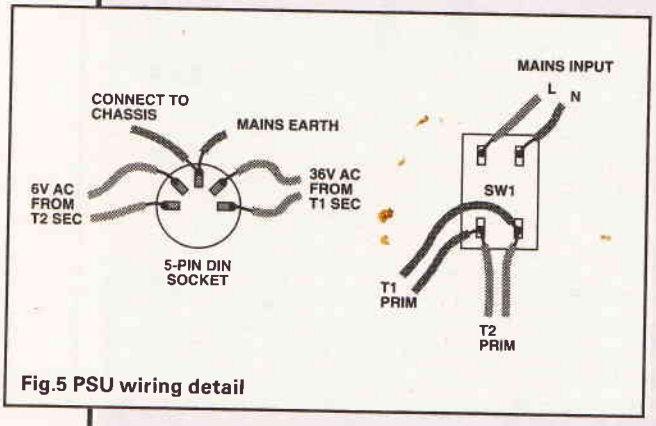
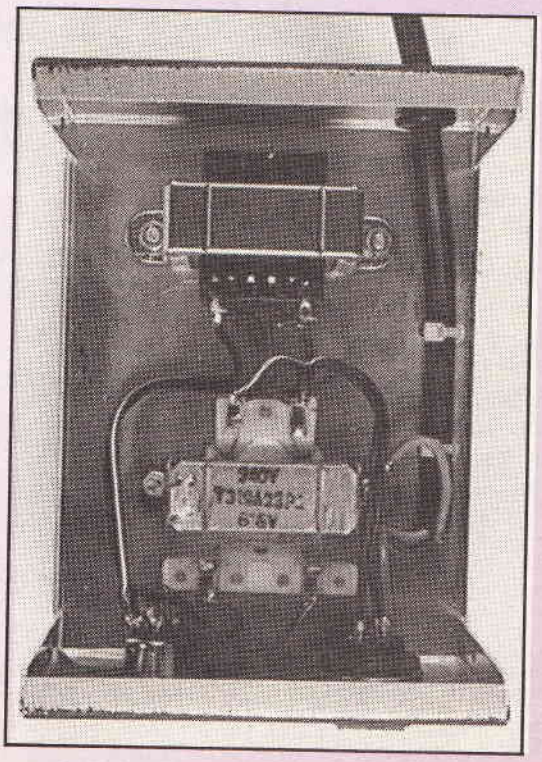


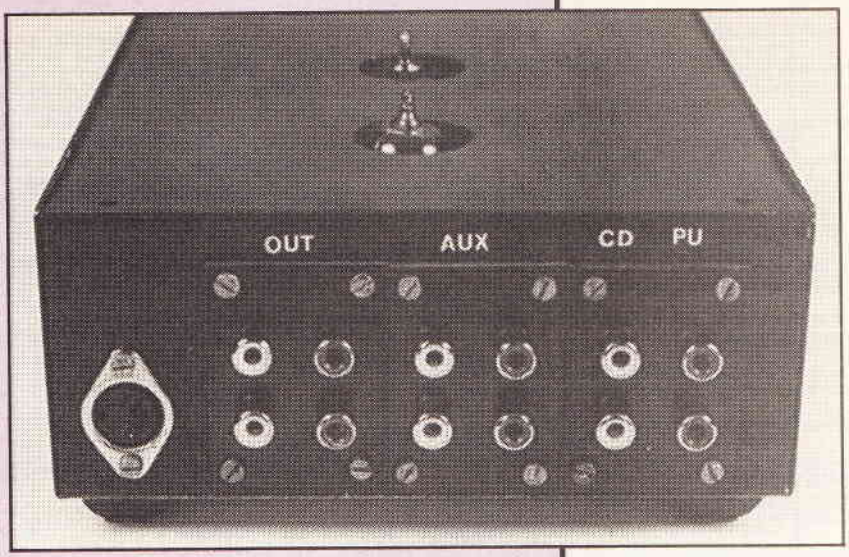
Fig.5 PSU wiring detail



is easy. First cover the panel with masking tape and mark out the rectangular cutouts. For the dual phonos drill three 10mm holes within the cutout. Remove the waste between them with your sidecutters. File the resulting holes to the required rectangle. The octal phono socket mounting hole can be made in a similar manner. Drill 3mm pilot holes within the cutout. Drill through these with a 10mm drill and remove the waste in the same way finally filing smooth. This may sound like hard work but in reality the task can be completed within a few minutes. At this stage flying leads about 12in long should be attatched to the main board. This is mounted in the chassis on 0.25in spacers to ensure that nothing shorts against the chassis.

Terminate the flying leads to their respective destinations. Now attention can be turned to the power supply. Again this is built on a single PCB. Note that the mains entry hole is fitted with a 10mm grommet. Connections from the power supply are taken to a panel mounted 5 pin DIN socket and from thence to the preamp proper via 4 way cable. This cable doesn't need to be that long, 1m is adequate.

Testing the unit starts with the power supply. Having fitted and wired this unit connect to the mains. Check that the HT supply measures 90-100V DC and that you have 6VAC on the heater pins. Having got this far connect the negative lead of your testmeter to the preamp case. Attach the power lead and switch on. Check on IC1 tab that you have approximately 80V DC. After a few seconds the valve heaters should begin to glow and you will measure 35-45V on the anodes of



V1 and V2. If not switch off and examine your circuitry for a fault. Assuming all measures OK the project is now functional. All that remains is to connect signal sources to the preamp, a power amp to the output and enjoy the good sounds!

Reference

[1] 'Introduction To Low Noise Amplifier Design', A. Foord, WW, April 1981.

[2] 'Understanding The RIAA Curve', Reg Williamson, The Audio Amateur, February 1990.

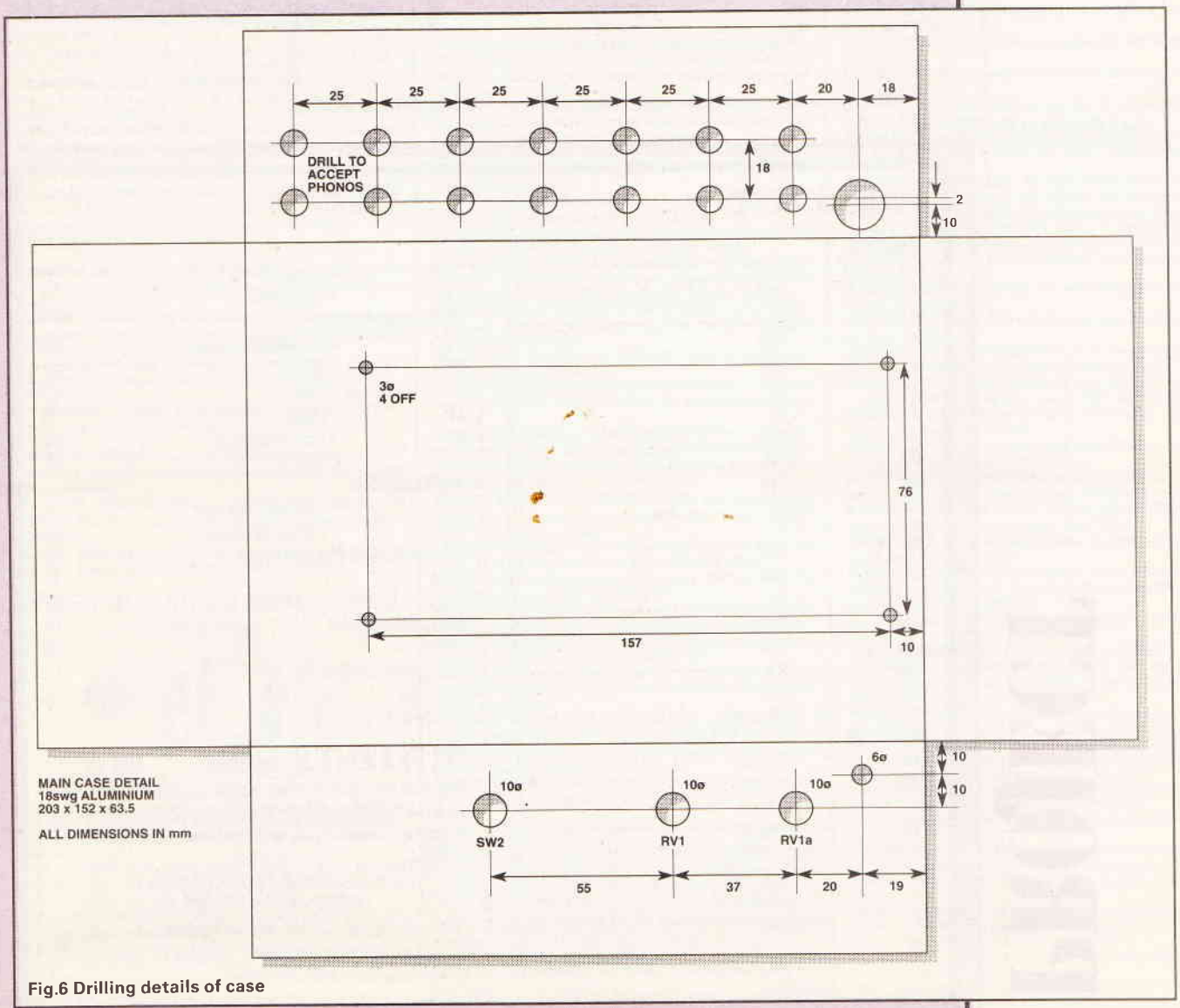


Fig.6 Drilling details of case

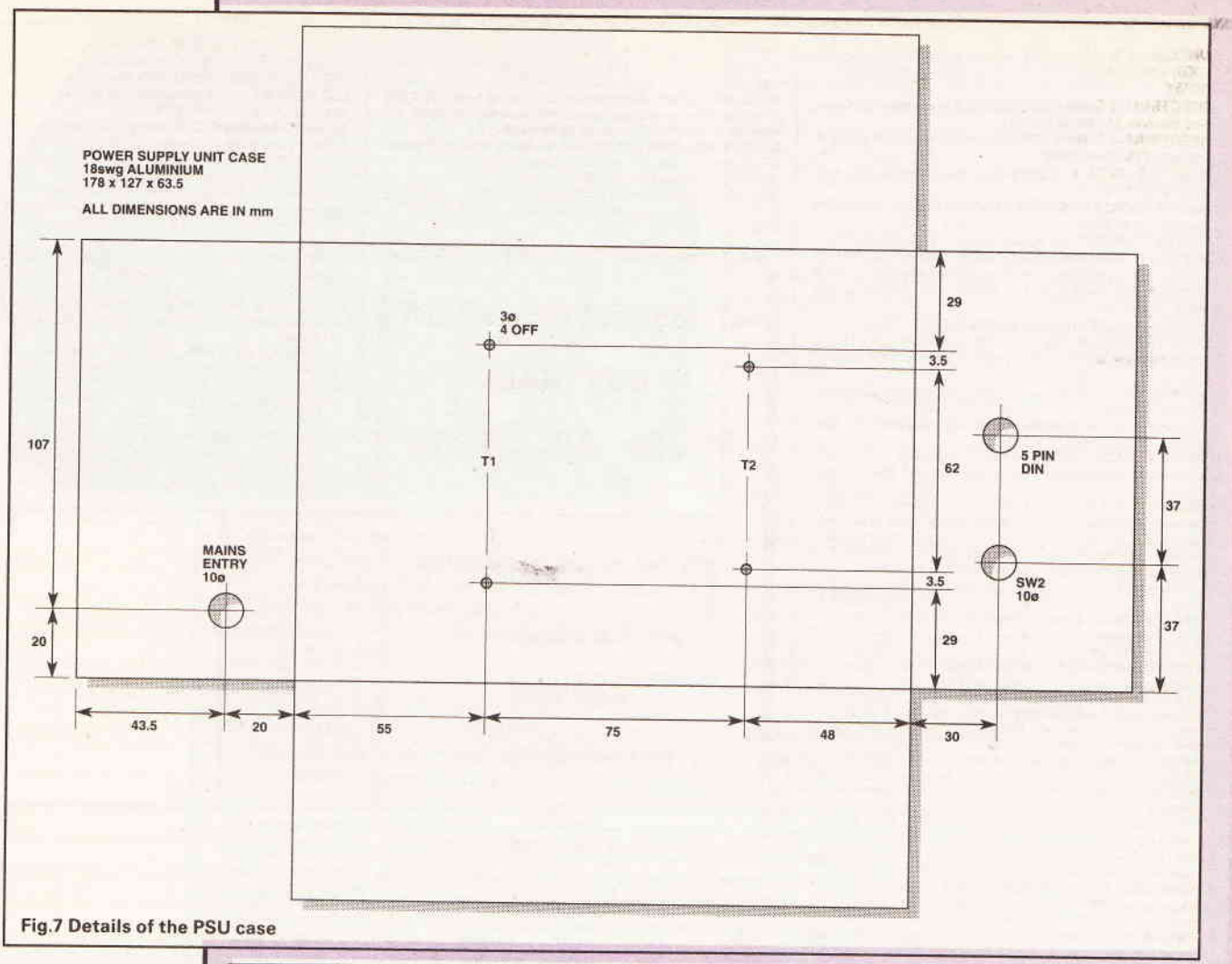


Fig.7 Details of the PSU case

PARTS LIST

RESISTORS

R1,2	= 270k	[3]
R3,25	= 220R	[2]
R4,10,11,12	= 47k	[8]
R5	= 560R	[2]
R6	= 150R	[2]
R7,18,28	= 10k	[4]
R8	= 22k	[2]
R9	= 560k	[2]
R13	= 180k	[1]
R14	= 390k	[2]
R15	= 15k	[2]
R16,28	= 1k	[2]
R17	= 470R	[2]
R19	= 150k	[2]
R20,23	= 15k	[4]
R21,22	= 82k	[4]
R24	= 330k	[2]
R26,27	= 3K3	[2]
R25	= 680R	[2]
VR1,2	= 47k log pot	[2]

CAPACITORS

C1,12,14	= 10µ/50V	[6]
C2,13	= 100µ/63V	[2]
C3	= 4n7 poly	[2]
C4,5,15	= 100µ/25V	[6]
C6,16	= 10µ/100V	[4]
C7	= 470µ/100V	[1]
C8	= 4n7 styr 1%-	[2]
C9	= 470 pstyr 1%-	[2]
C10	= 1n5 pstyr 1%	[2]
C11	= 270 pstyr 1%	[2]
C17,18	= 2200µ/63V	[1]
C19	= 1000µ/100V	[1]

ACTIVE COMPONENTS

V1,2	= CV2492 Military version	[2]
Q1,2	= BC549	[2]
D1,2	= 1N4007	[2]
D1	= 1N4001	[1]
D2	= Panel mounting LED	[1]
IC1	= LM317T	[1]

MISCELLANEOUS

T1	= O-36V sec, 240V prim.	[1]
T2	= O-6Vsec, 240V prim.	[1]
PCB mount ceramic B9A valve holders		[2]
PCB's		[2]
Cases		[2]
2P6W rot switch (SW2)		[1]
Knobs		[3]
On/off switch (S1) DPST		[1]
Phono skts		[8+2+2+2]
5 pin din plug, socket.		[1+1]

BUYLINES

Since some of the parts are dificult to obtain I have made arrangements with a mail order electronics firm to supply the preamp in kit form. A full, designer approved kit of parts for this project is available from:

'HOBTEK',
THE COTTAGE, 8 BARTHOLOMEWS,
BRIGHTON, EAST SUSSEX BN1 1HG

The kit contains everything required, the glass fibre and premium quality electronic and mechanical parts. Price is £89.99 + £3 post packing and insurance. Please order as HAP 1 kit.

PROJECT

UNIDEN SATELLITE RECEIVER Brand new units (model 8008) £60.00 ref 60P4Y also some 7007s also £60.00 ref 60P5Y

SPECTRUM +2 COMPUTER Built in data recorder, 128K, psu and manuals £59.00 ref 59P4Y

SPECTRUM +3 COMPUTER Built in disc drive, 128K, psu and manuals £79.00 ref 79P4Y

AMSTRAD CPC464 COMPUTER No manuals but only £79.00 ref 79P5Y

AMSTRAD CPC6128 COMPUTER Again no manuals but only £149.00 ref 149P4Y

AMSTRAD GT65 Green screen monitor £49.00 ref 49P4Y

AMSTRAD PORTABLE PC'S FROM £149 (PPC1512SD). £179 (PPC1512DD). £179 (PPC1640SD). £209 (PPC1640DD). MODEMS £30 EXTRA.NO MANUALS OR PSU.

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Pack of two PAR38 bulbs for above unit £12.00 ref 12P43Y

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MINATURE RADIO TRANSCEIVERS A pair of walkie talkies with a range of up to 2 kilometres. Units measure 22x52x155mm. Complete with cases. £30.00 ref 30P12Y

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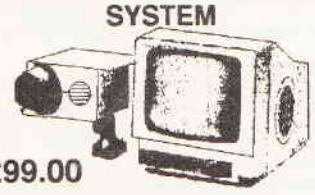
VIDEO AND AUDIO MONITORING SYSTEM



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As above but with fitted 4 to 1 inline reduction box (800rpm) and toothed nylon belt drive cog £40.00 ref 40P8Y.

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640K RAM

UPGRADABLE TO 4M

AT CASE

AT POWER SUPPLY

AT KEYBOARD

MANUAL

NO I/O CARDS

£139

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6V 10AH LEAD ACID sealed battery by yuasha ex equipment but in excellent condition now only 2 for £10.00 ref 10P95Y

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FRESNEL MAGNIFYING LENS 83 x 52mm £1.00 ref BD827Y.

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Instrumentation & Test Gear Basics

Ray Marston presents an introduction to instrumentation and test gear principles in this new mini-series.

This 2-part article introduces the reader to the basic terminology and principles of modern instrumentation and test gear. The author intends to follow it up with a number of articles dealing with practical instrumentation and test gear design techniques and circuits.

Basic Terminology

The terms INSTRUMENTATION and TEST GEAR mean different things to different people. In the context of this new mini-series, an instrumentation circuit is one that translates an intangible quantity such as voltage, resistance, inductance, speed or temperature and the like, into a tangible form (such as an analogue or digital meter reading or an alarm signal,) that is meaningful to a human operator. Such circuits consist of a converter that changes the intangible quantity into an easily processed form (such as a DC voltage), and a translator that changes that into a tangible form.

If the instrumentation circuit is one that gives a meter reading that is read at a spot close to the point where the conversion is made (see Figure 1), the circuit may be called a metering system. If the system is one that enables the reading to be made at a point very distant from that of conversion (see Figure 2), the circuit is known as a telemetering system. Note in the latter case that a sender and a detector are interposed between the converter and the translator, and are interconnected via a data link. This link may take the form of a ground line or an infra-red or radio link, etc.

A piece of TEST GEAR (or test equipment) can be loosely defined as any item of equipment that is specifically designed to generate, simulate, or analyse electrical/electronic signals or parameters. Individual items of test gear may be designed for either laboratory use, or what may be called 'industrial' or 'dedicated' use. Laboratory test gear is usually very versatile, and is designed for use in a wide spread of applications. Industrial test gear is usually very specialised, and designed to perform just one specific function or production-testing task. Thus, a laboratory RF signal generator (see Figure 3) may be able to generate good CW, AM or FM sine wave signals over the entire 100 kHz to 220 MHz frequency range, and to give output signal levels that are fully and accurately variable from a fraction of a microvolt to several hundred millivolts, but an industrial RF generator (see Figure 4) may simply be designed to pump out a 465 kHz CW signal at 100 µV.

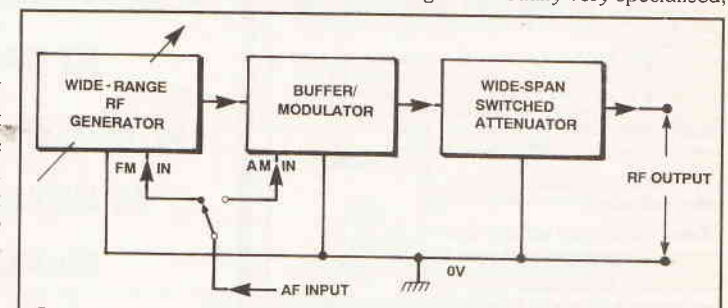

Fig.3 A laboratory RF signal generator is a versatile wide-range instrument

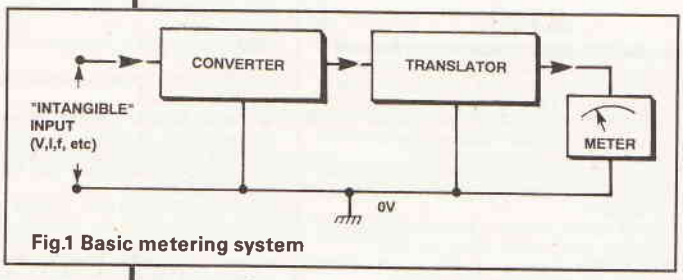

Fig.1 Basic metering system

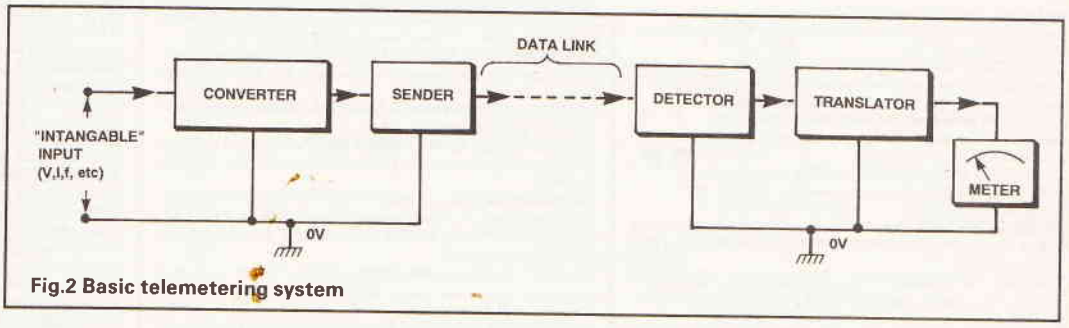

Fig.2 Basic telemetering system

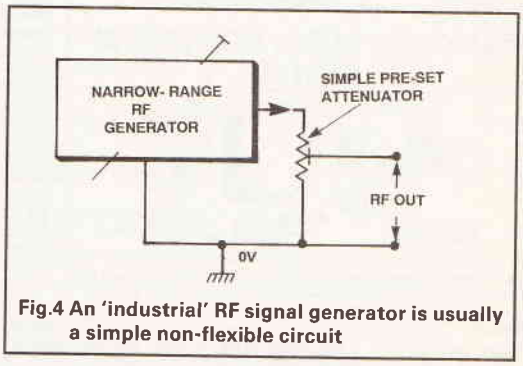

Fig.4 An 'industrial' RF signal generator is usually a simple non-flexible circuit

Most practical electronic 'testing' operations call for the use of two or more items of interconnected test gear. For example, the items needed to carry out a simple performance check on an audio amplifier are a variable-frequency variable-amplitude sinewave genera-

TEST GEAR

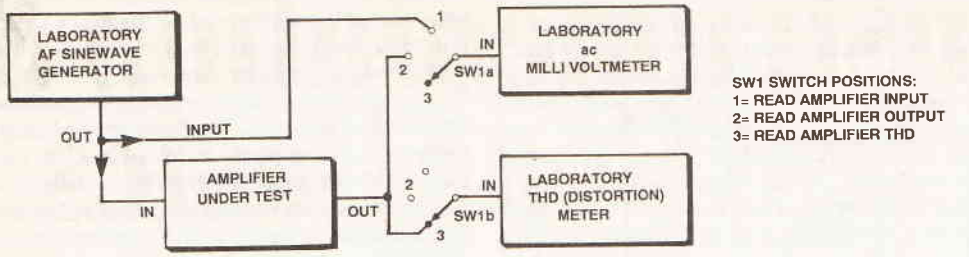

Fig.5 This amplifier-testing TEST *RIG* is made by temporarily interconnecting a number of items of laboratory test gear

tor (to generate a test signal), a wide-range AC millivoltmeter (to read input/output signal levels and thus facilitate frequency response checks), and a 'total harmonic distortion' or THD meter (to check the amplifier's reproduction quality or fidelity). If such a performance-testing facility is made by temporarily interconnecting or 'hooking up' a number of individual items of test gear (see Figure 5), the resulting assembly is known as a test rig, but if it is made by permanently interconnecting a number of test gear items (see Figure 6) the resulting unit is known as a test set. Many industrial test-gear engineers spend their working lives eternally designing new test sets for use on their company's production testing and quality control lines.

The reader should note that some of the above technical terms can be interchanged. Thus, a simple multimeter is an item of test gear, but when in use becomes a metering system. Again, a THD meter is correctly called an item of test gear if it requires the use of an external low-distortion sine wave generator, but should be called a test set if it has such a generator built-in.

Types Of Test Gear

There are four broad categories of test gear, and these can be named as GENERATORS, INDICATORS, COMPOSITES, and STANDARDS. A generator is simply any item of test gear that acts as a source of signals or power (e.g., AF and RF signal or pulse generators, power supplies, etc.), and an indicator is simply any item of test gear that gives a visual or audible indication of the absolute or relative value of a monitored parameter (analogue and digital meters, audio/visual GO/NO-GO testers, and oscilloscopes, are examples of these).

A composite is any item of test gear that can directly carry out a complete test action and contains the equivalent of two or more individual items of test gear (L-C-R bridges and 'distortion' meters are classic examples of 'composite' test gear). A standard is any item of test gear that has such high precision that it can be used to calibrate or corroborate the accuracy of other items of test gear; precision voltage references, crystal frequency standards, and precision 'R' and 'C' substitution boxes and attenuation boxes are typical examples of these.

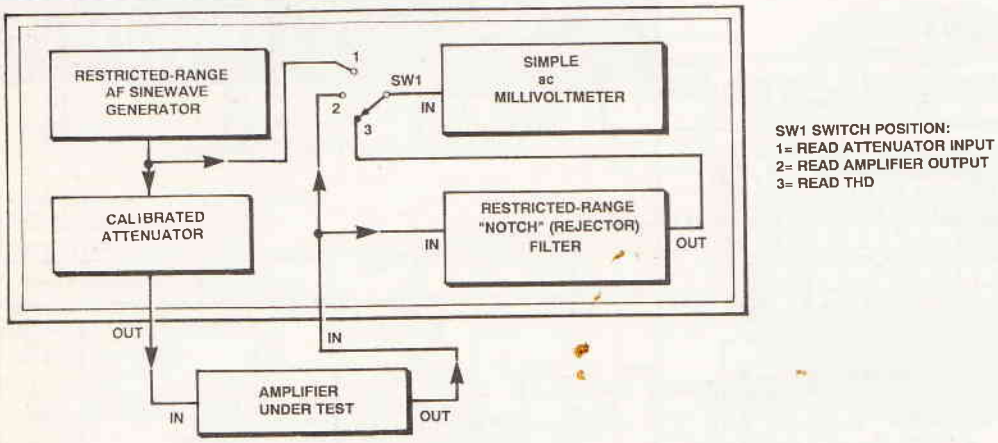

Fig.6 This amplifier-testing *SET* is made by permanently interconnecting a number of items of dedicated (industrial) test gear

The reader should also note that dedicated test sets are often far easier to use than temporary test rigs. Thus, to measure the dB voltage gain of an amplifier via the Figure 5 test rig, the sine-wave generator should be set to give (say) 1 volt output from the amplifier (read with SW1 in position '2'), and the amplifier input voltage must then be read (with SW1 in position '1') and the 'gain' value calculated from the difference between the two readings. This same measurement can be made via the Figure 6 test set by merely setting the attenuator input to 1 volt (read in SW1 position '1') and then adjusting the attenuator setting to give the same reading (in SW1 position '2') from the amplifier output, at which point the dB gain value can be read directly from the attenuator setting.

Test Gear To Buy Or Build?

The electronics amateur or the professional working on a low budget will, when wanting to acquire new instrumentation or test gear units, be faced with the question of whether to buy or build them? As a general rule, the following items are relatively easy and cost-effective to build and calibrate:-

Simple analogue and digital meters amd multi-range meters. Low frequency (up to 100 kHz) waveform generators of all types, including function generators and pulse generators. Simple RF generators. All types of power supply. Most dedicated or industrial types of test gear. L, C, and R bridges. Distortion-factor meters. All simple to medium complexity circuits.

As a general rule, the following items are either

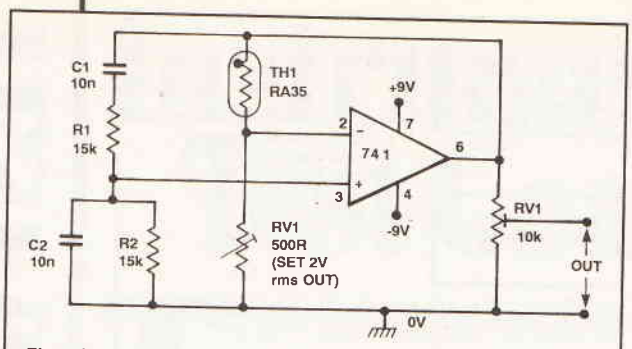

Fig.7 Simple 'industrial' 1 kHz Wien-Bridge sinewave generator

very difficult to build or to calibrate to an adequate standard, or are too expensive in terms of time or money (or both) to be worth the effort of building, unless you are an exceptionally ardent enthusiast:-

Wide-range analogue and digital multimeters (they are rarely cost-effective to build).

Wide-range 'laboratory standard' RF generators (the problem here is one of providing adequate RF screening and adequate calibration).

Modern laboratory oscilloscopes (another problem of cost effectiveness); note in this case that a good performance can be obtained from an old or second-hand model by up-dating it with home-built 'add-ons' such as trace doublers, calibrators, triggered time-bases, and probes, etc.

Before leaving this to build, or not to build theme, it may be of academic interest to note that it was quite normal in the 1950s, '60s and '70s for ordinary amateurs (including the author) to build all three of the above-mentioned types of test gear. Few of us had any alternative in those days; good commercial test gear was simply too expensive for us to buy. In the 1930s (so I am told) enthusiasts even built their own capacitors and resistors. Fortunately, time has marched on and things have, in the electronics world, changed for the better since then. It is now possible to buy excellent ready-built multimeters, RF generators, and 'scopes at a lower price than the do-it-yourselfer would have to pay for the component parts of those instruments.

Let's now move on and take a fairly detailed look at some of the various types of test gear that are available. The rest of this month's article deals with 'generators'. Next month's issue will deal with indicator, composite, and 'standards' types of test gear.

'Generator' Types

The following 'Generator' types of test gear are in common use:-

AF Sine-Wave Generators. These are designed to generate low-distortion (typically 0.1% at 1 kHz) low frequency (usually 20 Hz to 30 kHz) sine waves, and are normally based on a Wien bridge or Twin-T oscillator. Figure 7 shows an example of a thermistor-stabilised Wien-based design that can be used in fixed-frequency 'industrial' applications, and Figure 8 shows, in block diagram form, how a wide-range version of the oscillator can be used, in conjunction with a sine/square converter and a variable attenuator, to make a laboratory sine/square waveform generator.

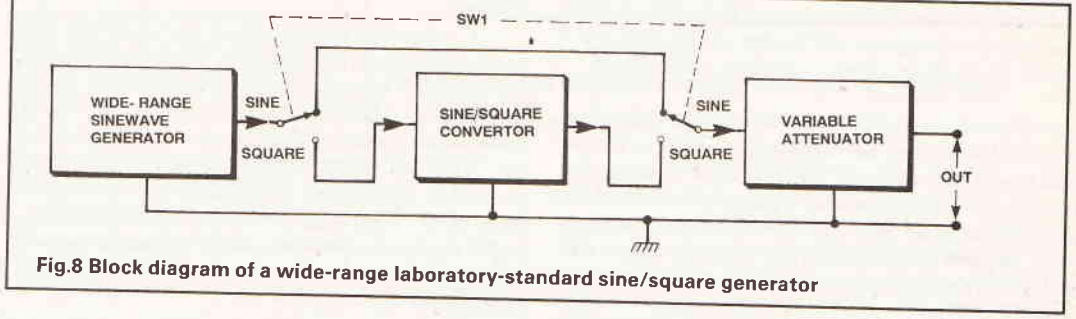

Fig.8 Block diagram of a wide-range laboratory-standard sine/square generator

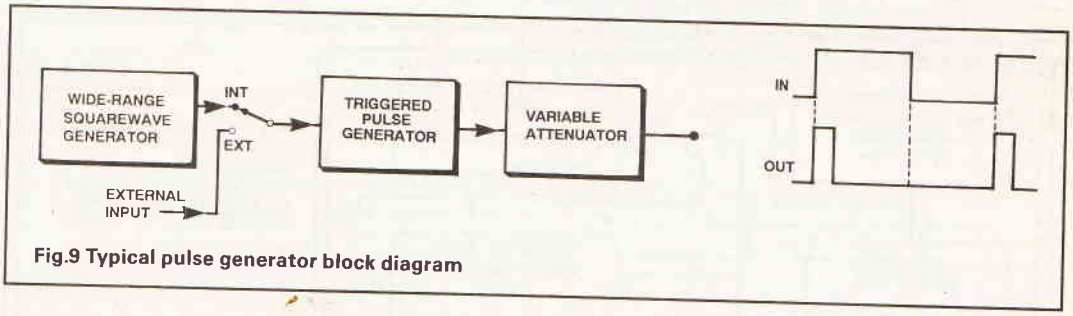

Fig.9 Typical pulse generator block diagram

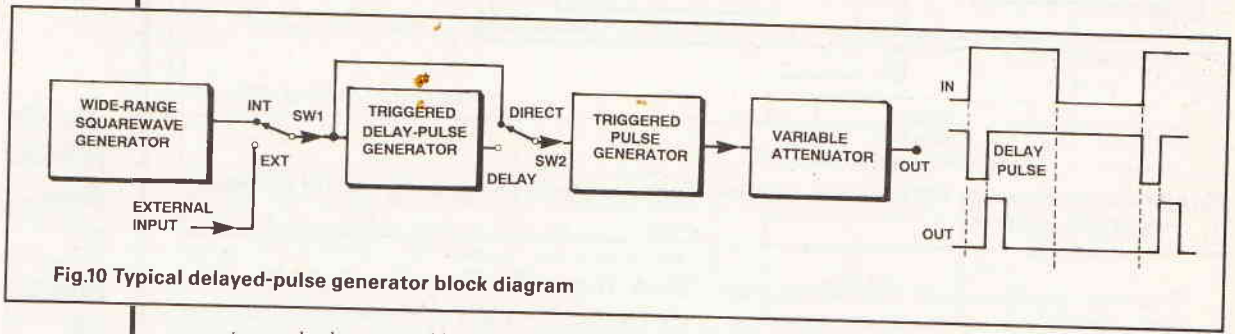

Fig.10 Typical delayed-pulse generator block diagram

LF Function Generators. These generate a basic 'triangle' waveform from which simultaneous sine and square waveforms are synthesised; typically, they can span the 1 Hz to 100 kHz range and their sine waves produce about 2% distortion at 1 kHz. Usually, the operating frequency can be controlled either resistively or via an external voltage, enabling the frequency to be

voltage-swept if required. Several companies produce dedicated 'function generator' ICs that enable a complete generator to be built from a single chip.

Pulse Generators. These produce an output pulse on the arrival of a suitable input trigger signal, which may be generated either internally or externally. Figure 9 shows the block diagram of a simple pulse generator that produces a single variable-width output pulse on the arrival of each rising edge of a rectangular input signal. Figure 10 shows a modified version of the above generator, in which the initiation of the output pulse can (when SW2 is set to the DELAY position) be delayed by a period equal to the width of the delay-pulse generator. Typically, both pulse widths can be varied from a fraction of a microsecond to hundreds of milliseconds.

RF Generators. These produce high-frequency sine wave outputs (of 100 kHz upwards), and usually have some type of modulation facility (AM and/or FM) and some means of varying the output signal amplitude; Figures 3 and 4 show (in block diagram form) examples of laboratory and industrial (dedicated) RF Generators.

Stabilised Power Supplies. These generate a mains (AC power line) derived DC supply in which the output voltage remains constant in spite of wide variations in load current. Modern versions of these are usually based on one or more dedicated 'voltage regulator' ICs. Industrial versions of such a PSU (power supply unit) usually consist of little more than a transformer-rectifier-capacitor AC/DC converter and a fixed-value voltage regulator IC, as shown in Figure 11. Laboratory-type PSU's are more complex, and include a variable-voltage regulator IC, overload protection circuitry, and an output voltage monitor (see Figure 12).

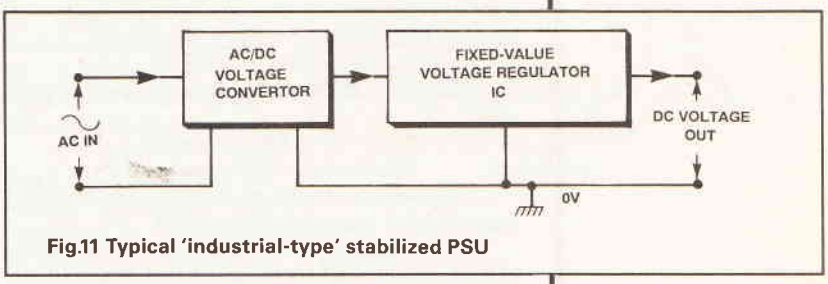

Fig.11 Typical 'industrial-type' stabilized PSU

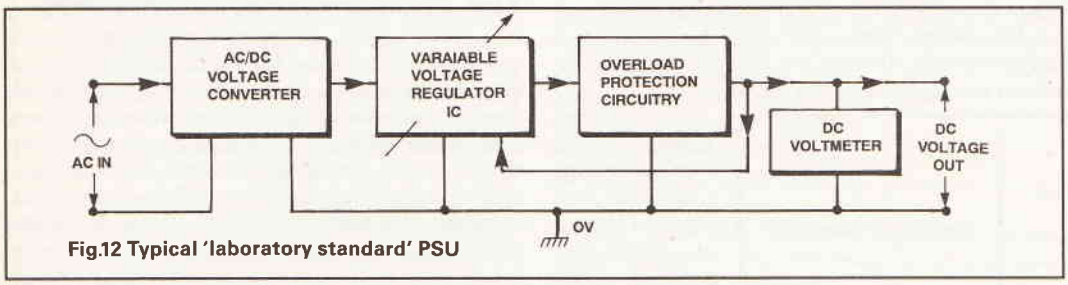

Fig.12 Typical 'laboratory standard' PSU

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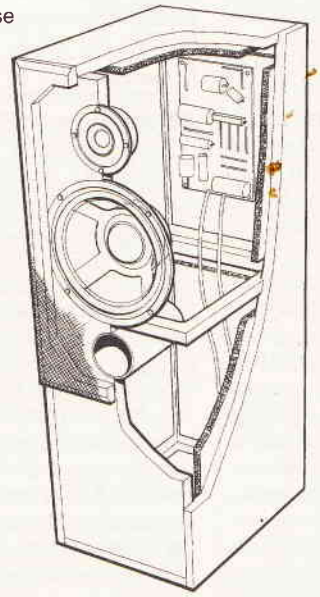

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Waves And Particles

A. P. Stephenson unravels some of the mysteries of electro-magnetic radiation.

Electro-magnetic waves

An electro-magnetic wave is a disturbance in free space travelling at a constant velocity (c) which, according to the teachings of contemporary physicists, has the distinction of being the ultimate velocity in the universe. In a vacuum, it has been measured to the following nine significant digits:

$$c = 2.99792458 \times 10^8 \text{ metres/sec}$$

Mercifully, rounded figures are usually acceptable:

$$c = (3 \times 10^8) \text{ metres/sec}$$

or 186 thousand miles per second

The velocity decreases slightly when travelling through other non-conducting media.

The value of c is usually referred to as the velocity of light but this can be misleading. Light certainly travels at this velocity but so do radio and television signals, infra-red and ultra-violet rays, X rays, gamma rays and cosmic rays. All these are examples of EM waves, alike in all respects except frequency.

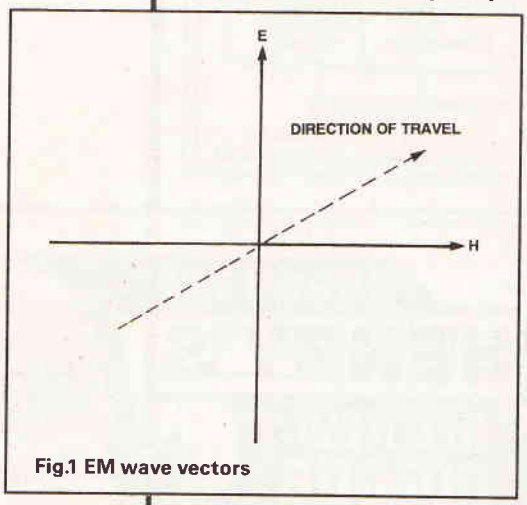

Fig.1 EM wave vectors

In 1864, James Clerk Maxwell, the first Cavendish Professor of Physics at Cambridge, supplied the scientific community with some rather awesome looking differential equations. I have never quite understood them myself but readers familiar with curls and other esoteric symbols would readily accept that they provide adequate descriptions of the essential properties of EM waves. Experimental verification was left to a German professor of physics, Heinrich Hertz who, in 1887, demonstrated the existence of Hertzian Waves as they were called before radio waves become popular.

Structure Of EM Waves

An electromagnetic wave consists of an electric field (E) and a magnetic field (H) at right angles to each other and travelling in a direction at right angles to both fields. The amplitude of the fields vary sinusoidally in phase as they travel through space. It is important to realise that it is just not possible to generate a non sinusoidal EM wave! Electronic circuits are constantly churning out wierd looking waveforms but they are not EM waves. For example, a speech modulated carrier, as viewed on an oscilloscope, is quite clearly non-sinusoidal but when such a wave is finally 'flicked' off an aerial system into space it undergoes a strange metamorphosis. The single complicated wave rearranges itself into a number of separate pure sinusoidal components, which the telecommunication professions describe as the carrier and sidebands.

Wavelength (λ)

As an EM wave of frequency (f) is travelling through space it varies sinusoidally in amplitude so it is possible to consider the concept of wavelength as the distance apart of two consecutive amplitude peaks (or indeed, two consecutive amplitude troughs). Since the velocity is (c) the wavelength is given by:

$$\lambda = c/f$$

Examples: The wavelength of a 200 MHz EM radiation is $(3 \times 10^8)/(2 \times 10^8) = 1.5$ metres.

Very high frequencies have very short wavelengths so the following submultiples are in use:

1 nanometre = 10^{-9} metre

1 Angstrom unit = 10^{-10} metre

(Most atoms are about one Angstrom unit in diameter.)

The electro-magnetic spectrum

In terms of radiation frequency, the spectrum extends over an enormous range from about 100 Hz (very low frequency radio waves) to at least 10^{23} (gamma rays). Cosmic rays, which originate from outer space have even higher frequencies. Certain bands within this range have, for descriptive purposes only, been given arbitrary names but, as shown in Table 1, the band limits are vague with considerable overlap. The width of the visible light band is too narrow to distinguish because of the scaling. It extends from red (4.29×10^{14} Hz) to violet (7.5×10^{14} Hz).

Table 1

Band name	Frequencies (Hz)	Wavelength (metres)
Radio waves	$10^2 - 10^{12}$	$10^7 - 10^{-3}$
Infrared	$10^{12} - 10^{14}$	$10^{-3} - 10^{-5}$
Light	$10^{14} - 10^{14}$	$10^{-6} - 10^{-6}$
Ultraviolet	$10^{14} - 10^{16}$	$10^{-6} - 10^{-8}$
X rays	$10^{15} - 10^{20}$	$10^{-7} - 10^{-12}$
Gamma rays	$10^{18} - 10^{23}$	$10^{-10} - 10^{-15}$

How is an EM wave produced?

Simple – just rig up a high frequency electrical oscillator! True of course but a superficial truth because there are many other ways. The following statement, although less informative, is concise and all-embracing:

> AN ELECTRO-MAGNETIC WAVE IS 'FLICKED' OFF INTO SPACE WHENEVER AN ELECTRIC CHARGE UNDERGOES ACCELERATION.

For example, bearing in mind that a DC current passing along a wire is a movement of charged particles, we might ask whether such a current produces radiation? If we assume that the current is steady, at say ten amps, then, although the electrons are travelling along the wire, their mean velocity is constant so there can be no acceleration and therefore no EM radiation. However, at the instant of switching on, or indeed switching off the current, the charges undergo acceleration, resulting in a burst of undisciplined EM waves. The reason for branding it undisciplined is of interest because it tends to emphasise the earlier remark that non-sinusoidal EM waves are impossible and also because it provides an excuse to make a few

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brief references to the brain-child of a learned gentleman by the name of Fourier.

The Fourier components

Early in the 19th century, Fourier showed that any non-sinusoidal waveform could be considered as a jumble of pure sinewaves of different frequencies and bearing certain amplitude ratios to each other. For example, a symetrical rectangular wave can easily be shown to consist of a parent sinewave called the fundamental plus a series of sinewaves of frequencies which are odd multiples of this fundamental and called the harmonic components. The instantaneous voltage equation (v) of such a wave has this appearance:

$$v = V \sin wt + V/3 \sin 3wt + V/5 \sin 5wt + \ldots$$

The first term is the fundamental of peak amplitude V. The second term is the third harmonic having 1/3rd the amplitude and three times the frequency. The third is the fifth harmonic having 1/5th the amplitude and five times the frequency. The higher order terms, which in theory extend to infinity, follow the same kind or progression. Thus the tenth harmonic is 1/10 the amplitude and 10 times the frequency.

As a numerical example, a 100 Hz rectangular wave can be thought of as a collection of sinewaves containing a 100 Hz fundamental plus sinewaves of 300, 500, 700, 900, . . . up to infinity. Figure 2 shows a fundamental plus only three of the harmonics but they are sufficient to show that the envelope is developing that characteristic rectangular appearance. Adding more harmonics would make the sides steeper and tops flatter.

Any other waveform can be synthesised by a suitable combination of harmonics. A triangular wave, for example, can be shown to be made up from predominantly even numbered harmonics.

We can return now to the question of our undisciplined wave which results when a steady current is suddenly switched on. Since the current attempts to rise instantaneously it represents the first edge of a square wave which, according to Fourier, is equivalent to a vast jumble of frequencies. Since such a rise represents a sudden acceleration of charges, a motley collection of separate EM waves are hurled off into space. The energy lost from the circuit in this way will normally only represent a tiny fraction of the total and even this will dissappear entirely after the current has settled down to steady state conditions.

Nevertheless, the initial transient disturbance may still be sufficient to produce annoying clicks in radio receivers when some quite unrelated piece of equipment is switched on. Although the receiver may be tuned to a narrow band of desired frequencies there is a high probability that some of the harmonics 'gate crash' their way in. The same things will happen when the circuit in question is switched off because charges suddenly stopped are also subjected to acceleration — negative acceleration is still acceleration within the meaning of the EM radiation law.

Perhaps it is worth recalling at this stage that currents can rise quickly but never instantaneously. This is because there are always traces of unwanted capacitance and inductance lurking around in the hidden recesses of the circuit. This is fortunate in a way for our peace of mind because taking Fourier to the limits, an instantaneous rise would cause the emission of X rays, gamma rays and possible other malevolent components of the EM spectrum. Nature can sometimes display surprising tenderness.

Alternating current behaviour

A circuit carrying alternating current is a different proposition because the current is continually changing so the charges must be in a state of continuous acceleration and therefore radiating. Even the 50 Hz main supply lines are radiating EM waves but, fortunately, the radiation is unlikely to produce interference. The distance which a wave can travel depends on many factors but one of them must clearly be the frequency — the higher the frequency, the greater is the acceleration of charges so it should not be surprising that 50 Hz AC mains occupy a low-status position in the EM spectrum.

Kinetic Energy

A car travelling at high speed has quite a lot of kinetic energy. If it comes to a dead stop due, say, to the sudden appearance of a reinforced concrete wall, the Conservation of Energy law demands that the kinetic energy it had before impact is duly accounted for. Not wishing to offend the law, the car changes shape, the anatomy of the occupants (if any) rearrange themselves and the temperature of both car and concrete increases.

Fast moving charged particles, such as electrons in an oscilloscope beam also obey the same conservation law so, when they finally impact on the screen, the kinetic energy must be accounted for. Some of it will be transformed into heat and some into EM radiation. To estimate the frequency of the radiation it is first necessary to calculate the energies involved.

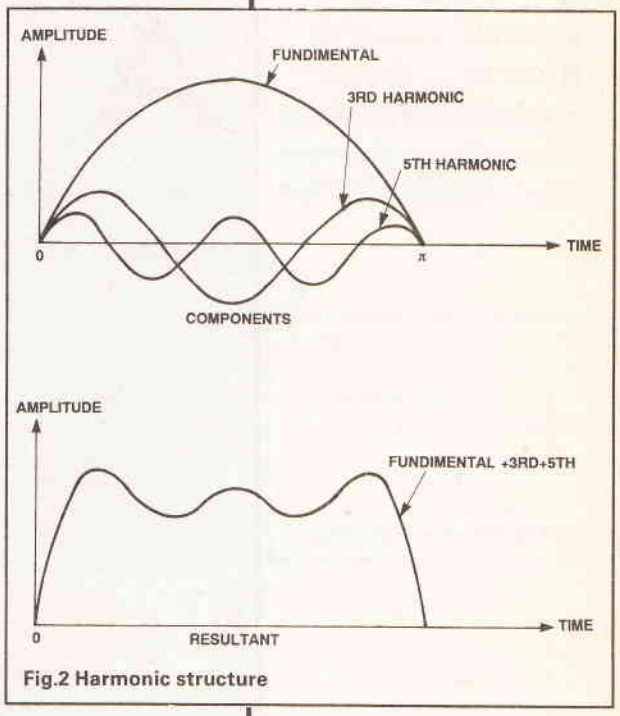


Fig.2 Harmonic structure

Potential And Kinetic Energy

Consider first the passage of an individual electron in a thermionic diode from the time it leaves the heated cathode until it hits the anode held at voltage V (see Figure 3). At the instant of leaving the cathode, the electron has, by virtue of the anode attraction, potential energy (Wp), given by:

$$Wp = qV$$

where the electron charge (q) = (1.6×10^{-19}) coulomb and V = anode voltage. By the conservation law, it follows that kinetic energy at the moment of impact must be the same so,

$$Wp = Wk = qV$$

This is all very nice but remember our prime object is to find the frequency of the EM wave resulting from the electron's impact. All we have achieved at the moment is the electron energy. To proceed any further we must delve a little into some particle physics.

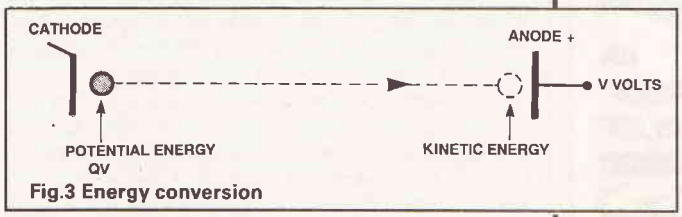


Fig.3 Energy conversion

Quanta

The quantum theory, first suggested by Max Plank in 1901 and later taken up by Einstein, shattered the cosy world of classical physics. Apparently EM waves are not quite so simple as originally thought. They have a

tendency towards schizophrenia, never being quite sure whether they should behave as wave functions or discrete particles called photons.

Max Planck suggested that energy interchanges can only take place in small discrete steps called quanta. Thus it is not possible to increase the energy in a system unless at least one quantum is added, – a half or any other fraction will have no effect! As Figure 4 shows, energy exchanges are step-like instead of a smooth ramp. (If a climber is too weak to lift himself to the next step he stays where is is.)

The quantum theory was a major breakthrough in the understanding of atomic structure although, as far as everyday experience is concerned, it has little relevance because the size of individual quanta is too small to be noticed. The actual size is governed by a strange number which, although ridiculously small, is fundamental to the whole theory. It is known as Planck's Constant (h) which, to three figure accuracy is:

$$h = 6.63 \times 10^{-34}\ Js$$

The almost earth-shattering contribution which we have inherited from the quantum theory has been a disarmingly simple equation which connects quantum energy (W) and frequency (f):

$$W = hf$$

For example, armed with this equation we can now find the frequency of the EM wave emitted when an electron of charge (q) strikes an anode held at voltage (V). Remembering that the impact energy was given by W = qV we can equate this to W = hf as follows:

$$hf = qV$$

so, $$f = qV/h \qquad \text{(Equation 1)}$$

Example: A typical 26 inch TV employs an EHT voltage in the order of 25 kilovolts. Plugging this value into Equation 1,

$$f = \frac{(1.6 \times 10^{-19}) \times (25 \times 10^{3})}{(6.63 \times 10^{-34})}$$

so $f = 6 \times 10^{18}$Hz
or $f = 6 \times 10^{9}$ GHz
or f = 6,000 million gigahertz

This is some frequency! In fact, by referring back to Table 1, it falls in about the middle of the X ray band.

Wavelength = c/f, which sets the corresponding wavelength of the rays generated by the TV tube at 5×10^{-11} or 0.1 Angstrom.

The Electron Microscope

An ordinary optical microscope can not resolve objects smaller than the wavelength of light however much the magnification is increased. Light wavelengths are somewhere around 5,000 Angstroms, depending on the colour so it is clear that an electron microscope using the same voltage as our 26 inch TV could resolve objects several thousand times smaller than the best optical version.

The Electron Volt

When dealing with the physics of the electron it is sometimes convenient to replace the standard SI unit of energy (the Joule) by the 'electron volt':

An electron volt is the energy needed to move an electron against a potential gradient of one volt.

Since W = qV and the charge on a single electron is 1.59×10^{-19} coulombs it follows that the electron volt = 1.6×10^{-19} joules.

Boltzman's Constant

The molecules in a substance are continually scurrying around in a random fashion which depends on the absolute temperature. It would be neither practical or worthwhile to calculate the vibration energy in a particular molecule but it is possible, with the aid of Boltzman's constant (k), to arrive at an average value. It is one of the fundamental constants in physics and its value has been calculated to nine figure accuracy. However to three figures, the value is:

$$k = 1.38 \times 10^{-23}\ JK^{-1}$$

With the help of this constant, the average vibration energy in a body can be found by the equation:

$$W = kt$$

where t is temperature in degrees Kelvin (Zero Kelvin is -273 degrees Celcius).

Some of the energy in a heated body is flicked off in the form of EM waves. These frequencies can be found by equating the vibration energy (kt) to the photon energy (hf):

$$hf = kt$$

so, $$f = kt/h$$

Example: Assume that on one of those rare hot summers days the ground temperature happens to be 27°C. By a fortunate 'coincidence', this turns out to be exactly 300° Kelvin so we can use the equation above to estimate the EM wave shooting up from the ground:

$$f = \frac{(1.38 \times 10^{-23}) \times (3 \times 10^{2})}{(6.62 \times 10^{-34})}$$

This reduces to 6.25×10^{12}. Consulting Table 1 reveals that such a frequency falls within the infrared band.

In contrast, the temperature at the surface of the sun is said to be about 6,000 degrees which, as a similar calculation would show, places the frequency within the visible lightband.

Matter waves

Physicists are no longer surprised when someone finds that a certain phenomenen also works in reverse. Not long after Planck and Einstein shocked the scientific establishment by declaring that waves can also behave as particles, a French methematician by the name of De Broglie declared in 1924 that particles in motion can also behave as waves. It was not idle talk because he offered an equation (subsequently proved experimentally) to substantiate his claims. De Broglie's matter waves, as they are now called, have a wavelength inversely proportion to the momentum (p) of the particle given by:

$$\lambda = h/p$$

Since p = mass × velocity, we can write:

$$\lambda = h/(mu)$$

where m = mass and u = the velocity of a moving particle.

We can try out this equation on one of the electrons in the beam of the 25 kV tube discussed earlier but a little more juggling is needed to calculate the impact velocity (u). Fortunately, $W = mu^2/2$ is a standard relation for kinetic energy so it can be equated to the potential energy (qV). The mass (m) of the electron is no problem because it is one of the universal constants and is approximately equal to 9.1×10^{-31}. Armed with these facts the rest is easy:

$$mu^2/2 = qV$$

so $$u = \sqrt{2qV/m}$$

Plugging in V at 25kV and the constants for electron mass and charge, the impact velocity turns out to be 9.4×10^{7} metres/sec. According to De Broglie, $\lambda = h/mu$ so:

$$\lambda = \frac{6.6 \times 10^{-34}}{(9.1 \times 10^{-31}) \times (9.4 \times 10^{7})}$$

$$= 7.7 \times 10^{-12}\ \text{metres}$$

So the electron, at the moment of impact has a matter wavelength of 0.077 Angstrom. It is worth noting that this value is considerably shorter than the 0.5 Angstrom value for the photon impact energy which was calculated earlier.

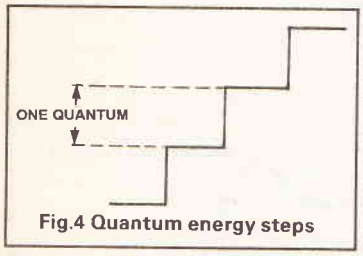


Fig.4 Quantum energy steps

ENERGY

Switched Mode Power Supply

Andrew Armstrong presents an alternative variable voltage supply.

I bought a second hand keyboard without a power supply. After the third set of batteries I decided that a mains power adaptor would be an asset. What was irritating was that I already had several power packs for different appliances, but none of them was suitable for the keyboard. Rather than buy or build another supply with only one application, I decided to build a universal one.

As a universal power supply, it needed switched output voltages, covering the range normally required for small gadgets, and a multiple output plug to fit as many sockets as possible. It was also necessary for the output polarity to be reversible, because there is no standard polarity for appliances that use external mains power adaptors.

The output connector requirement was easily solved by using a universal power plug from Maplin, which includes a reversing connector. The switched output voltage was also straightforward in principle: a selector switch, a range of suitable resistors, and a programmable voltage regulator such as the LM317.

The wide range of output voltages involved makes the use of a linear regulator less attractive, however. To provide a 12V regulated output, a 15V transformer is required. When supplying a 3V load drawing 200mA, the dissipation in the regulator will exceed 2W, while the power delivered to the load will only be 0.6W. This would be tolerable, but the power supply could get hot enough to cause unreliability if buried under, say, a pile of papers for a while.

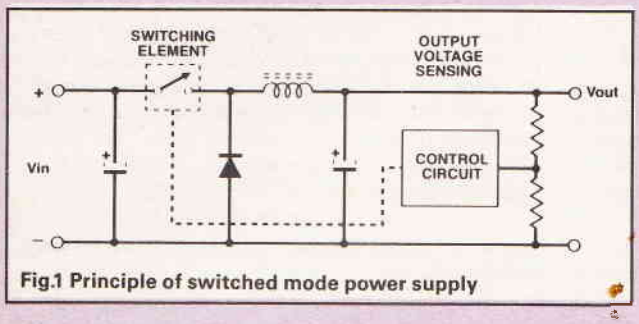


Fig.1 Principle of switched mode power supply

It is not too complicated to build a switched mode voltage regulator, and this solves the problems of efficiency and heat dissipation elegantly. Perhaps the most widely known switched mode regulator IC is the 78S40, and it was this which I decided to use.

The principle of the switched mode power supply is illustrated in Figure 1. In a simple implementation, the control circuitry senses the output voltage of the supply and, if it is too low, turns on the switch. The output voltage starts to rise, and after a short time it overshoots the aiming voltage. The control circuit then turns off the switch. When the switch is on, the current in the inductor rises approximately linearly (assuming its resistance is low) at a rate given by the formula:

$$\frac{dI}{dt} = \frac{(V1-V2)}{L}$$

When the switch is off, the inductor current falls. The rate of fall is again determined by the voltage across it. The left hand end is at minus one diode drop, while the output is still at the output voltage (ignoring the output ripple).

The interesting fact about all this is that the switch does not dissipate power when it is on, nor when it is off. Linear regulators dissipate power according to the difference between input and output voltages, while switched mode supplies only dissipate as a result of irreducible imperfections in the switching devices. Losses in the series switching element and the diode are caused by voltage drops while conducting, and by the finite switching time. During the switching action, the peak power dissipation can be substantial, but because the switching action only occupies a tiny part of the overall cycle time, the average dissipation is low.

This puts a limit on the switching frequency. If too high a frequency is used, the switching time will no longer be insignificant. Clearly, the required switching frequency for any application depends on the allowable output ripple, and the rate of rise and fall of current in the inductor. Larger values of inductor permit lower switching frequencies while maintaining any given output ripple.

The 78S40 uses a slightly more sophisticated version of the control system detailed above. In addition it incorporates an internal oscillator to control switching times, and a current limiter.

The 78S40 also includes a voltage reference, a comparator to compare the output voltage with the reference voltage, an op- amp, output switching transistors, and a Schottky diode. This design does not use either the op-amp or the internal Schottky diode. An external diode is used instead, as shown in Figure 2, in

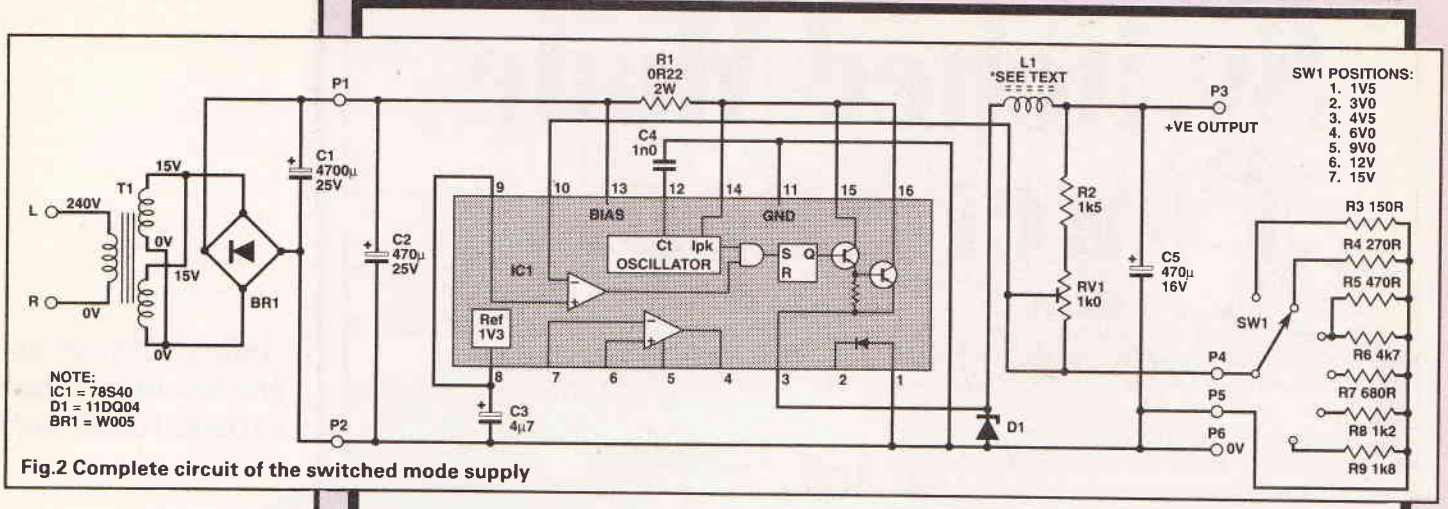


Fig.2 Complete circuit of the switched mode supply

HOW IT WORKS

Starting at the mains input, the mains transformer reduces mains voltage to 15V AC, while providing isolation. The AC output from the transformer is rectified to give approximately 18V (on load) on the reservoir capacitors C1 and C2.

The main reservoir is provided by an external capacitor, but a substantial local decoupling capacitor on the PCB is provided to prevent the high peak switching currents from upsetting the operation of the internal circuitry of the 78S40. The fast high current switching waveforms in switched mode power supplies can cause substantial voltage spikes on the power connection, if it has significant resistance or inductance.

As a further means of preventing voltage spikes from affecting the accuracy of control, the voltage reference is decoupled. This has been found by experiment to be beneficial, though it is not listed in all application notes.

Inside the 78S40 is an oscillator, whose operating frequency is set by an external capacitor. This is illustrated in the circuit diagram, Figure 2.

The capacitor sets the minimum off time of the switching transistors. In this design, a time of 2µs is chosen. In operation, however, actual off times of 10 to 20µs are observed. The reason for the short time is to allow other circuit considerations to control the off time in most circumstances. The current in the inductor does not decline to zero, so that the DC output current which can be drawn is more than half the peak current. This is illustrated in Figure 4.

Once per cycle the oscillator switches on the output transistors, unless the output voltage is too high. When the transistors have been switched on they remain on until one of three things occurs: either the current in R1 rises high enough to drop 330mV across the resistor, or the output voltage rises above its aiming point, or the oscillator circuit times out.

While the output transistors contained in the 78S40 are on, the current in L1 ramps up. While they are off, the current ramps down. At medium to high load currents, the current fed to the output capacitor never falls to zero, and in any case it never stops and starts abruptly. This limits the output ripple to some extent.

order to permit a slightly higher output current. Had an even higher output current been required, it would have been possible to use an external switching transistor, but that was not necessary in this design.

The current limiting resistor is chosen to give a nominal peak current of 1.5A. The average output current will be considerably less than the peak current, and will depend to some extent upon voltage tolerances on the 78S40. The peak current achieved in practice will be less than the theoretical figure, because a wire-wound resistor is used for R1, and the inductance of this resistor will give a higher peak voltage while the current is changing. Practical output currents achievable at lower voltage settings may be in the region of 800 mA.

Though the internal Schottky diode is not used, one side of it is connected to the substrate, and should be grounded. In applications requiring a lower output current, D1 may be omitted, and a wire link connected between pins 1 and 3 of IC1 to make use of the internal diode.

The output smoothing capacitor is of a higher value than theory might suggest is required. Because of the spiky nature of the ripple current in a switched mode power supply, the esr (equivalent series resistance) and esl (equivalent series inductance) of the smoothing capacitor affects the quality of the output. Because of the wound foil construction of electrolytic capacitors, not all of the capacitance is effective at high frequencies. In larger value capacitors, there is generally capacitance available to decouple high frequency signals, even if a smaller proportion of the total capacitance is available. Experiment has shown that the value chosen provides a fairly clean output.

Measured ripple at 9V with a 500mA load on the PCB model was 10mV pk-pk on a 10MHz bandwidth. On 100MHz bandwidth there was a series of 20ns 60mV pk-pk rings dying away in 100ns, followed by two 40mV rings over the next 200ns, occurring at the switching frequency.

If it is desired to remove this very high frequency disturbance, a filter as shown in Figure 3 may be used.

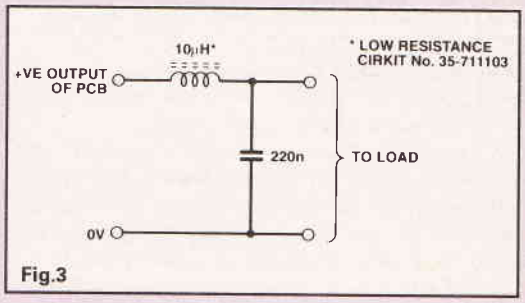
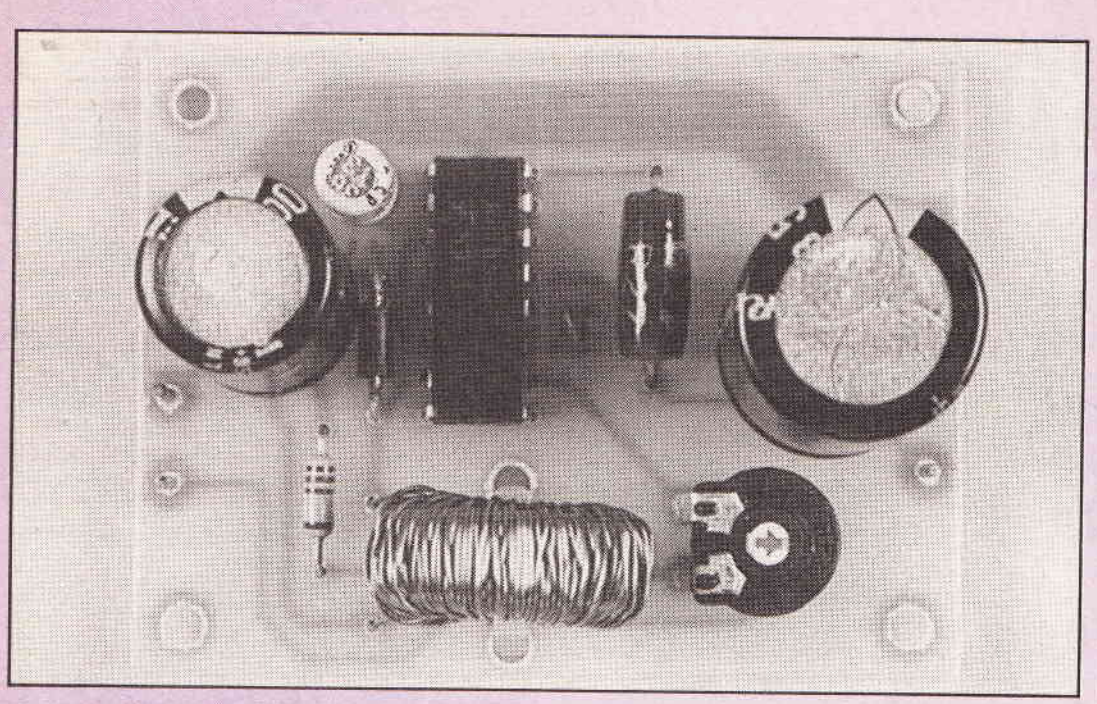


Fig.3

The components of this filter can be supported on the output pads of the PCB.

Output voltage selection is by means of resistors mounted on a selector switch. A break-before-make switch should be used, and the circuit is so designed that it produces its minimum output voltage (1.3V) when no external resistance is present. This avoids the possibility of brief output excursions to maximum voltage as the switch is operated. The output voltage can be calibrated by means of RV1, and it is recommended that it is adjusted to minimise the maximum percentage error on any output voltage.

PROJECT



Layout

After the comments about esr and esl, it should not surprise anyone that the PCB layout is critical to the correct operation of a switched mode power supply. The layout shown here minimises the resistance of the 0V track, while referring output voltage measurement to the output rather than to the input side of the circuit. Other power supply track lengths are also minimised.

It is recommended that the PCB should be used to build this project, but experienced constructors should be able to make a Veroboard layout work properly. The prototype was built on Veroboard, and worked quite adequately once a pair of tracks were connected in parallel for the 0V.

Construction

Assembling the PCB should present few problems. It is worth remembering, however, to drill out the mounting holes and the holes for the tyrap which retains the inductor if necessary before mounting any components.

A toroidal switching inductor is used. It may be made by winding 70 turns of 0.5mm diameter wire onto a T94-40 iron dust core, available from Cirkit. It should be firmly fixed to the PCB by means of a tyrap or several turns of lacing cord, tied tightly. Only when the inductor cannot move on the PCB should its connections be soldered. This avoids straining already soldered joints.

The power supply is intended to fit into an aluminium box 102x70x64mm, available from Maplin (order code LH10L). The transformer, a 6VA chassis mounting type, must be mounted diagonally across one end of the case. The printed circuit board is bolted to the other end. The reservoir capacitor should be mounted with a p-clip or with double sided adhesive pads to the base of the box, with the bridge rectifier supported on its wires from the transformer or from the capacitor, whichever is more convenient.

Do not forget to sleeve any long uninsulated leads, and make sure that the mains connections are insulated. Fit a solder tag to one of the transformer mounting bolts, and make sure that the mains earth is connected securely to this. This connection must not be under stress, and should be arranged so that, if the mains wire is pulled out of the case, the live connection will break first.

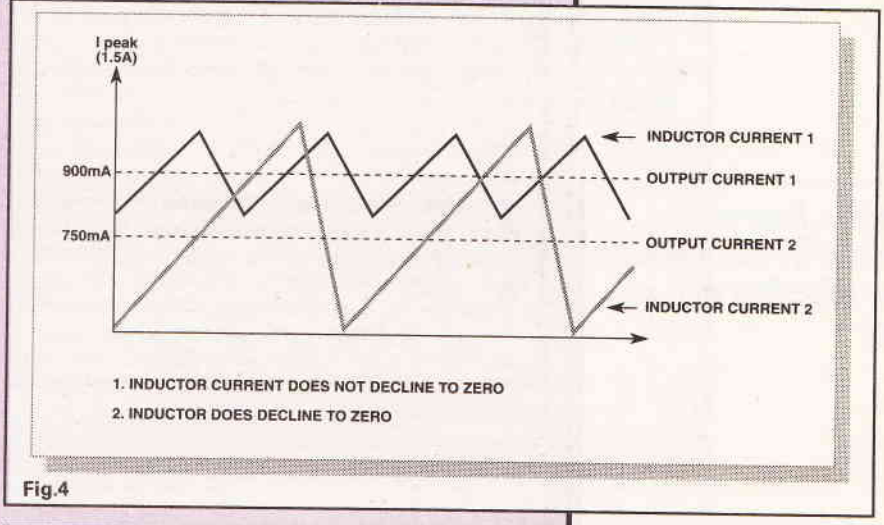


Fig.4

PARTS LIST

RESISTOR

R1	0R22 2W (wirewound is acceptable)
R2	1k5 5% 1/4W
R3	150R
R4	270R
R5	470R
R6	4k7
R7	680R
R8	1k2
R9	1k8
RV1	1k preset

CAPACITORS

C1	4700µ 25V can electrolytic.
C2	470µ 25V radial electrolytic 0.3" pin spacing.
C3	4µ7 16V radial electrolytic 0.1" pin spacing.
C4	1n ceramic 0.1" pin spacing.
C5	470µ 16V electrolytic 0.2" pin spacing.

SEMICONDUCTORS

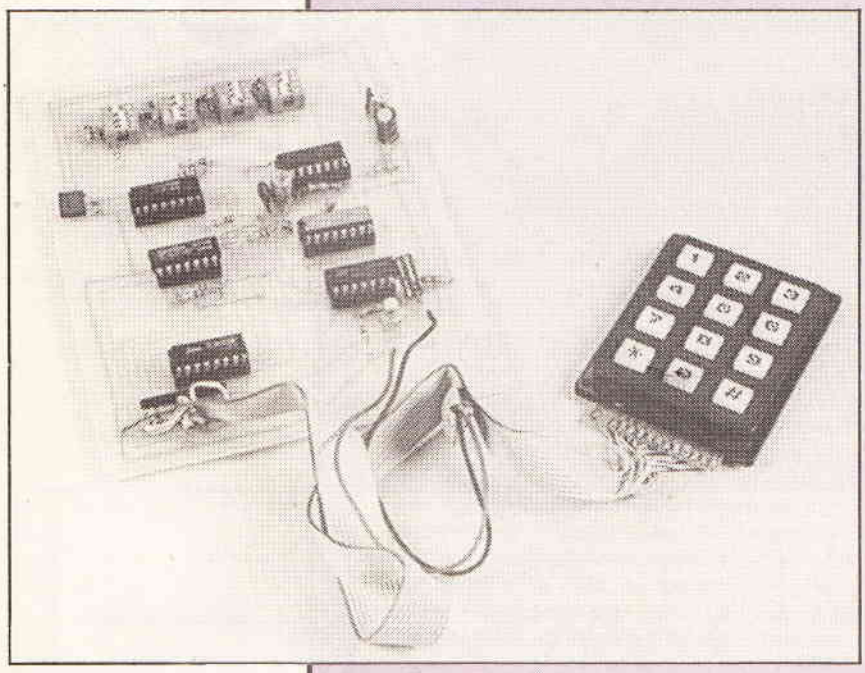
D1	11DQ04 or similar Schottky diode
IC1	78S40
BR1	W005 or similar 1A bridge rectifier.

MISCELLANEOUS

L1	300µH toroidal inductor. Maplin inductor stock no JL73Q OR 70 turns on Cirkit core stock no 55-09440
SW1	6 way rotary switch
TR1	15V 6VA transformer eg Maplin order code WB15R
Case	102x70x64mm aluminium box, eg Maplin order code LH10L

Multi power plug eg Maplin order code HH38R
PCB
Mains lead, wire, solder, M3 nuts bolts and washers

Digital Code Lock



Edward Barrow provides a circuit to keep your valuables in a safe place.

One of the main boom areas of the small scale side of the electronics industry in recent times has been the security sector. Companies seem to offer a profuse number of designs utilising many different and novel sensors in various combinations. But these usually come in sealed boxes with little chance of interfacing or modification. What is lacking is the ability to tailor designs without boring a large hole in your pocket. For example if you wanted a code lock for some purpose other than front door locks, say for argument sake you wanted to code lock your drinks cabinet from your adolescent son, the large code locks for doors are virtually useless.

This project fills this gap in the market, being both easily understandable and adaptable. To enter the required four number code a keypad is used with the standard 0 to 9 range. After checking the sequence of the four numbers an electrical signal is generated that can drive a relay or solenoid or similar mechanical device. The code is held internally in binary format in an array of 4-way DIL switch packages, thus allowing the code to be changed by someone with less than an expert knowledge of binary. It is the electronic nature of the output signal that allows it to be used in many situations. This output pulse lasts for about 3 seconds, which is only common sense, only allowing access for this period, more about that later.

The schematic diagram in Figure 1 along with a sequential diagram in Figure 2 are both helpful in understanding the going's on. A simple keypad is used to enter data to the unit. The type used here has separate outputs for each key and a single common input which is held high. Binary coded or matrix type keypads cannot be used with this design, which is good as these are usually more expensive. To make the information usable in the digital realm, it must be converted into a binary number. This is done by a device called a priority encoder, which as the word 'priority' suggests has the added benefit that it can cope with two or more keys being pressed at once by giving only the higher of the two.

To give meaning to the order in which the keys are pressed a decimal Johnson counter is incremented every time a key is pressed and after four are recorded

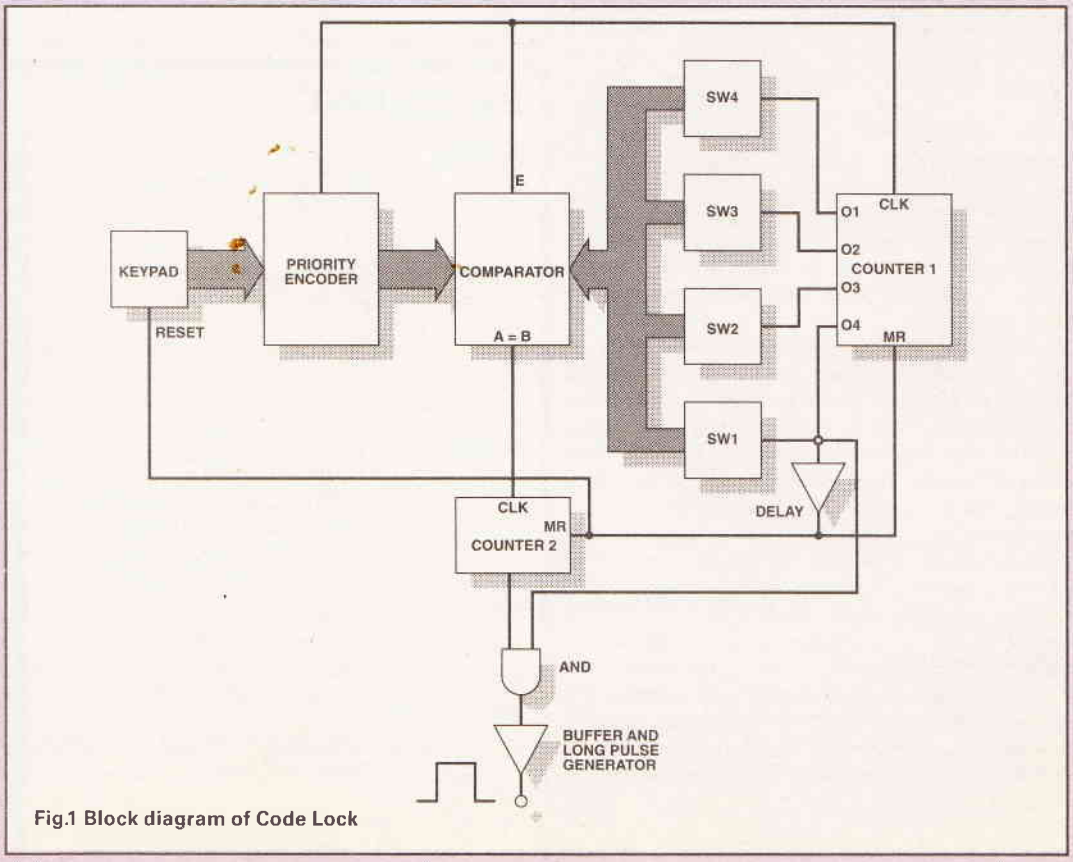


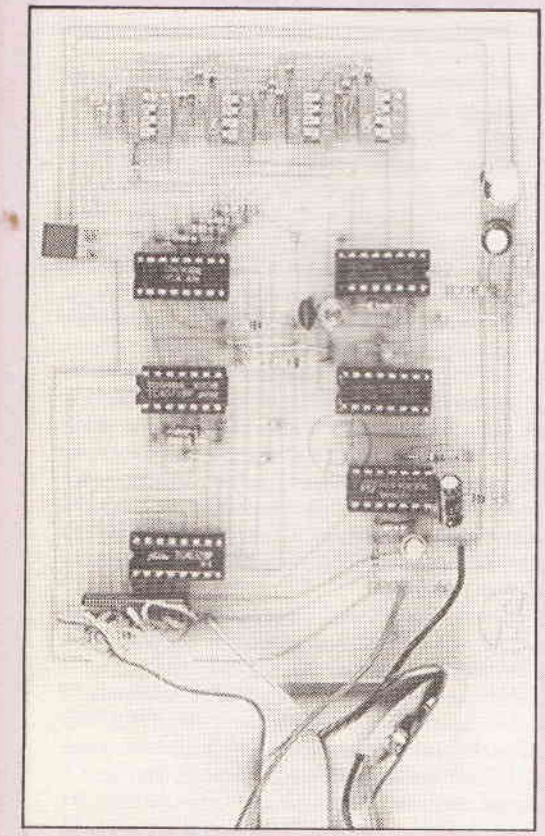
Fig.1 Block diagram of Code Lock

PROJECT

the counter is automatically reset to zero. An overriding reset key is incorporated on the keypad to allow the user to know exactly where in the program cycle he is and so have full control. The output of this Johnson counter fulfils another purpose of acting as a multiplexer for the stored numbers. In doing this it selects the correct stored number to correspond with the entered number. The set numbers being held in an array of 4 quad DIL switches. As only one of them is selected at any one time they can be overlapped, with a total of only 4 binary output lines.

Comparison of the two numbers, (the output of the priority encoder and the selected stored number), is carried out by a 4-bit digital comparitor. The three possibilities of these numbers, A greater than B, A less than B, and A equal B, are all catered for. We are only interested here in the A=B case, which is active high. When this case is reached a positive pulse is generated by this output, which is connected to another Johnson counter. This is the counter that gives the go ahead for the door to open or what ever function has to be preformed. It's sole job is to see if four pulses are generated in sequence, something that can only happen if the person pressing the keys is in the know or is extremely lucky. So as to prevent any flukes the same reset line is used for both counters, so after four numbers this counter is also reset. If this was not the case, it would be possible to gain entry by just pressing a amount of numbers, if any of them were correct the counter would increment, four pulses later, and bingo.

When the go ahead is given a pulse is transmitted to a transistor, which performs the task of a high current switch, opening doors closing doors, setting off alarms or what ever.



Construction

As always solder in all link wires first. Then resistors, diodes and other bits that lay flat. Do not forget about polarities when soldering in the diodes. Note that for R1-R8 a SIL package was used to be neat and trendy, but these only come in packages of 8 and not 10 (annoying binary again). So the other two tie down resistors R9 and R10 are of the normal 1/4 watt variety. IC sockets should be used and can also be used for the switches if you think they look decorative. Take the usual CMOS precautions with all the chips. Lastly solder in the capacitors and solitary transistor. I suggest you use ribbon cable for connecting the keyboard to the PCB, it makes for less mistakes and less hassle.

Testing

With power flowing, press some key say 3, and check that the inputs to IC4 say 3 in binary (1100). Now press 9 simultaneously, the same binary lines should say 9 (1001), regardless of how many keys are pressed. While on this part of the circuit it is instructive to see whether the gate select line is operating. To do this meter pin 11 on IC1 while pressing some key on the key pad, this line pulses high every time. If all is well here in the decoding part move on to the switch array part. To start afresh, push the reset button (#), and pin 3 on IC6 should be high. On pressing another key the counter should advance to O1 and so on to O4 (pin 10). O4 should however be only momentarily high, which might be hard to see on a hand held meter.

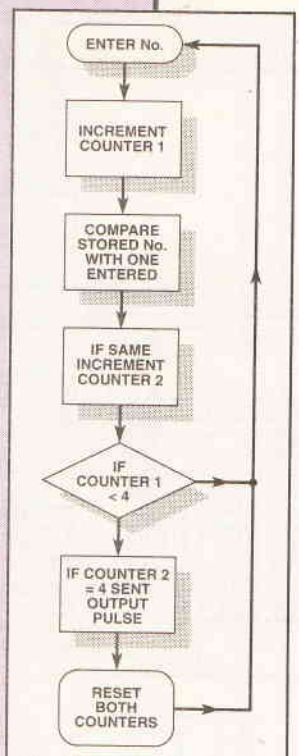


Fig.2 Sequential events

To check the comparitor is working consult Table 1 and program the first digit with some number say 5. Reset the counter by pressing and the press the same number on the keypad. The A=B line, pin 6 on IC4, should go high while the key is held down. Also the second counter IC5 should be incremented, that is O1(pin 2) should now be high. If this is the case then all that is left to do is to program a four digit number in and test the whole circuit. Upon completing the sequence O4 (pin 10 on IC5) should pulse high momentarily while pin 4 on IC2 should remain high for 3 seconds. Now the unit can be hard wired into use.

Setting Up

Looking on top at the switch matrix, the bottom set (SW1), corresponds to the first number and so on, see Figure 3. So the top set is the last number. Similarly on each bank of switches, the most left hand individual one corresponds to the lowest significant bit (LSB) and so on. So the right hand one is the most significant bit (MSB). Table 1 gives a few basic clues on programming, please note that here on=1 and off=0.

It is important to note that any other combination such as 1101, equivalent of 10, should be excluded. Not because the unit will self-destruct but rather your keypad's range is from 0 to 9 and cannot attain numbers from 10 to 15. If these are programmed in then not even you yourself will be able to operate the unit.

The output transistor can handle currents to switch a small relay or solenoid. But if you want to launch the Space Shuttle its best to use two relays, a small one connected to this circuit, switching a much larger one.

A single DC supply greater than +5V is needed to power this unit. A simple method has been incorporated to allow a form of battery back-up, useful if the main power fails. All it amounts to is two diodes separating the two power supplies. It is therefore important to ensure that the main power supply has a higher voltage than the battery back up. This prevents the circuit drawing power from the battery while the main one is on. Something that would make the battery redundant as a back-up, as it will be spent by the time CEGB has a power failure. Remember that batteries do have a shelf life and so must be replaced every year or so even if not ever used.

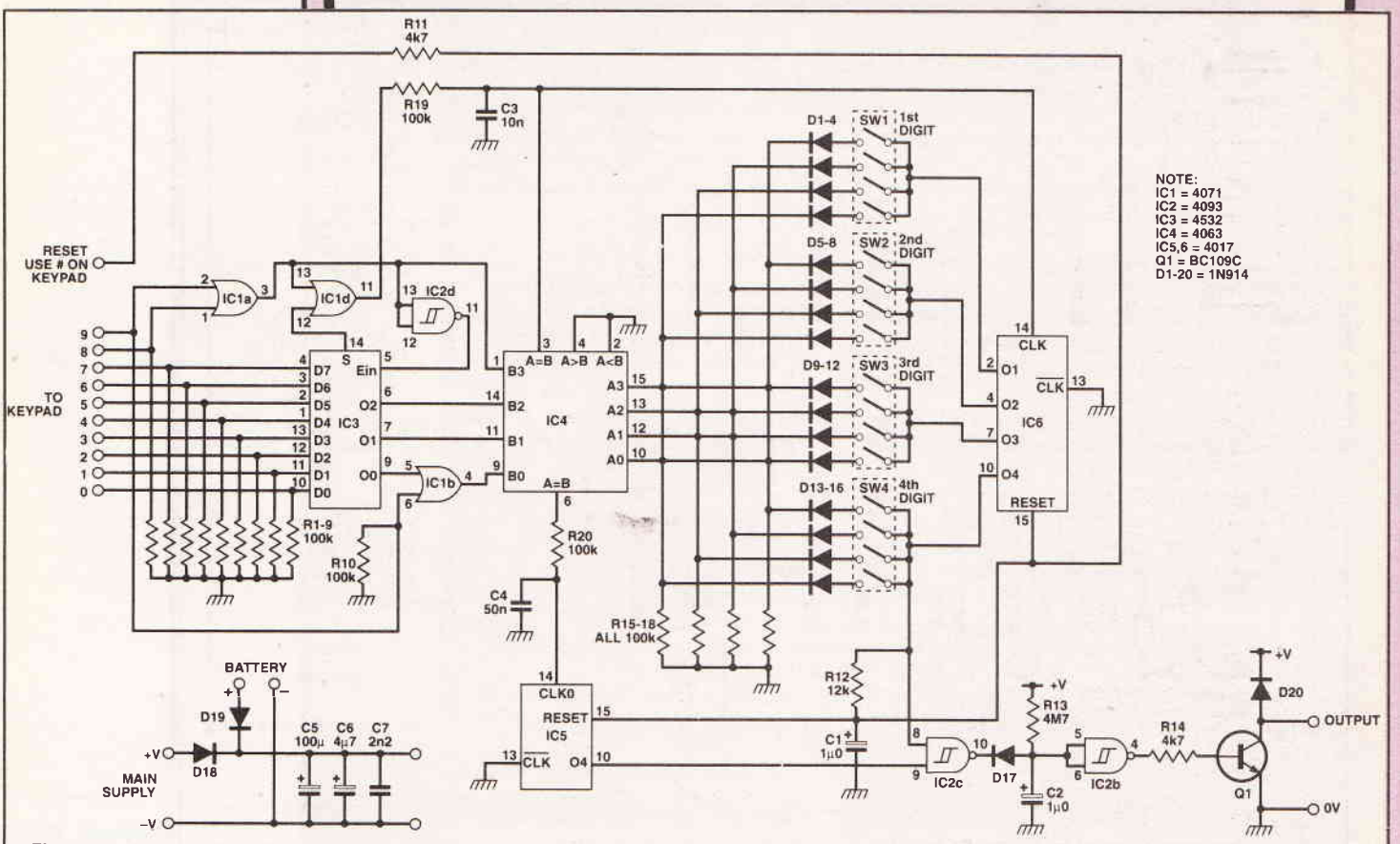


Fig.3 Circuit diagram of Code Lock

HOW IT WORKS

The common input of the keypad is tied high, but to ensure that the dreaded floating state does not occur when no key is pressed, some tie-down resistors to ground are included. Because the priority encoder can only deal with 8 inputs some external circuitry is needed to expand this to 10. An OR gate on the 8th and 9th input provides the highest binary line (O3). To get correct gating of the priority encoder this binary line must be inverted and fed into the chip enable input. If this is not done two things can happen. Firstly if two or more keys are pressed and one of them is 8 or 9, this circuit will no longer display the highest number as the priority encoder chip would be enabled and so decode the lower number while the OR gate will give a high output as well. Hence the total output would be a case of mumbo jumbo. Secondly the gate select function will no longer be valid and as this tells us if a key is being pressed, it is needed to one of the counters. To generate a coherent gate select signal the highest binary line needs to be ORed with the priority encoders gate select output. One final OR gate is needed on the lowest binary line (O0) to cater for the 9th state. Before any further use of the gate select-line it is necessary to debounce it. This is the technical term to describe the removal of any unclean signals due to the mechanical nature of the contacts (see Figure 4). In practice this usually involves a simple R-C filter to dampen down the glitches.

Now we have a coherent binary number to work on, with associated control line, next comes retrieving the stored numbers from the switches. The first 4017 Johnson counter has two inputs, one for high to low transitions and one for low to high transitions. Here the latter is used while the other is held low. The first output O0 is not used to multiplex the switches because it is high before any pulses arrive, and so when one does arrive it will only remain high for 1µs or so. Hence O1-O4 are used.

Resetting this and the other counter is done by the O4 output, ie after four numbers have been entered. Some delay is needed on the O4 as the comparitor and following circuitry time to respond to the fourth number and decide to cause a stir and open a door or something. The delay is provided by a simple RC unit, here set to about 1/10 of a second.

The outputs of this counter directly feed the switch matrix but to prevent any nasty back-currents when two bits are selected on different switches, and the resulting problems this will indifferently cause, diodes have been fitted on the outputs of all the switches. This does entail however the inclusion of tie-down resistors to prevent any floating states, and so make the zero state mean exactly that.

Both these binary numbers feed the inputs of the binary comparitor. Because this chip was designed to work in a higher bit system, for example 8 or 16 bit, expansion inputs were included. These must be dealt with to ensure proper functioning. Imagine cascading a number of these devices; if you have two equal numbers being compared, the highest chip must first say to the next one down that its four input lines are the same and so on down the line. The precedent is the same for one chip, so the A>B and the A<B input line must be disenabled ie. tied low, and the A=B input line tied high thus saying to the chip that all is well higher up the line. The output of this chip cannot be used in this raw state. However if you cast your mind back you will remember the simple switch debouncer used on the gate select line, this causes a little problem that the programmed number selected will lag behind the number appearing on the priority encoder by about 10ms. So for this period the number pressed will be being compared to the previous stored number, and could theoretically generate surplus pulses. This is solved by connecting the A=B line to the debounced gate select line, thus only when a key is pressed does this circuit respond. To be doubly sure as a stray pulse could ruin your day, another RC filter set to 30Hz is used and should cover the worst possible case.

The other counter is simple, the same low to high transition mode was set, with the clock input coming from the filtered binary comparitor's A=B output. Again O4 is the decision maker here, but it is ANDed with the other previous O4 for double safety. The delay provided by the before mentioned RC unit determines the length of the output pulse which is set in the region of 100ms. To operate locks this is useless, Six Million Dollar Man would have problems opening doors with locks that fast, even if he was desperate for a drink. Yet another delay circuit does the trick here. A reverse biased diode momentarily discharges C2, and then R13 slowly recharges it while a schmitt trigger invertor, made with a spare NAND gate, provides clean switching. On time is given by 0.7RC in seconds and is set here to about 3 seconds. The final stage here is a transistor switch with the obligatory reversed biased diode across the supply rail and the output. This is here for the switching of any inductive loads like relays or solenoids and it should not be left out as it provides a return path for the back EMF created by the collapse of the magnetic field in any inductive load.

PROJECT

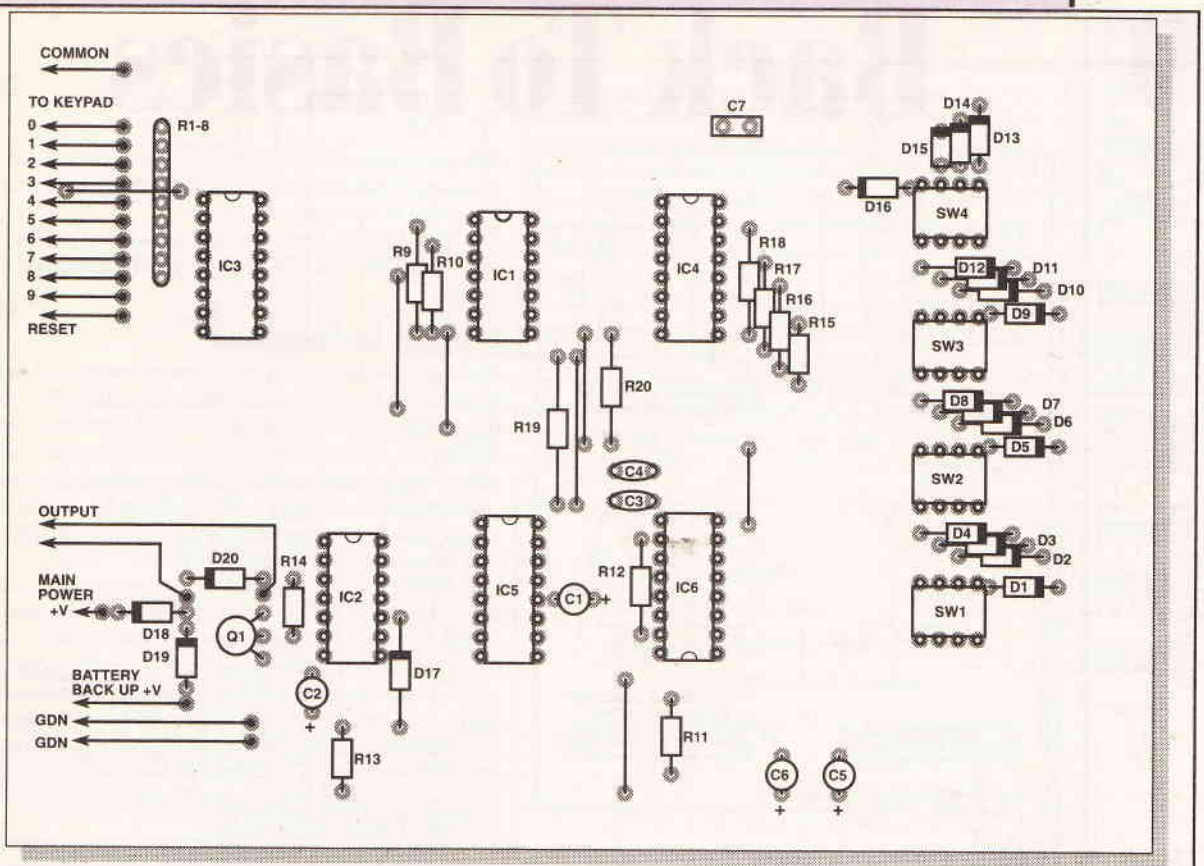


Fig.4 Component Overlay for Digital Code Lock

BUYLINES

All bits needed for this project are widely available and should not present any problems to find. No particular high tolerance components are required in this circuit, so 5% resistors are the order of the day, the same goes for capacitors. The keypad was obtained from Rapid Electronics as were the DIL switches

PARTS LIST

RESISTORS

R1-8	100k (SIL)
R9,10,15-20	100k
R11,14	4k7
R12	12k
R13	4M7

CAPACITORS

C1,2	1µ Tant
C3	10n poly
C4	50n poly
C5	100µ elec
C6	4µ7 elec
C7	2n2 poly

SEMICONDUCTORS

IC1	4071
IC2	4093
IC3	4532
IC4	4063
IC5,6	4017
Q1	BC109C
D1-20	1N914

MISCELLANEOUS

Keyboard: Simple switch format (NOT Matrix type)
SW1-4 4way DIL switch packages
PP3 battery clip and battery
Power supply to suit

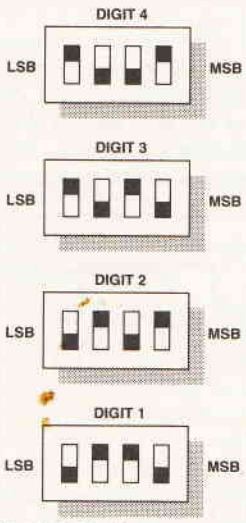


TABLE 1

No. PRESSED	O0 (LSB)	O1	O2	O3 (MSB)
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	0	1	0
5	1	0	1	0
6	0	1	1	0
7	1	1	1	0
8	0	0	0	1
9	1	0	0	1

Fig.5 Switching arrangement to set code

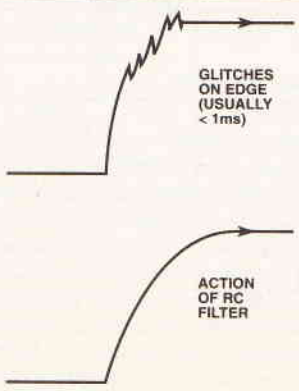


Fig.6 Action of RC filter

9 Back To Basics

In the final part, Paul Coxwell looks at the action of transformers.

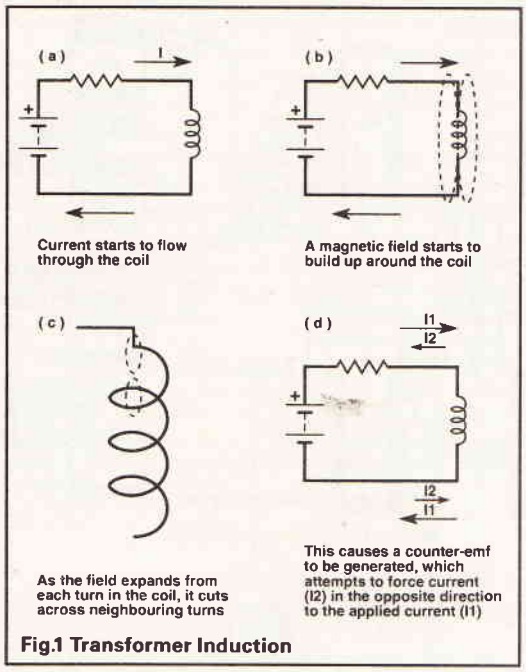


Fig.1 Transformer Induction

In an earlier installment in this series we saw the effect of inductance on an electrical circuit and how electromagnetic induction is put to good use in the motor and generator. It is also employed in another common electrical component: the transformer.

Recall the way in which a coil opposes a change of current in a circuit (Figure 1). As current starts to flow through the coil, a magnetic field builds up around each turn of wire in the coil. As this field expands it cuts across neighboring turns of wire. This motion satisfies the requirement for electromagnetic

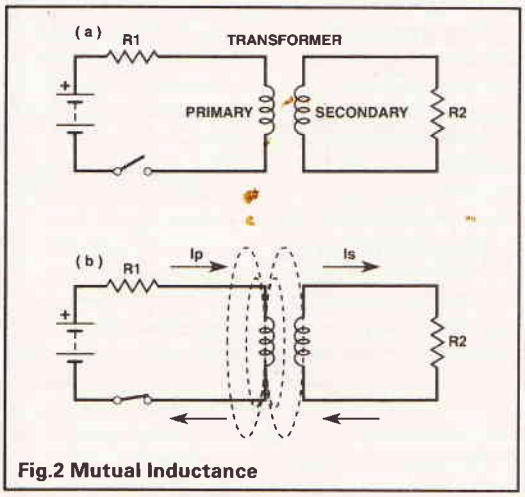


Fig.2 Mutual Inductance

induction – there is relative motion between a conductor and a magnetic field. A counter EMF is generated by the coil, which attempts to make current flow in the opposite direction to the applied current. This current is less than the applied current, so the overall effect is to reduce the normal current flow in the circuit.

As soon as the current settles at some value the magnetic field stops expanding. There is no relative movement between the conductors and the field, so no counter EMF is generated. If current through the coil is decreased, the magnetic field starts to collapse. The collapsing lines of flux cut through the turns of the coil once again, inducing an EMF and causing the decrease in current to be opposed.

The effect is known as self-inductance, and you have seen how it can be used in tuned circuits and filters.

Mutual Inductance

A coil generating a magnetic field will affect not only itself, but also any other conductor that falls within the magnetic lines of flux. Figure 2 shows this principle as it applies to a transformer. Notice that there are two coils placed close together, but there is no direct electrical connection between them. One coil can be connected to a power source; the other connects only to a resistor and has no apparent source of power.

When the switch is closed, current starts to flow through one coil. The coil supplied with current is called the primary. This current flow generates a magnetic field which expands outward from the primary and, as with any other coil, self-inductance delays the build-up of current from the battery. More importantly, the magnetic field also cuts across the turns of wire that form the second coil. This latter coil is called the secondary and the magnetic coupling between the two coils is called mutual inductance.

The expanding magnetic field causes an EMF to be induced in the secondary, which in turn causes a current to flow in the secondary circuit. Remember, there is no direct electrical connection between the

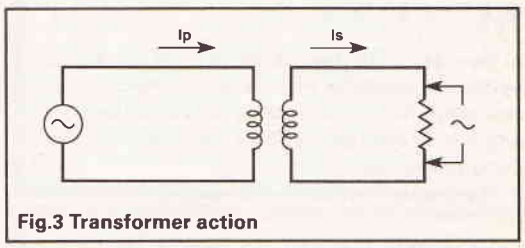


Fig.3 Transformer action

primary and secondary circuits; it is the magnetic coupling, or mutual inductance, that has caused current to flow in the secondary. Once the primary current has settled at its final value (which is determined by the resistance of the circuit, of course), the magnetic field stops expanding and no flux lines cut across the secondary. With no relative motion, there is no induced current so the secondary current is zero.

When the switch is opened the primary current drops, causing the magnetic field to collapse. As the field contracts back into the primary coil, it cuts across the turns of the secondary once again, inducing a short pulse of current.

In the form shown, the circuit is of little practical use: current only flows in the secondary for a brief period of time when the primary switch is opened or closed. If the battery is replaced with an alternating-current source, however, the primary current is continually changing (Figure 3). This causes the magnetic field to expand and collapse, thus ensuring that there is always relative motion between the magnetic field and the secondary coil. The result is an alternating current in the secondary circuit.

Transformers

It may appear that little has been achieved by using two coils to obtain an alternating current that resembles the one that was already available. The transformer

ELECTRICITY

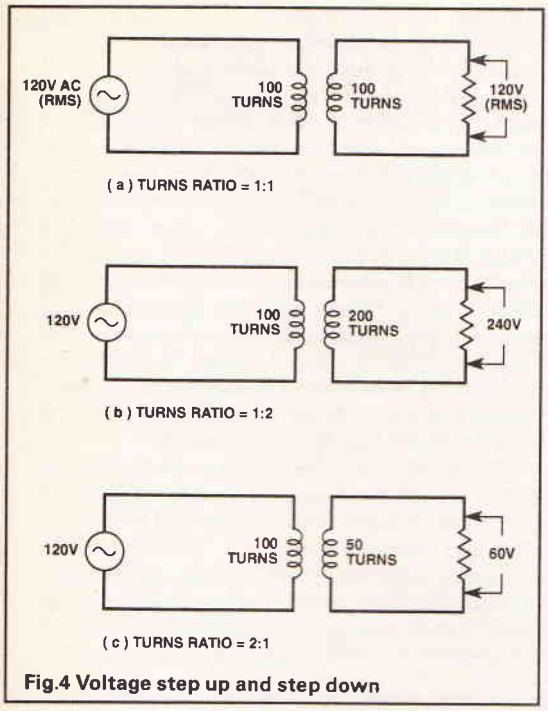


Fig.4 Voltage step up and step down

has many practical uses, however, one of the most common being to change a low voltage into a high voltage or vice versa.

Recall that when magnetic induction is taking place the induced voltage can be increased by passing a longer length of conductor through the magnetic field. In a transformer a conductor can be lengthened by increasing the number of turns. Refer to Figure 4. At A the primary supply voltage is 120V and each winding has 100 turns. The secondary output voltage is also 120V. At B the secondary winding has 200 turns; the number of turns has been doubled and the output voltage has also doubled. At C the secondary winding has been reduced to 50 turns. With the secondary having half the number of turns of the primary, the output voltage is half of the input voltage.

Figure 5 shows the effect of varying the number of turns in the primary winding of the transformer. It should be fairly clear from the diagrams that it is the ratio of the number of turns that determines the output voltage. If the primary and secondary have the same number of turns, whether 50,100,or 1,000, the output voltage will equal the input voltage. Whenever the secondary has a greater number of turns than the primary, the output voltage will be higher; when it has fewer turns the output will be lower. The ratio of secondary turns to primary turns may be used to calculate the output voltage if the supply voltage is known, because the primary to secondary voltage ratio is equal to the primary to secondary turns ratio (Figure 6).

When the secondary voltage is higher than the primary voltage, the transformer is called a step-up transformer. When the secondary supplies a lower voltage than that connected to the primary, it is called a step-down transformer. Both types are used extensively in many applications, from small radio receivers to power stations.

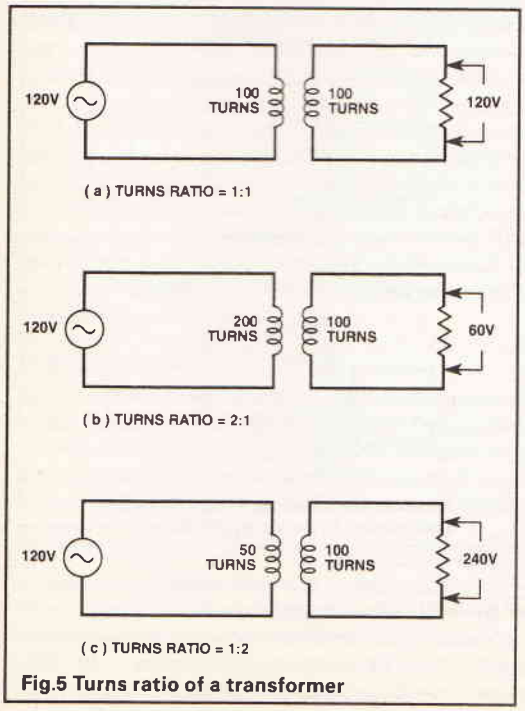


Fig.5 Turns ratio of a transformer

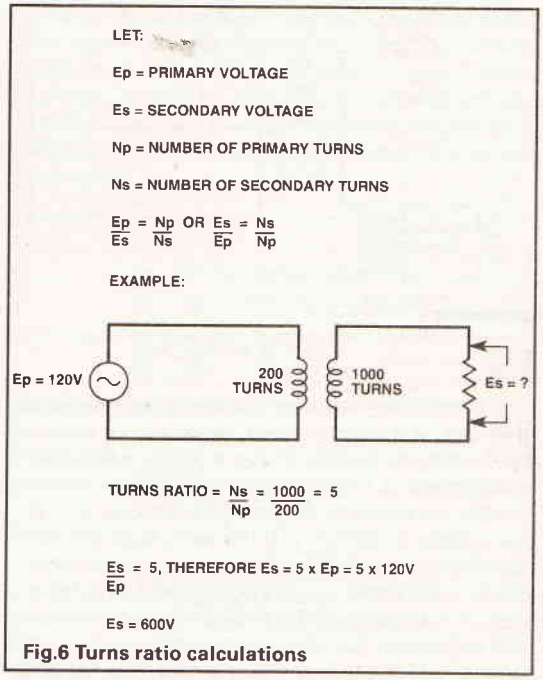


Fig.6 Turns ratio calculations

Practical Transformers

In practice, most transformers are more than simply two coils of wire placed next to each other. We have already seen that placing an iron core inside a coil increases the coil's inductance. Winding the primary and secondary of a transformer around such a core increases the magnetic coupling between the two windings, and Figure 7 shows some ways in which the coupling can be achieved. The shell core is by far the most usual arrangement, with a plastic bobbin being fitted over the centre of the core to hold the windings.

Magnetic lines of flux travel far more easily in an iron core than they do through air, so the core concentrates the flux, ensuring that as much as possible passes through the secondary coil instead being lost to the outside of the transformer. This improves the efficiency of the transformer; we shall see some other important factors that affect efficiency

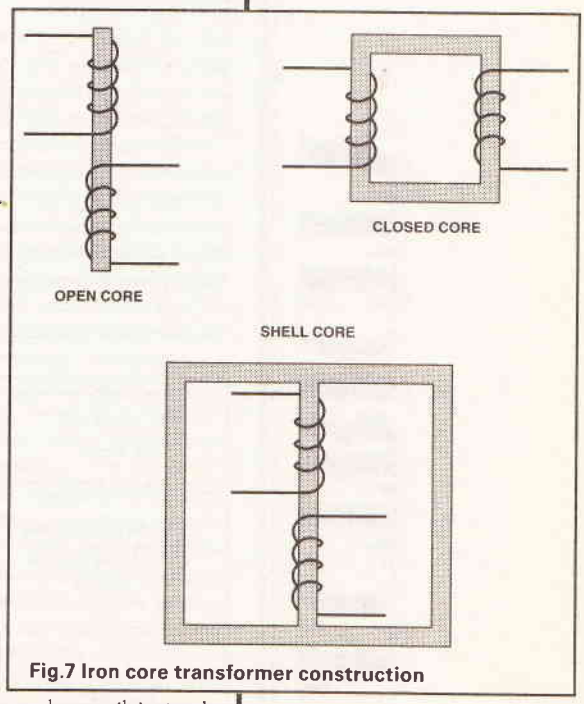


Fig.7 Iron core transformer construction

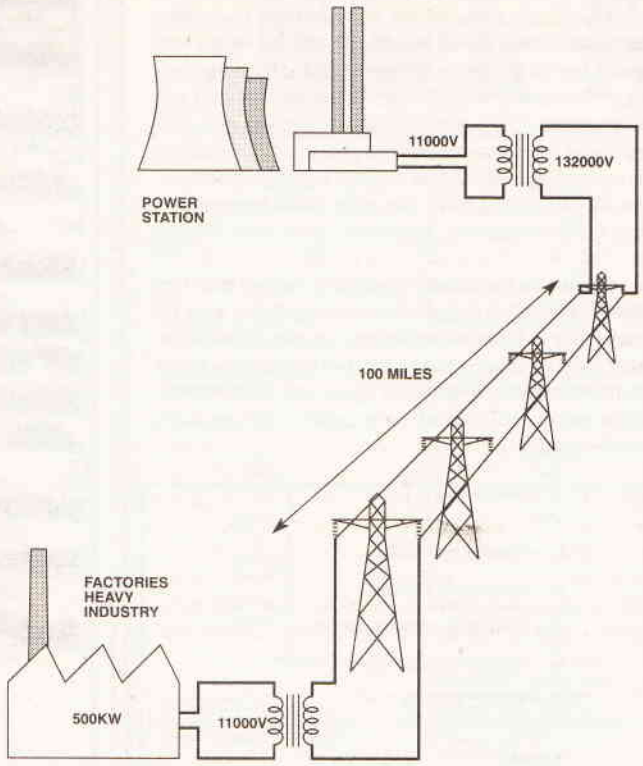


Fig.8 Power distribution

shortly.

Having seen how a transformer steps voltages up and down, it is appropriate to examine some reasons for wanting to do this. Figure 8 shows a simplified arrangement of a power distribution system. Assume that the generators at the power station have an output voltage of 11000V (11kV). Many large factories take their power supply at this level to run the heavy machinery that they use. In the diagram, a large industrial centre requiring 500,000 watts of power is located 100 miles from the generating station, so it would seem logical to just run cables to carry the required 11kV from one place to the other. As you can see, this has not been done; instead, two transformers have been installed so that the long-distance transmission line operates at the much higher voltage of 132kV. The reason for this is power loss.

We know that all cables have a certain amount of resistance and that the longer the cable the higher the resistance. Also if current flows through any resistance, power is dissipated as heat. Assume that the 100-mile run of cables in our diagram has a total resistance of 100 ohms. It is possible to calculate the current flowing in the lines, because the voltage and power consumption are known (see Figure 9). The formula for power dissipation, I^2R, shows that with a fixed value of resistance the power varies with the square of the current. Power loss in the line is just under 1.5kW.

To see what would happen if the same lines were used to carry power at 11kV, repeat the calculation with the new value for voltage. To obtain the same amount of power with a lower voltage requires a higher current, so the line current has increased many times. The line resistance, however, is the same, which has resulted in a power loss of over 200kW. To reduce the power loss while using the lower voltage would require cables with a much lower resistance. Such cables cost more, are harder to work with, and are heavier; heavier cables imply heavier support towers, which will also cost more. It is for this reason that long-distance power lines use such high voltages — to keep the current, and hence the power loss, as low as possible.

The transformers used for power distribution can be huge — some are the size of a house. At the other end of the scale are the transformers used in domestic radio and television receivers. These represent another reason for stepping AC voltages up and down. A typical transistorized radio receiver requires about 10 to 20V and a transformer can be used to convert the incoming 120 or 240V supply to the required level.

(a) 132KV SYSTEM

P = 500KW

E = 132KV

SO I = $\frac{P}{E} = \frac{500}{132} = 3.79A$

LINE POWER LOSS = $I^2R = 3.79^2 \times 100 = 1436W$

(b) 11KV SYSTEM

P = 500KW

E = 11KV

SO I = $\frac{P}{E} = \frac{500}{11} = 45.5A$

R = 100R

LINE POWER LOSS = $I^2R = 45.5^2 \times 100 = 207025W$

Fig.9 Transmission line power loss
a)132kV system b) 11kV system

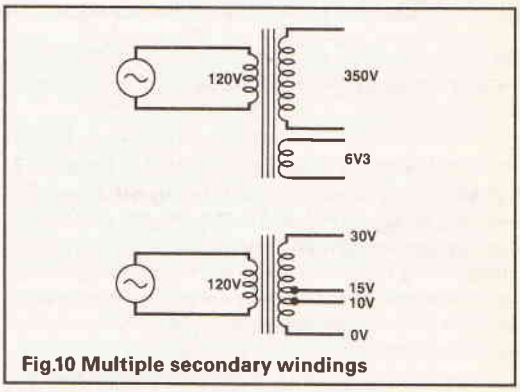


Fig.10 Multiple secondary windings

Many transformers have more than one secondary (Figure 10). A typical valve-type transmitter, for example, requires 300 to 400V and a separate 6.3V supply to light the valve heaters. Using a transformer with two secondary windings is much less expensive than employing two separate units; it also saves a great deal of space.

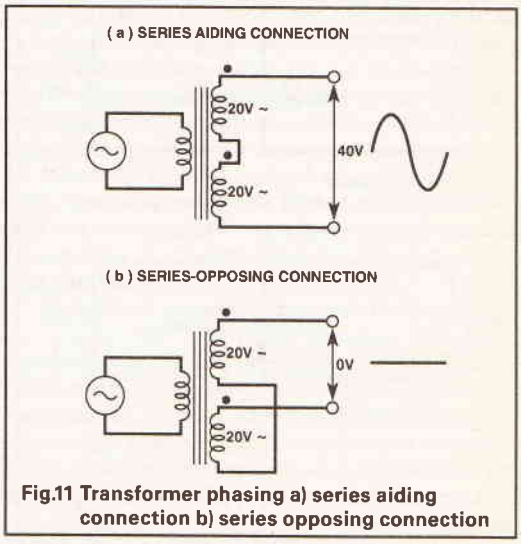


Fig.11 Transformer phasing a) series aiding connection b) series opposing connection

Another method that can be used to save costs is to tap a secondary winding. This enables a single winding to supply several different voltages, so long as each can share the same ground, or common, point. The tapped winding behaves in the same way as two separ-

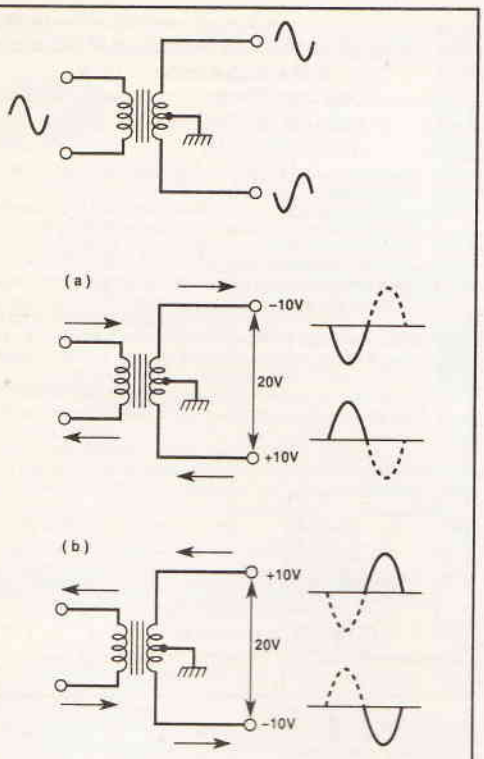


Fig.12 Phase splitter transformer

ate windings connected together would behave.

An important consideration of the output voltages is that of phase. Consider the transformer connections shown in Figure 11. The dots at one end of each secondary winding are often used to indicate phase. They show that when the marked end of one secondary is positive with respective to its other end, the marked end of the second winding will also be positive with respect to its other end. With a series-aiding connection the two voltages combine in phase, giving an output voltage equal to the sum of the secondary voltages. With a series-opposing connection, the voltages combine 180° out of phase, and so tend to cancel each other.

The ability of a transformer to give a reverse phase output makes its useful in some amplifier circuits which require two signals 180° out of phase with each other. Figure 12 shows how a transformer with a centre-tapped secondary can be used in this way; it is often referred to as a phasesplitter transformer. Assume that with the primary current flowing as shown in A, the secondary develops an EMF of 20V with the top end of the coil being negative and bottom end positive. Because the centre tap is connected to a common, zero volts, point, the top is −10 and bottom is +10 volts. When the primary current changes direction, as shown in B, the secondary polarity also reverses. The centre tap is still grounded, leaving the top end at +10 and the bottom end at −10 volts. The two AC outputs are, therefore, 180° out of phase.

Impedance Matching

So far, we have seen how the magnetic field generated by the primary current induces a current into the secondary. The situation is slightly more complex than this, however, because the current flowing in the secondary creates its own magnetic field which affects the primary.

The field generated by the secondary winding is of such a polarity that it opposes the primary magnetic field, thus reducing the total magnetic flux. This reduction of flux reduces the self- inductance of the primary, which in turn reduces the counter-EMF generated by the primary winding. With less counter-EMF in the primary, its inductive reactance is lowered.

The result of this interaction of magnetic fields is that when more current is drawn from the secondary, current in the primary increases. Current is inversely proportional to impedance (by Ohm's Law), so another way of stating the situation is to say that if the load impedance on the secondary is decreased, the impedance seen by the source driving the primary will also decrease. The transformer thus reflects any impedance change.

The ratio of primary to secondary impedance is determined by the turns ratio of the transformer (see Figure 13). Notice that the impedance varies with the square of the turns rario, unlike voltage which varies directly with the turns ratio. In the example shown, any circuit driving the primary of the transformer would see an impedance of 800R.

Thus, the transformer can be used to connect two circuits together which are of greatly differing impedances. A typical use of an impedance matching transformer is in an audio amplifier. Many amplifier circuits require a load impedance of several thousand ohms (for reasons which are outside the scope of this article). Most loudspeakers have an impedance of between 3 and 16R, so a transformer is used to match the source to the load.

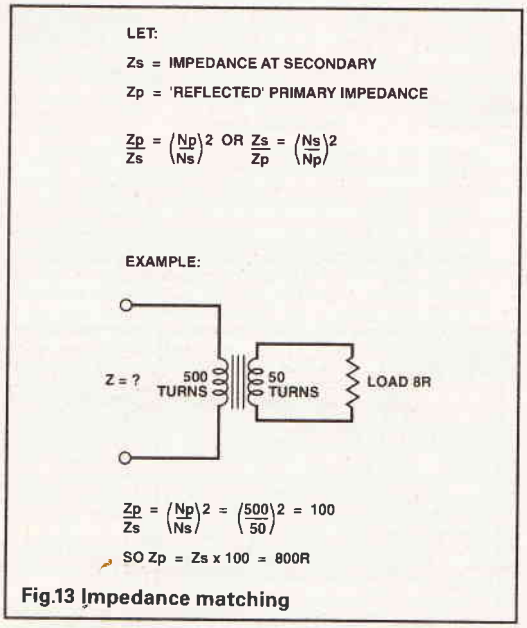


Fig.13 Impedance matching

Transformer Efficiency

Earlier, it was mentioned that the voltage-to-turns ratio formula applied to a perfect transformer. In practice there are some power losses in a transformer, as with any other component.

First, there is the resistance of the wire used for the primary and secondary windings. The resistance contributes nothing to the magnetic field and consumes power according to the usual I^2R power formula. Such power loss is often called copper loss (because the windings are copper).

Second, for 100% efficiency every line of flux generated by the primary winding must cut across the secondary winding. The iron core helps to concentrate magnetic flux where it is needed, but it is impossible to prevent any leakage of magnetic flux. Again, energy used to generate magnetic flux that does not cut the secondary winding is wasted.

Third is a property called hysteresis loss. The magnetic domains in the iron core are continually being polarized first one way and then the other by the alternating current in the primary. Some energy is required to keep re-aligning these domains.

Finally, there is loss due to eddy currents. We know that when a magnetic field cuts a conductor a current is induced. Without this reaction it would not be possible for the transformer to work. The iron core also forms a good conductor of electrons, and the magnetic field induces small currents in the core. These are called eddy currents, and power is used up in the form of heat. Eddy currents are minimized by making the iron core laminated rather than solid. The laminated core consists of several thin iron sheets which are bonded together with an insulating material. Eddy currents are thus confined to each lamination and cannot flow through the low resistance of a single, large core.

Even with all these losses, most transformers are around 90 to 95% efficient, which means that the theoretical calculations are accurate enough for all but the most demanding of applications.

Conclusion

We have now come to the end of our examination of basic electrical circuits. This series has, of necessity, been a somewhat condensed course, and if you want to study basic principles in more detail the Basic Electricity course by Van Valkenburgh, Nooger & Neville, Inc. is highly recommended. This course is in five parts and obtainable from many public libraries. Also recommended are Heathkit's DC Electronics and AC Electronics courses; these include parts packages for you to perform experiments that help reinforce your knowledge with practical examples.

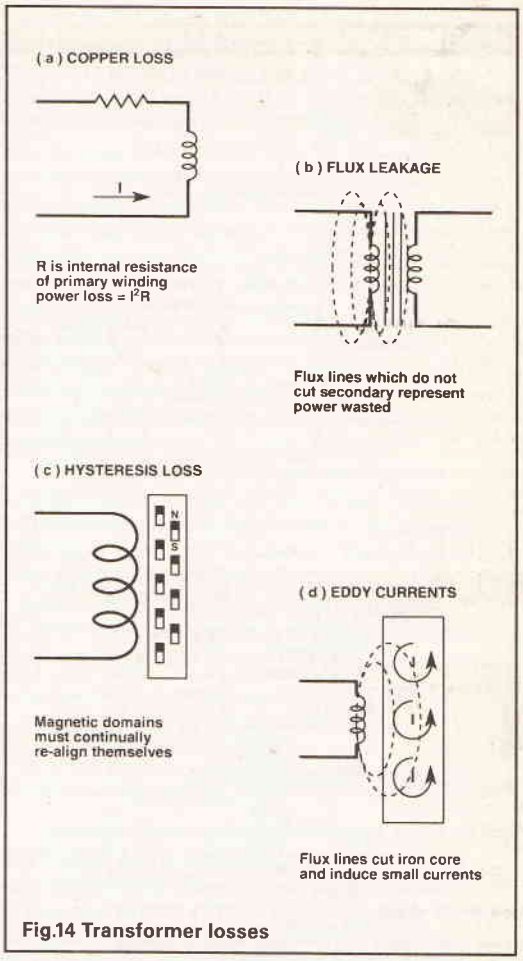


Fig.14 Transformer losses

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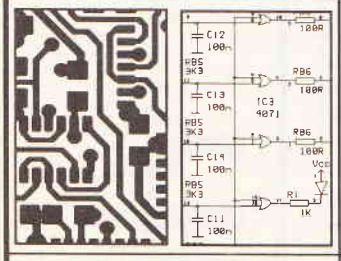	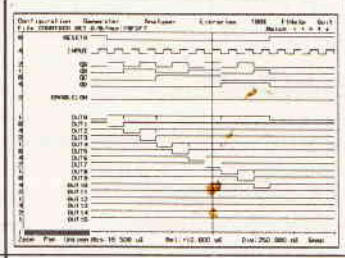	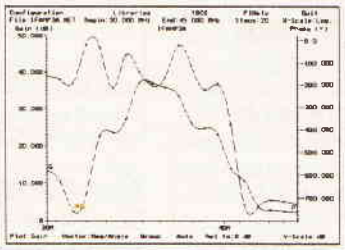	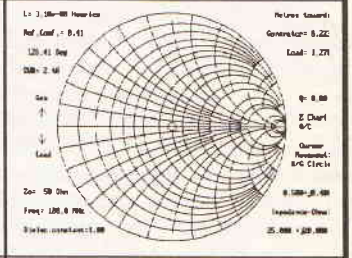
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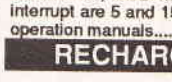

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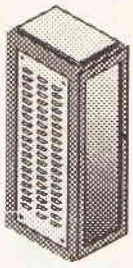

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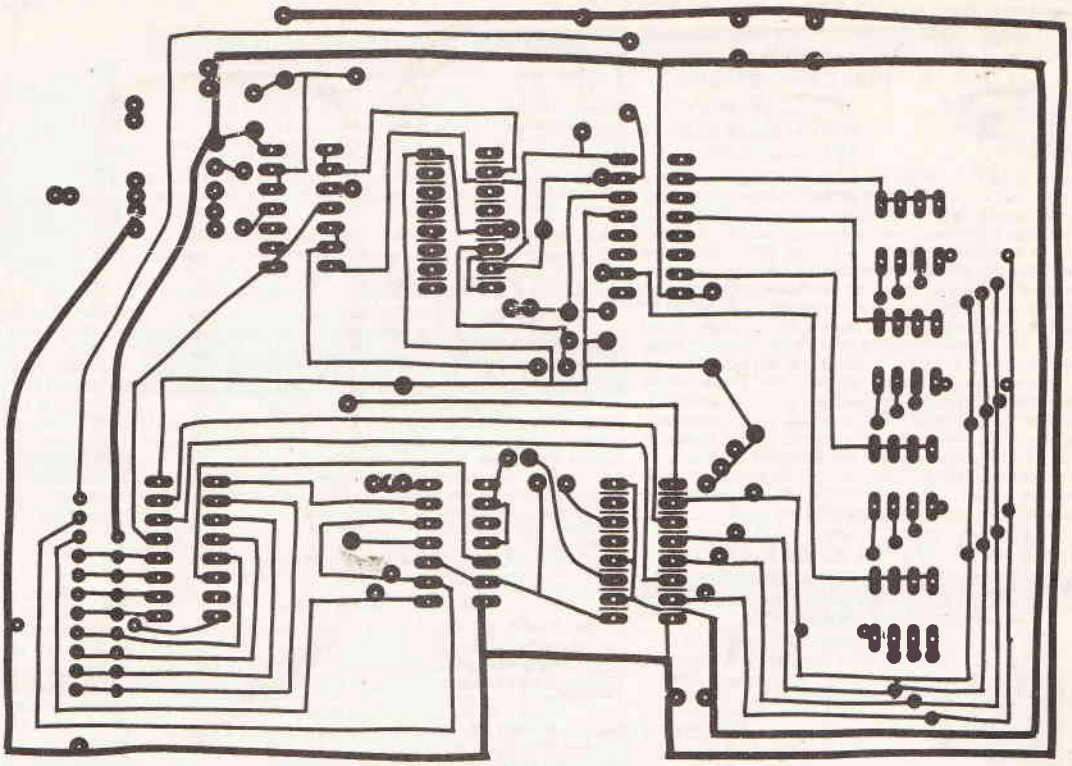

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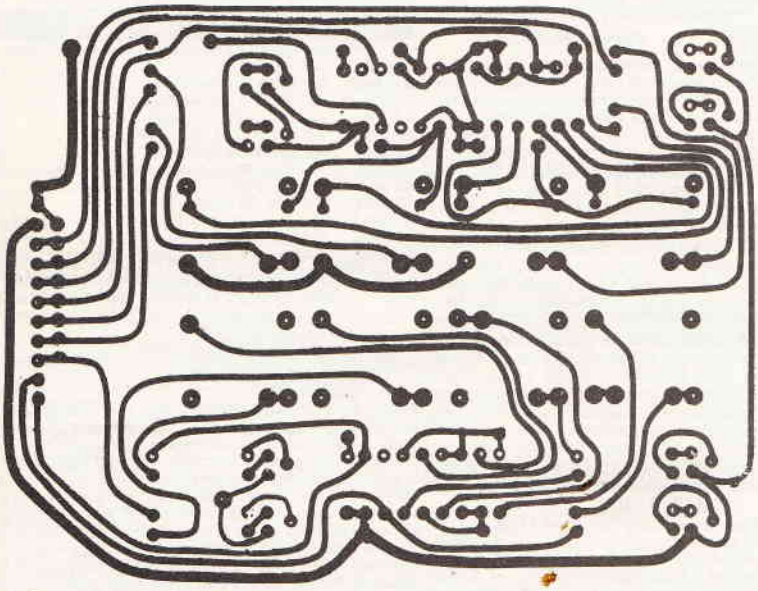
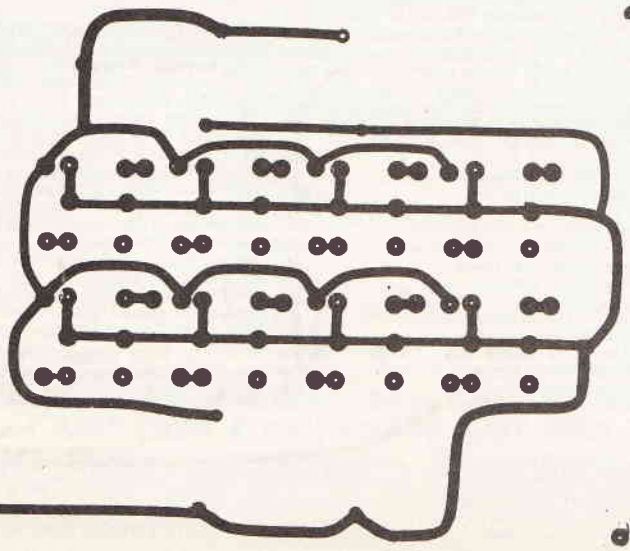
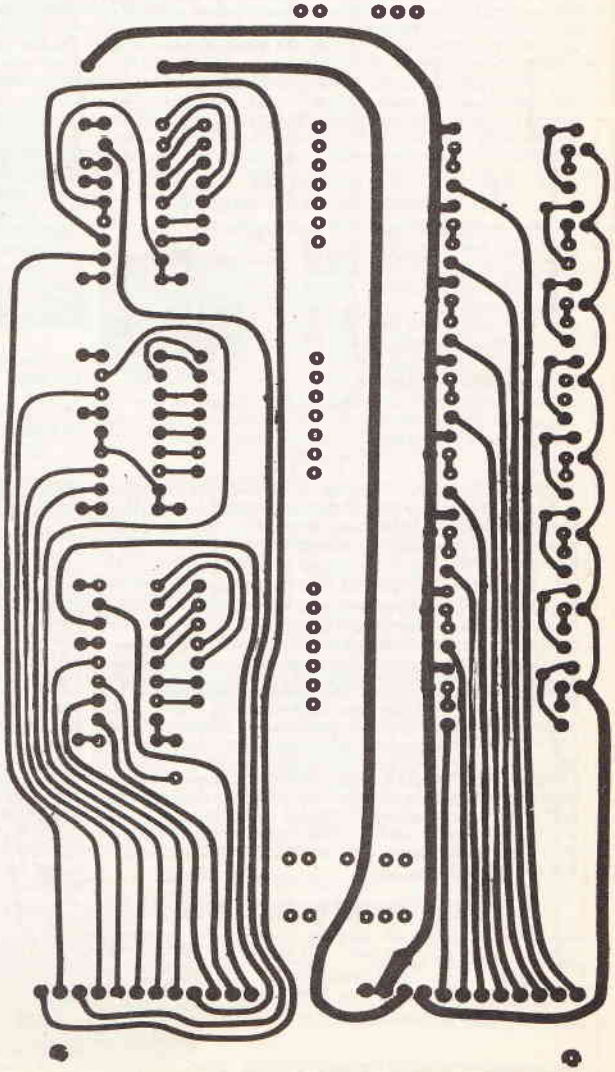


Mode Selection Board solder side

Mode Selection Board top side



Nightfighter Display Board solder side



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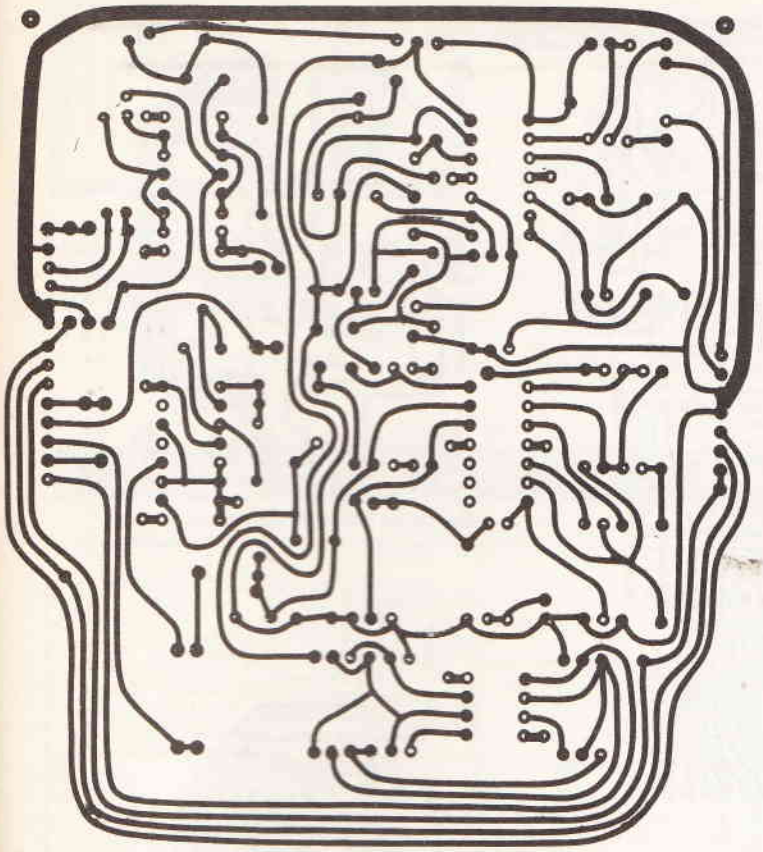
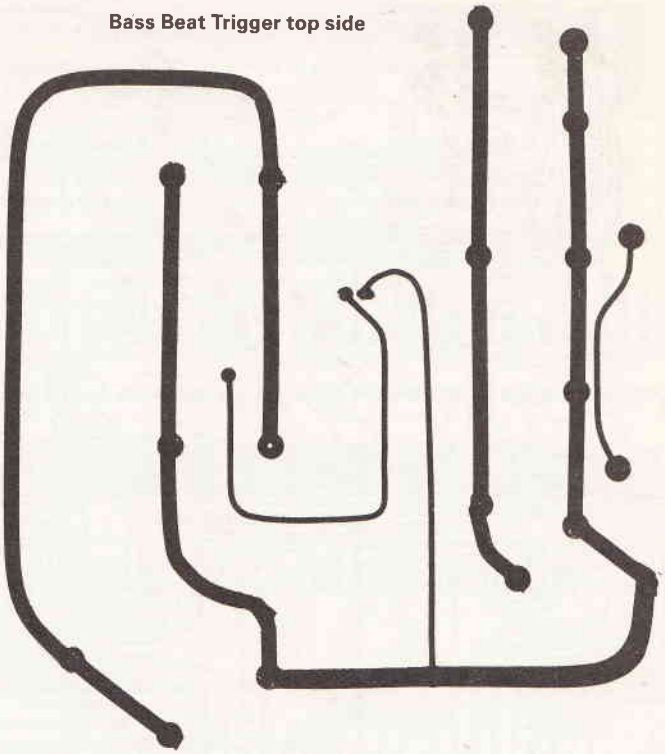


Bass Beat Trigger top side



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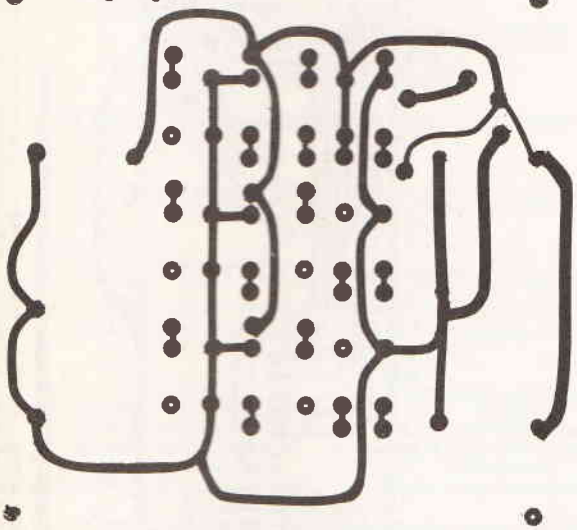
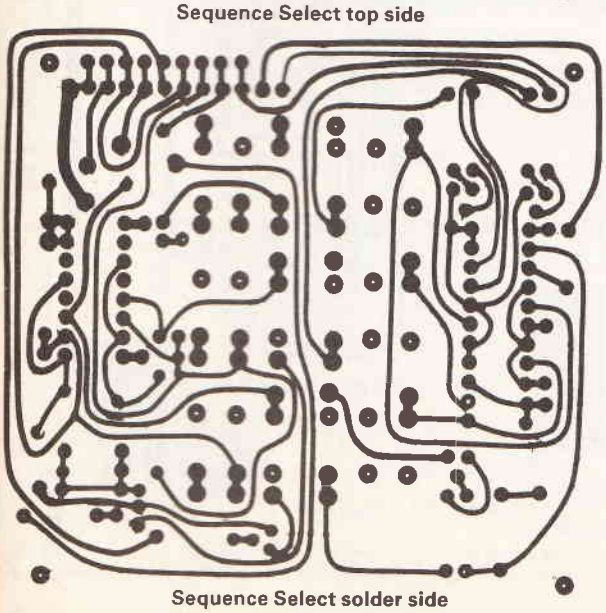
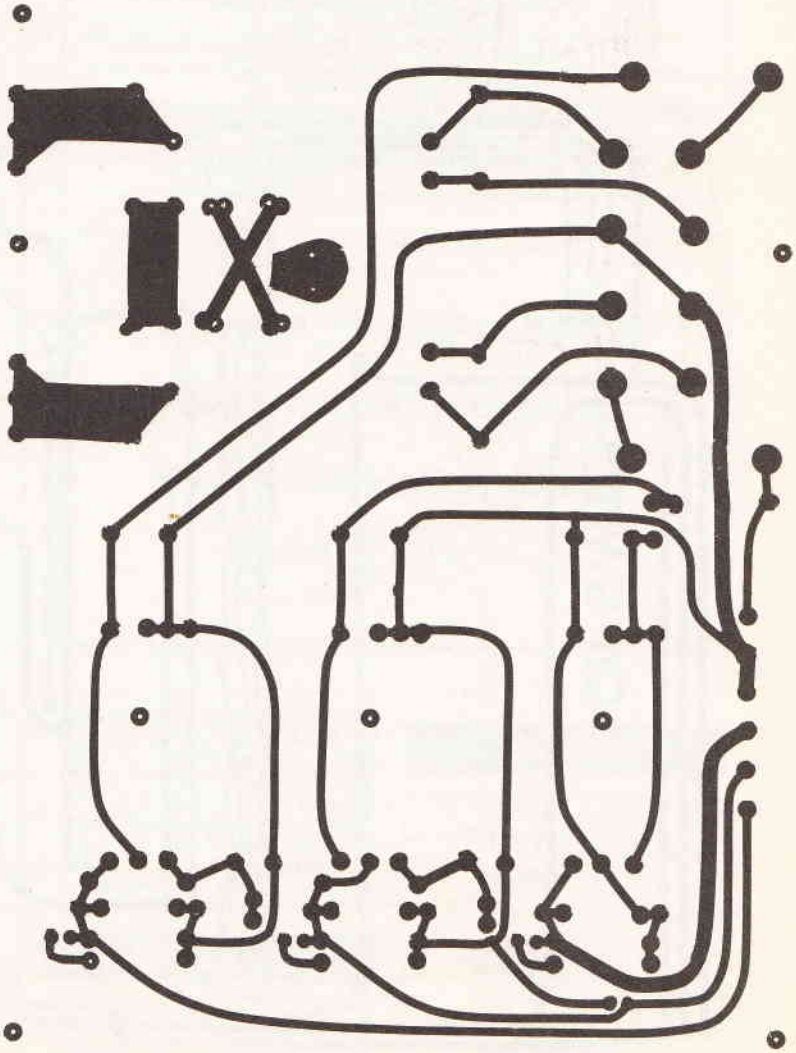


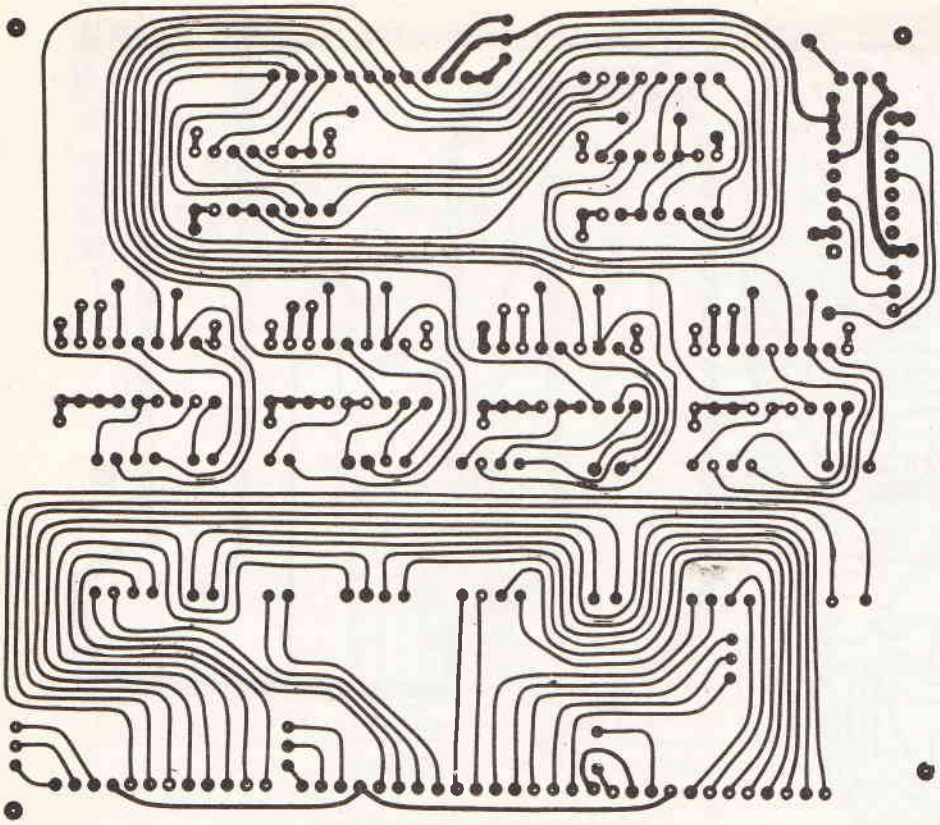
Sequence Select top side



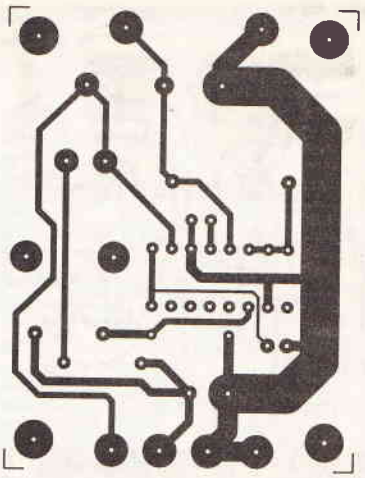
Sequence Select solder side



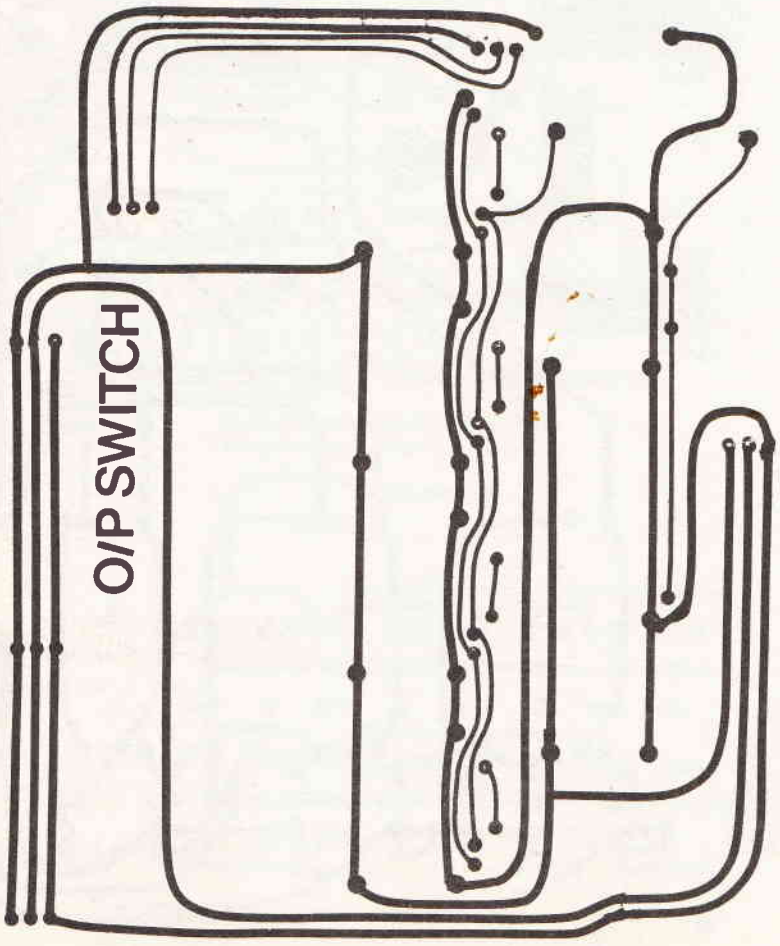
Nightfighter Master Controller PSU Board



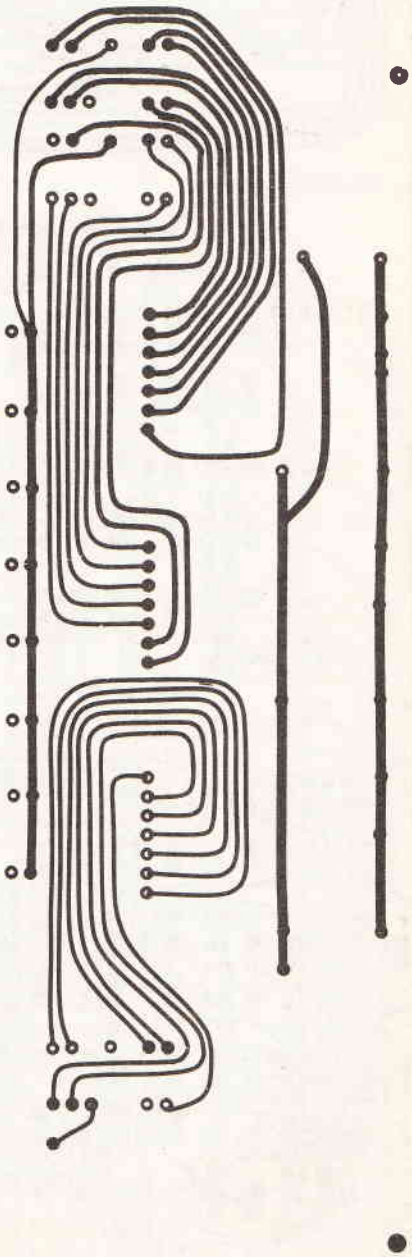
Nightfighter Output Switch solder side



Switched Mode Power Supply Board



Nightfighter Ouptut Switch top side



Nightfighter Display Board top side

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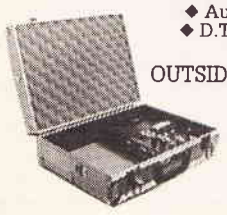

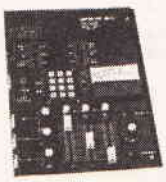

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NEXT MONTH

Next month sees the first of a series of two cover mounted gifts to help you construct your own printed circuit board for one of our projects. This is in response to readers asking about PCB production at home and to encourage readers to have a go from scratch. We feature an article on the various ways of producing PCBs at home with helpful hints at acheiving the best results.

Our major project next month is a Colour test-card and cross-hatch generator. The generator contains many test patterns stored in its own software for alignment of colour cathode ray tubes.

We have features on the action of negative feedback and what it achieves and an interesting article on the effect of electromagnetic radiation on man. Have we become immuned to low levels of this natural radiation or will the constant bathing within low energy waves produce long term illness?

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The above articles are in preparation but circumstances may prevent publication

LAST MONTH

In the October edition of ETI we featured:

Freezing alarm project to warn of an impending frost or freeze up. The Nightfighter 2 showed the construction of an 8kW dimmer pack to operate from the master controller. A mains failure alarm system warned of drooping mains voltages whilst the Prototype designer offered benchtop circuit experimentation. Our features included Cosmic rays, the Magnetron and how a cash machine works.

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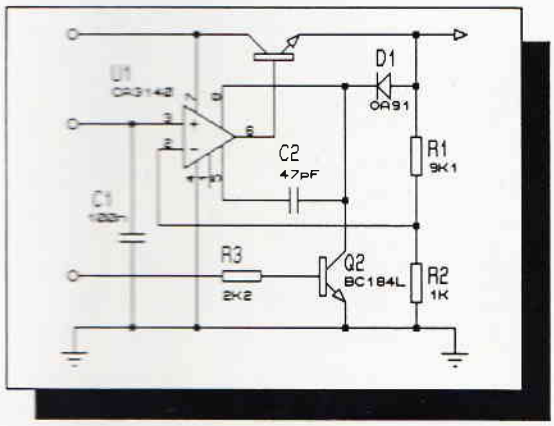

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