NOISE

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Introduction

The purpose of this article is twofold. Firstly, to give an introduction to types of noise and possible sources of noise. Secondly, a design, and full constructional details, for a noise generator are given. The main use of a noise generator is in testing equipment on the lab bench which will be subjected to noise in the field. For example, a modem designed to work over normal telephone lines may work fine in a noise free lab with zero line length, however as we all know, telephone lines can be very noisy, especially as they get longer. If you have ever built something which worked fine in the lab, but failed in the field, then noise may be the problem.

Virtually any signal in a system that is not desired might be classified as noise. However, the term noise is usually taken to mean an unwanted signal that has random properties. A few types will now be considered.

White Noise

The noise power of white noise is flat across the frequency spectrum. That is to say, there is the same power of noise in each hertz, and it occurs at all frequencies. What ever frequency an item of equipment operates at it cannot escape white noise. The term 'noise bandwidth' is sometimes used with respect to an item of equipment. This means the bandwidth to which the item of equipment is sensitive to noise. For example, if a particular piece of equipment is designed to observe a low level analogue signal with a frequency of DC to 100Hz, then to help bring the signal out of the noise it would be sensible to low pass filter the signal, with a filter cut-off frequency just above 100Hz. The signal would be unaffected by the filter, but the unwanted noise above 100Hz would be rejected. The noise bandwidth would be said to be 100Hz. Of course, noise below 100Hz would still be present.

Now let us consider some origins of white noise. Noise is often caused by thermal effects (including problems like thermal drift). All resistors generate white noise merely because they have a temperature, sometimes called 'Johnson' noise. The RMS noise is proportional to the square root of absolute temperature. The only way to get rid of the noise is to operate the resistor at 0°K (−273°C), not exactly an easy condition to meet!

The second most well known source of white noise is shot noise. This noise is due to the fact that current is not constant and smooth flowing, but consists of a stream of electrons. This causes current flow to fluctuate.

Both thermally generated and shot white noise are due to fundamental principles and as such can not be reduced by making better quality components, for example a carbon film resistor and a metal film resistor of the same value will cause the same amount of thermally generated white noise. We have to live with this noise.

Flicker Noise

Flicker noise is also known as 1/f noise and pink noise. It is known as 1/f noise since this describes the noise power spectrum, noise power is proportional to 1/f, where f is frequency. 1/f noise has equal power per frequency decade. 1/f noise is an extra in that it is due to manufacturing imperfections. For example, a carbon film resistor will generate more 1/f noise than a metal film resistor, simply because carbon film resistors are of lower quality than metal film resistors.

Interference

Most other types of noise are commonly put into this class. It includes things such as mains 50Hz pickup, which is not at all random, and impulsive interference such as electrical motors, car ignitions, lightning, etc. Impulsive interference is broad band in the frequency spectrum.

The Noise Generator

As mentioned at the start of this article any unit which may have to work when subjected to noise/interference will require testing on the lab bench before it can be placed in the field. To test noise performance a controllable noise source is needed. The noise generator design to be described here produces band limited white noise from virtually DC (0.0001Hz) to around 250kHz. The generator requires a supply between +5V (or ±2.5V) and +18V (or ±9V), split supply rails are not required, but can be used. The supply will typically be taken from the unit under test. A noise level control is provided to allow the noise output level to be adjusted. The absolute maximum output level is dependent on the supply voltage. Three outputs are provided, DC coupled, AC coupled and digital, the use of these outputs is described later.

Psuedo Random Bit Sequences

The noise is generated using a psuedo random bit sequence (PRBS). A psuedo random bit sequence is a sequence of logic ones and zeros that appears to have random properties, that is the sequence has the same probability properties as that produced by repeatably tossing a coin and calling logic one for heads, logic zero for tails. The bit sequence is produced using a digital shift register with exclusive OR feedback, thus the sequence is entirely predictable, however any portion of the sequence looks random. Since the sequence in this design is 8, 589, 934, 591 bits long and takes over two hours to repeat, it can be assumed to be as good as random in just about all circumstances.

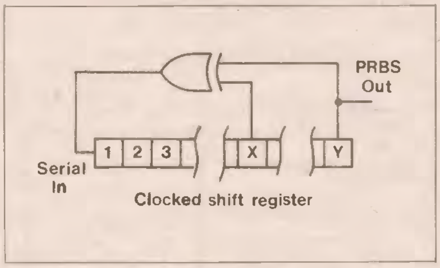


Figure 1. PRBS generator.

The basis of a PRBS generator is shown in Figure 1, a Y bit long shift register with EXOR feedback from the X and Y bits. In Figure 1, only two feedback taps are shown, in fact more than two taps may be needed, depending on the shift register length. The circuit described here uses a 33-bit shift register with feedback from bits 20 and 33. The feedback taps must be chosen correctly to give a maximum length bit sequence. The maximum number of different states for a Y bit shift register is 2^Y (i.e. all binary permutations). However, the state of all zeros causes feedback of zero and the register stays stuck at zero. The maximum sequence length possible is 2^Y-1.

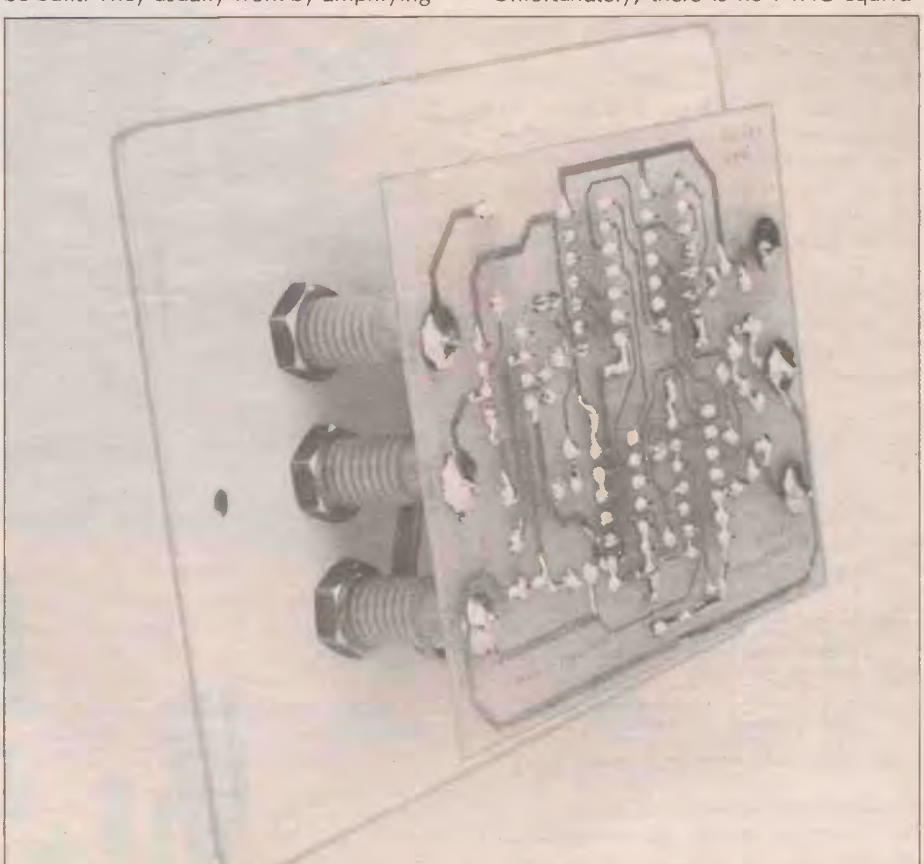
PRBS generators have other uses such as, encipherment of data, radar ranging codes, error checking (typically on disks, cyclic redundancy check characters, CRCC), digital signature analysis, etc. For the applications involving data, the data is fed into the shift register by adding it to the EXOR feedback. PRBS generators can be implemented in software, and are sometimes used as the basis of random number generators.

Analogue based noise generators can be built. They usually work by amplifying the noise produced by a diode or resistor. Since the noise generated by resistors and diodes is reasonably low level, a lot of amplification may be required, this causes sensitivity to interference pickup. The main advantages of using a digital noise source are, the ability to produce noise of known spectrum, all circuits built to the same design will behave the same, that is better repeatability of design and finally insensitivity to supply variation and other interference pickup.

Circuit Description

The noise spectrum generated by a PRBS is almost flat up to a frequency 26% of the shift register clock frequency. At this frequency the noise power is −1dB down. Band limited white noise is simply produced by low pass filtering the PRBS output.

Referring to Figure 2, the shift register clock does not need to be particularly stable or accurate and a simple RC oscillator, using IC3d, has been used. This gives a clock frequency of approximately 1MHz. Increasing the clock frequency increases the bandwidth of white noise, the higher the clock frequency the better. The maximum clock frequency is limited by the propagation delays to 1.5MHz. The 4000 series CMOS integrated circuits used are rather slow, but do have the advantage of operating from a wide supply variation, it was for this reason that they have been used. The schmitt trigger NAND gates and EXOR gates could be replaced by 74HC series equivalents, which are around ten times faster. Unfortunately, there is no 74HC equiva-



Rear view.

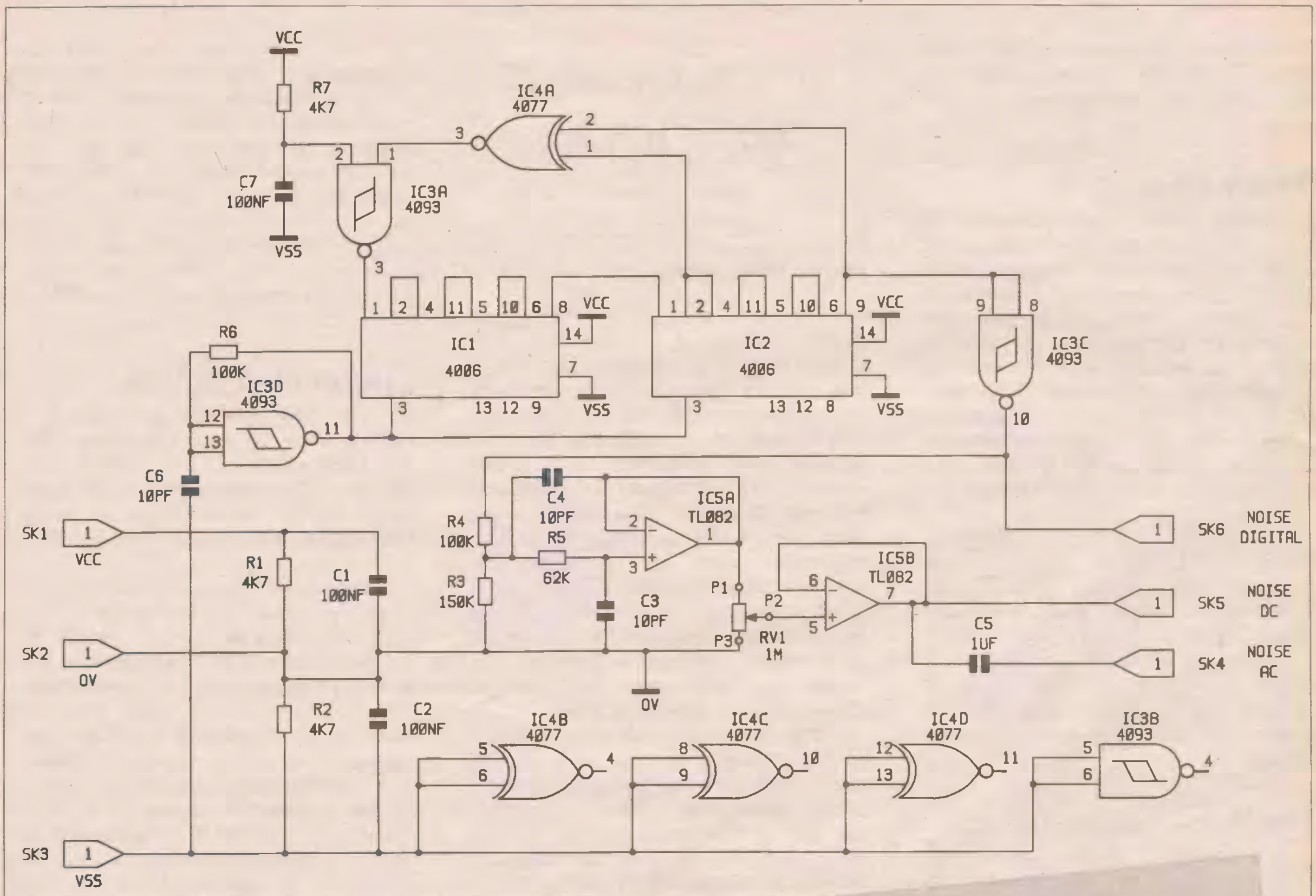


Figure 2. Noise generator circuit.

lent of the 4006 (IC1 and IC2) 18 bit static shift register. The 4006 is internally organised as shown in Figure 3, it consists of two four bit shift registers with outputs after the fourth stage available, and two five bit shift registers with outputs at the fourth and fifth stage available, all registers are operated from the same clock. IC1 is used as a 16 bit shift register and IC2 is used as a 17 bit shift register, this gives a total length of 33 bits.

As stated earlier, PRBS generators have a 'stuck at zero' state. At power up this state must be avoided. The usual trick to get round this is to use EXNOR feedback, all data is then inverted and the 'stuck at zero' state becomes 'stuck at

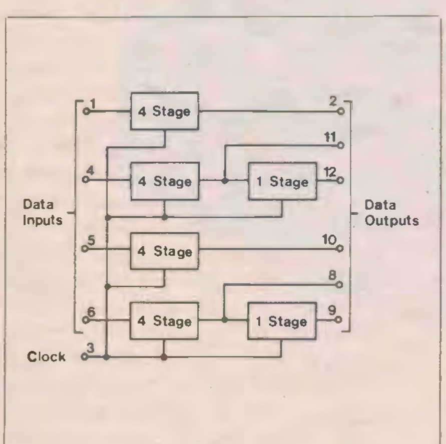
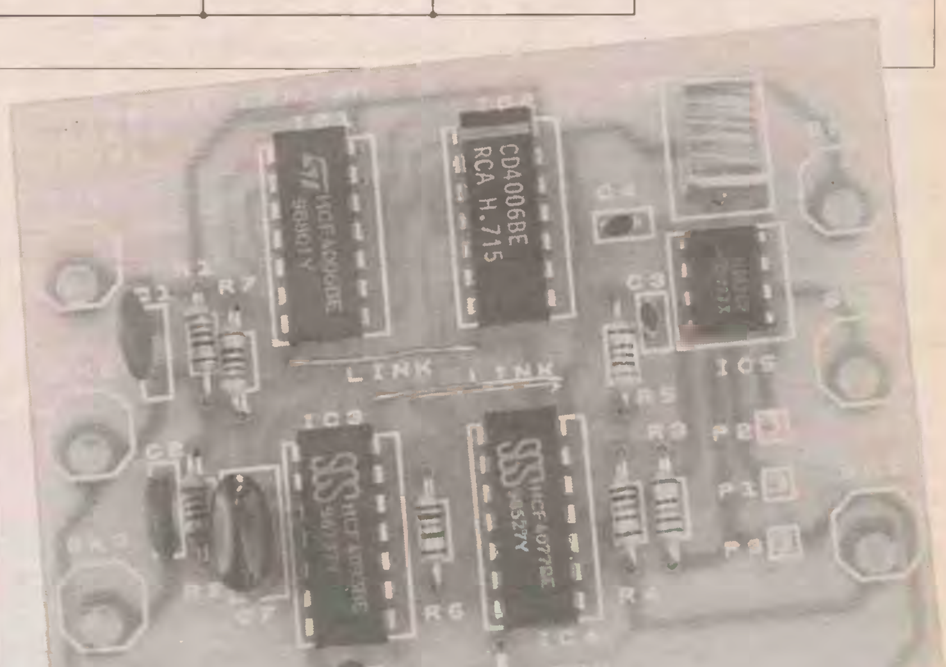


Figure 3. Pin-out of the 4006.



PCB Assembly.

one', a reset input on the register is then used at power up to ensure that it starts operation in the all zero state. The 4006 has no reset input so this trick can not be used. The problem has been solved by forcing logic ones into the 33 bit shift register at power up. This is done by IC3a, at power up C7 takes one input low, the output is high regardless of the other input. After a period given by R7 & C7 time constant, the input goes high and IC3a then inverts the output of IC4a. The shift register feedback is thus EXOR and the 'stuck at zero' state has been avoided by shifting in ones at power up. The R7 & C7 time constant is much longer than 33 clock periods, this ensures the shift register always starts in the state of all ones.

Band limited white noise is produced by low pass filtering the shift register output, in fact any shift register tap will do. IC5a and associated components form a second order low pass filter. This gives a roll off of 40dB per decade, starting at 250kHz. The circuitry around IC5 requires a mid-supply rail. This rail, called 0V, is derived by R1 and R2 from the logic supply rails, Vcc and Vss. R3 and R4 reduce the input voltage swing to IC5, to avoid clipping distortion. IC5a is followed by the noise level control, and finally IC5b, a unity gain buffer. Three outputs are provided, the unfiltered output of the shift register buffered by IC3c, a DC coupled output and an AC coupled output. The AC coupled output is DC decoupled by a 1μF polylayer capacitor. This capacitor needs to be as large as possible because when the output is connected to a load impedance it will cause high pass filtering and thus attenuate the low frequency noise. For example, with a 10k resistive load, noise below 16Hz will be filtered out. Electrolytic capacitors have not been used to DC decouple, because they have poor high frequency performance.

Construction

The PCB does not contain many components and should be easy to construct, use Figure 4 to help in building it. The 4mm sockets are mounted in the case lid, drilling details shown in Figure 5. The PCB is then mounted directly onto the rear of the sockets, component side to the case lid, see Figure 6. Connections to the noise control are made by flying leads. Since once the PCB has been soldered onto the sockets it is difficult to remove, the unit should be tested before final assembly. Testing will require temporary connections to the socket PCB pads. The best method to test the noise source is to check the noise output on a spectrum analyser. Since not many people own a spectrum analyser the next best method is to use an oscilloscope, the noise output should look reasonably the same for any timebase setting upto around 20μs/div. Since the signal is random, it is difficult to say exactly what it will be!

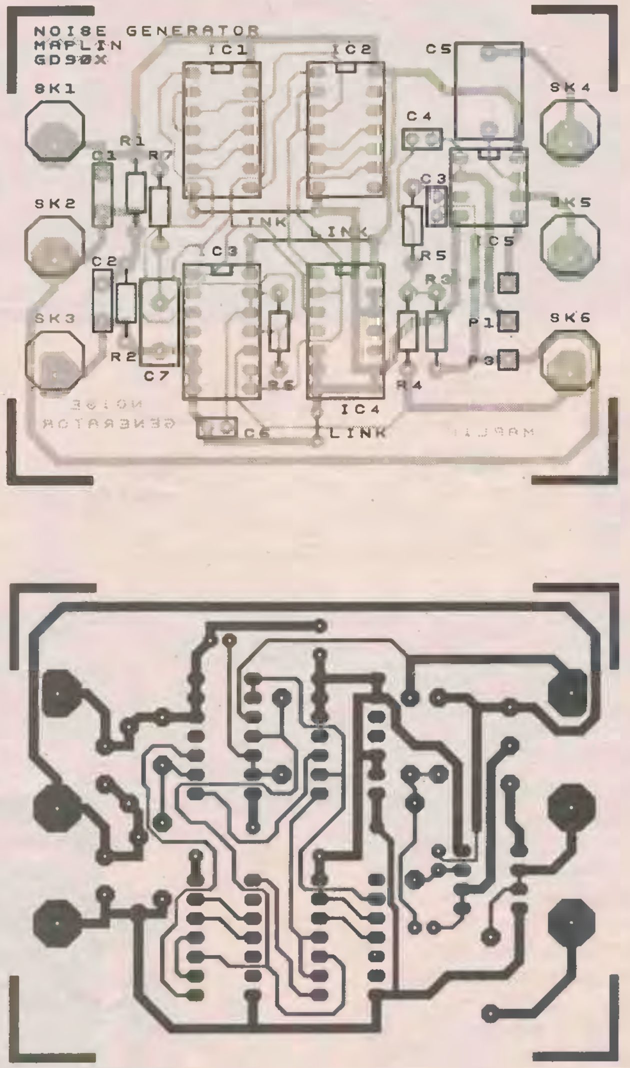


Figure 4. Track and overlay of PCB.

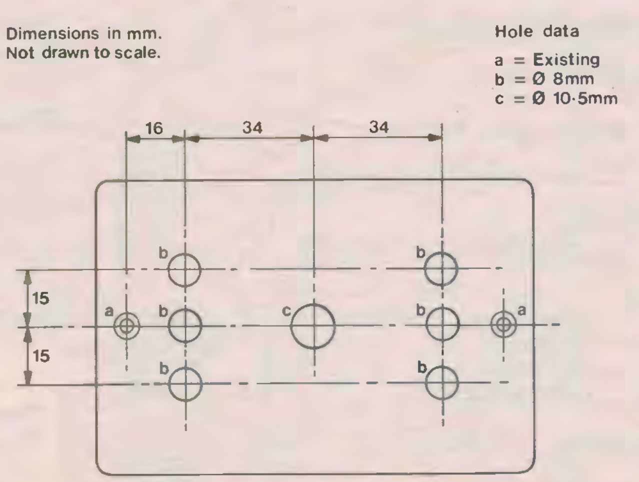


Figure 5. Case lid drilling details.

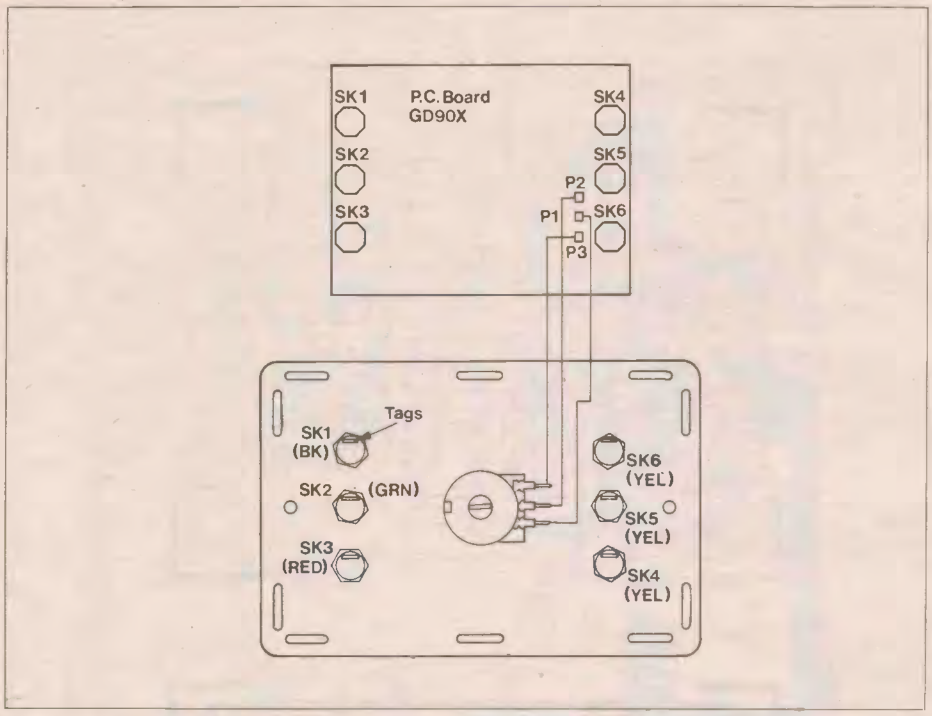
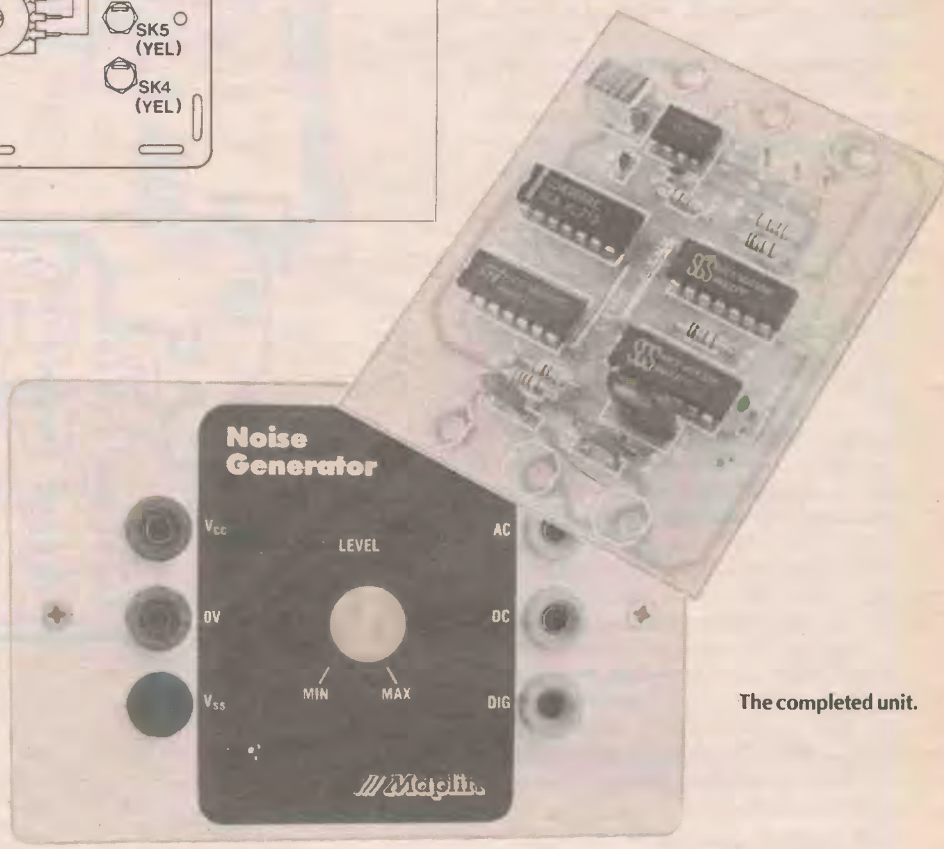


Figure 6. Assembly.

Using the Noise Generator

It is intended that the noise generator is operated from the power supply of the equipment under test, of course there is no reason why it should not have its own supply. A supply between +5V and +18V should be connected from Vss to Vcc, black and red sockets respectively. The green 0V socket can be left unconnected. If the equipment under test has a mid-supply rail then it can be connected to the 0V socket. This ensures the 0V rails will be at the same potential and thus the DC coupled noise output will have no DC offset with reference to the equipment 0V.

The exact method for coupling the noise into the equipment under test will depend on the exact nature of the equipment. Basically the noise must be added to the signal for which noise rejection is being tested. The simplest method is by means of a high value resistor, however this may be too basic in some cases. The DC coupled noise output should be used whenever possible as this output will not attenuate low frequency noise. Indeed when very low frequency noise performance is being tested this output must be used. If equipment DC bias levels must not be upset then the AC coupled output can be used, but remember the high pass filtering problem discussed above. In some cases this may not matter, for instance when testing equipment that works in the audio range (about 30Hz to 20kHz).



The completed unit.

NOISE GENERATOR PARTS LIST

RESISTORS: All 0.6W 1% Metal Film			
R1,R2,R7	4k7	3	(M4K7)
R3	150k	1	(M150K)
R4,R6	100k	2	(M100K)
R5	62k	1	(M62K)
RV1	1M Lin Pot	1	(FW08J)
CAPACITORS			
C1,C2	100nF Minidisc	2	(YR75S)
C7	100nF Mylar	1	(WW21X)
C3,C4,C6	10pF Ceramic	3	(WX44X)
C5	1μF Polylayer	1	(WW53H)
SEMICONDUCTORS			
IC1,IC2	4006	2	(QX03D)
IC3	4093	1	(QW53H)
IC4	4077	1	(QW47B)
IC5	TL082	1	(RA71N)
MISCELLANEOUS			
SK1	4mm Socket Red	1	(HF73Q)
SK2	4mm Socket Green	1	(HF72P)
SK3	4mm Socket Black	1	(HF69A)
SK4,SK5,SK6	4mm Socket Yellow	3	(HF75S)
	Collet Knob	1	(YG40T)
	Yellow Knob Cap	1	(QY06G)
	Box PB1 White	1	(LF01B)
	PCB	1	(GD90X)
	Front Panel	1	(JG29G)
	Wire	1 Pkt	(BL00A)

A complete kit is available:
Order As LM56L (Noise Generator Kit) Price £10.95
The following parts are also available separately, but are not shown in our 1988 catalogue:
Noise Generator PCB **Order As GD90X Price £3.95**
Noise Generator Front Panel **Order As JG29G Price £1.50**