For checking amplifiers, digital circuits, etc —

A low cost, high quality pulse generator

This new pulse generator design uses state-of-the-art circuitry to provide a standard of performance out of all proportion to its modest cost and parts count. You'll find it an ideal instrument for testing digital circuits and evaluating amplifiers, filters and attenuators.

by RON de JONG

Considering the simplicity of this new pulse generator design, its performance is most impressive. It provides pulses with a variable amplitude of between 1 and 10 volts peak to peak, at a low 50 ohms source impedance, and with rise and fall times of only 40 nanoseconds. The repetition rate is variable between 1Hz and 100kHz, and the pulse width from a nominal 1 second down to 1 microsecond. Similarly there is an adjustable delay for the main output relative to a 'scope triggering output, again variable from 1 second down to 1 microsecond.

In short, the performance is fully comparable with expensive professional instruments — yet you can build it for a fraction of the price.

This is largely because we have been able to take advantage of the latest state-of-the-art components: modern CMOS pulse generating circuitry, driving an output stage which is designed around one of the new VMOS power transistors. It is the VMOS device which produces the exceptionally good rise and fall times, and allows the new generator to provide 10V P-P pulses at 50 ohms impedance.

What can you do with a pulse generator? Well, it is just the thing for testing digital circuits. The ability to vary both the pulse rate and width makes it very flexible as a source of clock signals. And with an adjustable delay between the main pulse output and the oscilloscope trigger output, you can look at any part of the pulse waveform as the pulses progress through gates, shift registers and other parts of the circuit — even with a 'scope which lacks fancy delayed trigger facilities.

Needless to say, it can make it much easier to track down subtle timing errors, "race" conditions and the causes of mysterious "glitches".

Another important application of a pulse generator is in testing the transient response and stability of amplifiers, filters and attenuators, Since a pulse waveform is effectively a whole set of different frequencies spanning a broad range, it provides concise information on a variety of response parameters — some of which would be much harder to obtain by any other means.

A typical pulse waveform is shown in Fig. 1, with most of the important characteristics marked. The rise and fall times can give important information as to the frequency and phase response of a circuit, along with its "slew rate" or the maximum rate at which the circuit's output voltage can change (usually expressed in volts/microsecond). Similarly the tilt can reveal the circuit's low-frequency performance, while the overshoot and/or ringing can give a good idea of its stability.

Incidentally, if the risetime of a pulse fed to an amplifier or attenuator is very short compared to the risetime of the pulse when it emerges from the amplifier, the output risetime can be used to find the amplifier's high-frequency response quite simply. The two are related by the formula

$$Ft = 0.35/Tr$$

where Ft is the amplifier's upper turnover frequency, where its response has fallen by 3dB, and Tr is the risetime.

But enough of the theory. Let's have a look at the circuit of the

The finished instrument is housed in a neat plastic box and the "Scotchcal" label gives it a professional appearance. Note that the switches and pots for each function are grouped together for ease of operation. The socket in the right hand end is the 12V AC inlet from the plug-pack.

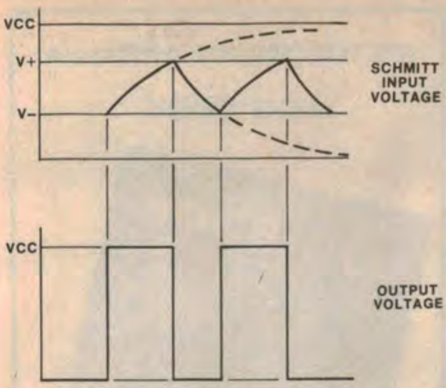


Fig. 2. Showing how a triangular wave at the input of the Schmitt trigger produces a square wave at the output.

new generator and see how it works. As you can see, it consists of four distinct parts: the pulse repetition oscillator, the delay circuit, the width circuit and the output stage.

The oscillator section is a simple relaxation circuit using an RC feedback circuit around a CMOS Schmitt trigger element. The Schmitt element is 1/6th of a 74C14 device, of which a second element is used as a buffer for the "scope output".

A Schmitt trigger element is similar to a normal inverter, except that it exhibits "hysteresis" in its switching characteristic. This simply means that its switching threshold for increasing input voltages is different from that for decreasing input voltages. In fact the threshold voltage for increasing input voltages (V+) is higher than that for decreasing voltages (V-).

The operation of the oscillator circuit takes advantage of this hysteresis effect. By connecting the output of the element back to its input via an R-C circuit as shown, the element is made to switch itself on and off alternately.

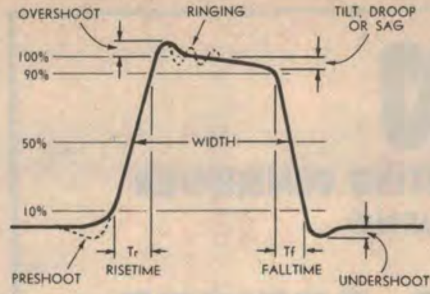


Fig. 1. No "square" wave is ever perfect, and this drawing shows the various faults and their manner of measurement.

The output (pin 2) of the 74C14 is taken back to the input (pin 1) via the 50k frequency pot and a 4.7k resistor, while the input is also connected to ground by one of a number of capacitors selected by S1b.

When power is first applied, the capacitor has no charge and holds the input at ground potential. Due to the inversion in the Schmitt element this makes its output go high; as a result the capacitor begins to charge up via the 50k pot and 4.7k resistor.

The charging continues until the capacitor voltage reaches the upper switching threshold of the Schmitt element, V+. When it reaches this voltage, the Schmitt element switches, and its output suddenly falls to ground potential. As a result the capacitor stops charging and begins to discharge, again via the 50K pot and 4.7k resistor.

The discharging continues until the capacitor voltage falls to the lower switching threshold of the Schmitt element, V-. Then the element switches again, its output goes high and the capacitor begins charging again. And this sequence repeats itself continuously, with the output of the element producing a series of pulses as shown, in Fig. 2.

Fairly obviously the pulse repetition rate or frequency is determined both by the R-C timeconstant and by the hysteresis range of the Schmitt trigger — i.e., the voltage difference between V+ and V-. The hysteresis does vary from IC to IC, but is substantially constant for a particular IC. Hence we vary the R and C values to adjust the frequency.

Switch S1b is used to select capacitors, to provide decade ranges in frequency. The 50k pot then provides continuous adjustment within each range. The maximum frequency for each of the five main ranges is 100kHz, 10kHz, 1kHz, 100Hz and 10Hz respectively, while the 50k pot allows interpolation within these figures and also extends the lower limit down to 1Hz.

Notice that S1b has a sixth position, in which the input is switched to a .01uF capacitor shunted by a pushbutton. In the same position, S1a of the same switch breaks the resistive feedback path, and connects the input instead via a 100k resistor to the +12V line. This produces a "single shot" facility, where a single output pulse is produced each time the button is pressed.

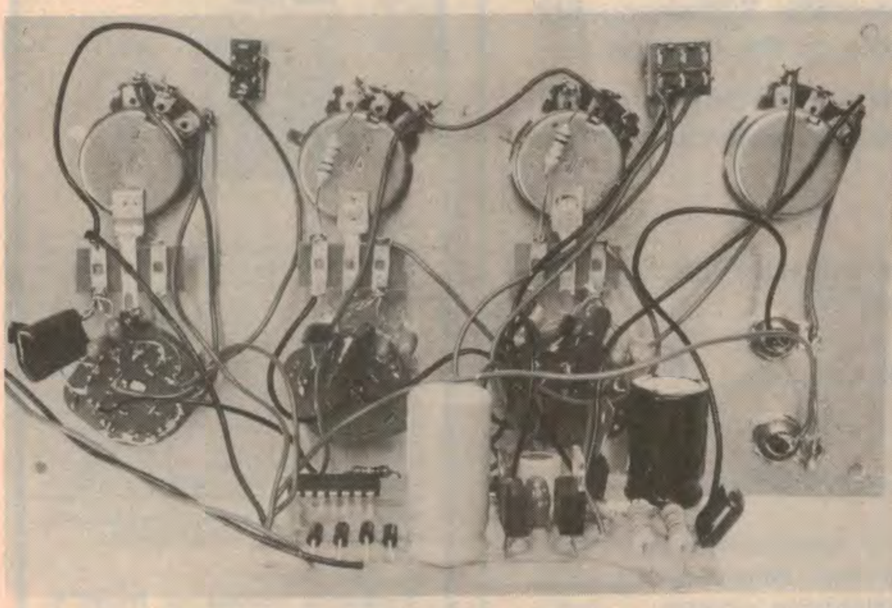
What happens in the single shot mode is that the pushbutton pulls the input of the Schmitt element low, forcing its output high as long as the button is held depressed. When the button is released the .01uF capacitor charges up via the 100k resistor, taking the Schmitt input above the V+ level and causing the output to go low. The time taken for the .01uF capacitor to charge provides suppression for contact bounce in the button, and prevents multiple pulses.

Although the pulse from pin 2 lasts as long as the button is depressed, this does not affect the output pulse width as the following circuitry is triggered only by the positive-going edge.

The output from the oscillator is buffered by another Schmitt element which drives the "SYNC" output. Since the trigger levels of CMOS Schmitt elements are fairly equally spaced about ½Vcc, the duty cycle of the "SYNC" signal is close to 50%. The regenerative nature of the gates also provides a clean signal which is free from spurious oscillations.

The output from the oscillator is also used to trigger the delay monostable, which uses one half of a 74C221 dual mono device. The monostable is connected in standard fashion, and is triggered from the positive-going edges of the clock output pulses. Switch S2 selects one of six capacitors to provide six decade ranges for delay, while the 100k pot provides a continuous adjustment within each range. The overall delay range is from one second down to 1us.

Actually the monostable itself simply produces variable width pulses, but these are used to produce a variable time delay by arranging for the follow-



Rear view of the front panel (turned upside down) with the printed board assembly. Note the terminal strips soldered to the pot covers, and used to terminate the capacitors from the switches and resistors from the pots.

PULSE GENERATOR

ing circuitry to again respond only to an edge of the monostable's output pulse. In fact the following circuitry is another monostable, using the second half of the 74C221, and is arranged to trigger from the trailing edges of the first mono's output pulses. The effective delay is thus equal to the width of the pulses produced by the first mono.

The second mono is connected in almost identical fashion to the first, except that its output pulses are used in their entirety to drive the output stage. So that the second mono's timeconstant determines the width of the generator's output pulses, rather than their delay relative to the sync output. Again the mono is provided with a switch S3 to select one of a series of capacitors for decade ranges, together with a 100k pot for continuous adjustment.

Note that the variable controls for both delay and width strictly have an 11:1 control range, due to the need to use standard preferred component values. However this is a little academic as the pots have a tolerance of ±20% anyway. This means that the scale calibrations can only be nominal; if accurate setting of pulse delay and width is required, it is best set using an oscilloscope.

Note also that the capacitor selected for the minimum pulse width and delay, ie 1us, is 82pF rather than the expected value of 100pF. This is mainly due to the parasitic capacitance of the monostable, which is 15pF; also some additional wiring capacitance.

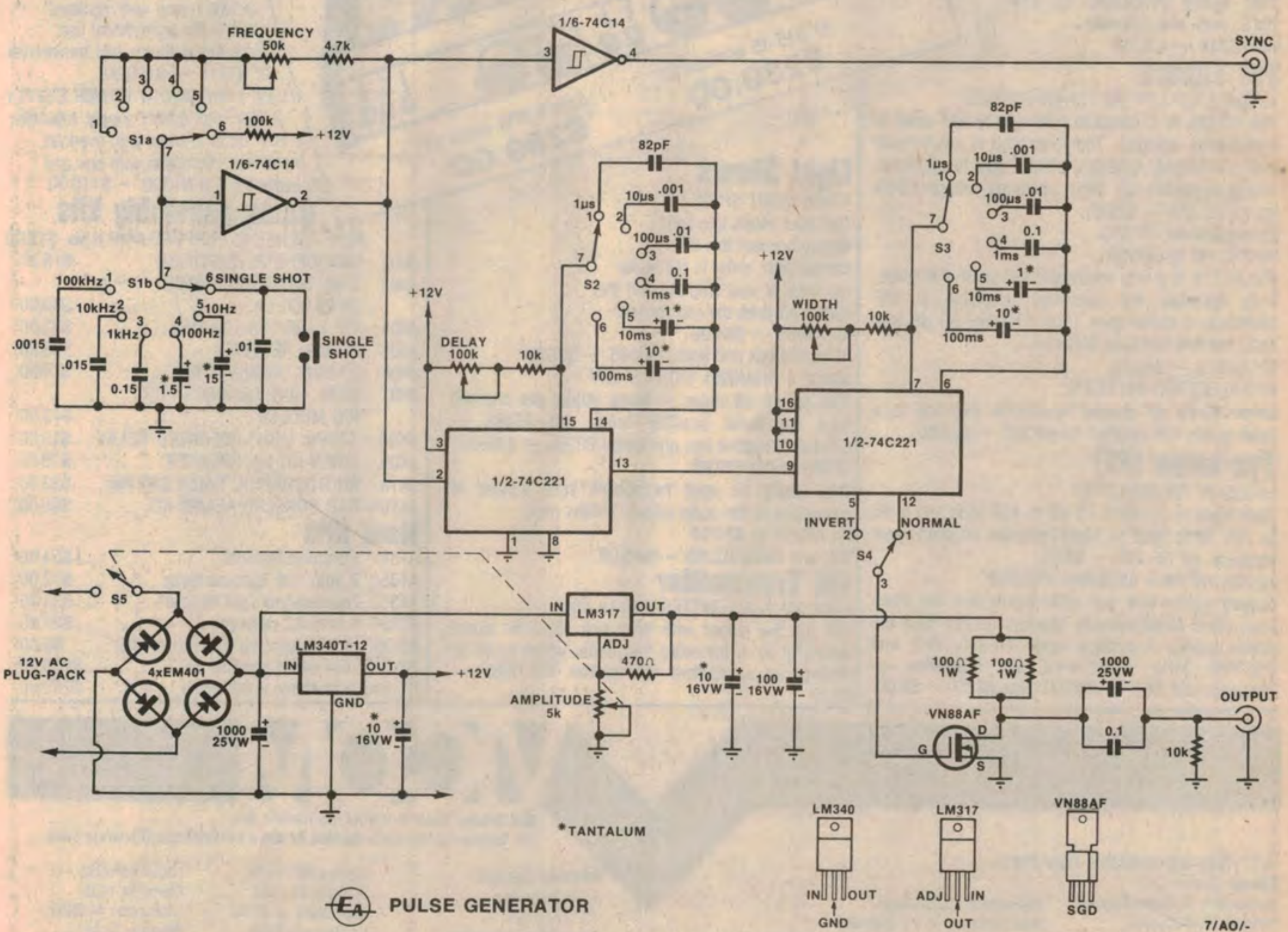
> We estimate that the current cost of parts for this project is approximately
>
> **$50**
>
> This includes sales tax.

As the width monostable provides both positive-going and negative-going output signals, switch S4 is used to select either one or the other to provide a choice of output pulse polarity. From S4 the selected signal then passes to the output stage, which uses one of the new VMOS power transistors, a VN88AF.

The VMOS device is used as a simple switch, with a 50-ohm resistive load formed by two 100ohm/1W resistors in parallel. The advantage of the VMOS device is that it can be driven directly from CMOS logic, and also that it is capable of very fast switching. It is a majority-carrier device, and does not suffer from the carrier-storage effects present in bipolar devices.

In a generator of this type, it is desirable to have the output impedance remain constant at 50-ohms, while still being able to adjust the pulse amplitude over a reasonable range. The conventional way of doing this to use a dual ganged 50-ohm pot, but the pot required must be of the non-inductive carbon type and must also have a suitably high dissipation rating. Such pots are both expensive and difficult to obtain.

To avoid the need for a such a pot while still meeting the constant output impedance requirement, we have used an alternative approach. The output pulse amplitude is varied by adjusting the output stage supply voltage, using an LM317 adjustable 3-terminal



At the top left is the Schmitt trigger oscillator, followed by the delay circuit and the width circuit. At the lower right is the VMOS output stage which is largely responsible for the generator's high performance.

regulator IC.

Because the VMOS transistor has a significant saturation voltage, the LM317 is arranged to vary the supply voltage over a wider range than the desired range in output pulse amplitude. In fact it varies the supply voltage between 1.2V and 12V, for a pulse amplitude range of 1V — 10V peak to peak.

Note that this amplitude range corresponds to the no-load situation, ie, open circuit output. Due to the fact that the generator has an output impedance of 50-ohms, the output amplitude will fall by 6dB if the output is fed into a matching 50-ohm load.

The output of the generator is taken from the drain of the VMOS device, via a DC blocking capacitor combination and a bleed resistor. These components could be omitted if DC-coupled output were required, or alternatively you could fit a shorting switch across the blocking capacitors to provide a choice of AC or DC output coupling. This is a matter of individual preference.

There is a separate 12V regulator IC for the rest of the generator circuitry. Both regulators are fed with unregulated DC from a conventional bridge rectifier, fed in turn with 12V AC from an "AC plug-pack" or plug-in transformer. This keeps down the cost of the pulse generator itself, while at

PARTS LIST

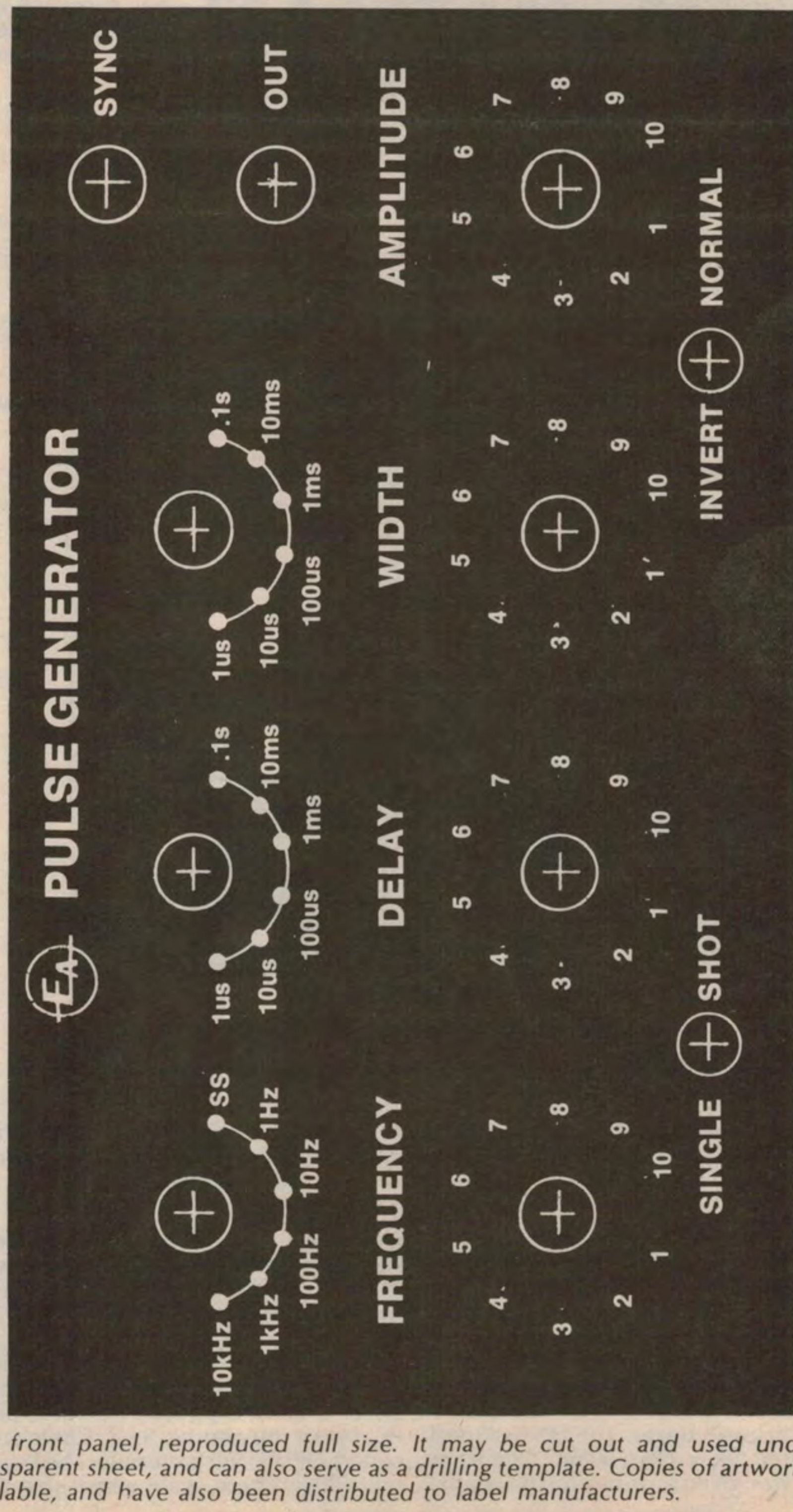
1 12V 500mA AC plug-pack transformer
1 utility box, 196mm x 113mm x 60mm
1 SPST momentary action push-button
1 SPDT miniature toggle switch
2 single pole 6-position rotary switches
1 Double pole 6-position rotary switch
2 100k linear rotary potentiometers
1 5k linear switch potentiometer
1 50k linear rotary potentiometer
1 PC board coded 79PG9, 59 x 91mm
2 RCA-type panel mounting sockets

SEMICONDUCTORS
1 74C221 CMOS IC
1 74C14 CMOS IC
1 VN88AF VMOS FET
4 4 IN4001 or similar power diodes
1 LM340T-12 three-terminal regulator
1 LM317 three-terminal regulator

RESISTORS ¼ watt: 100k, 3 x 10k, 4.7k, 470ohm 470ohm 5 watt.

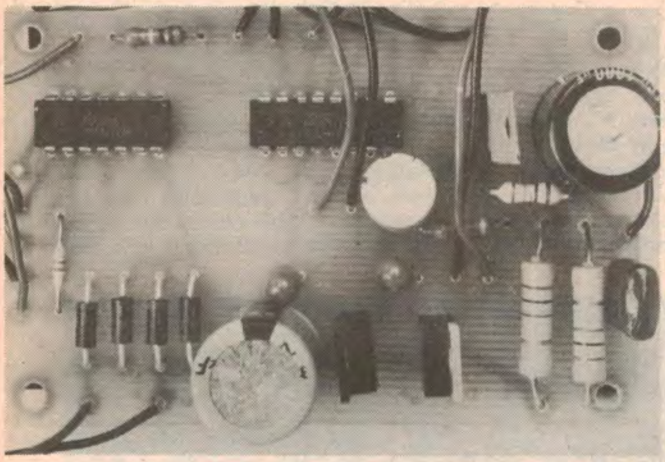
CAPACITORS
2 82pF polystyrene
2 .001uF greencaps
1 .0015uF greencap
3 .01uF greencap
1 .015uF greencap
3 0.1uF greencaps
1 0.15uF greencap
2 1.0uF 16VW tantalum
1 1.5uF 16VW tantalum
4 10uF 16VW tantalum
1 15uF 16VW tantalum
1 100uF 16VW tantalum
2 1000uF 25VW electrolytic

NOTE: Resistor wattage ratings and capacitor voltage ratings are those used on the prototype. Components with higher ratings may generally be used providing they are physically compatible. Components with lower ratings may also be used in some cases, provided the ratings are not exceeded.

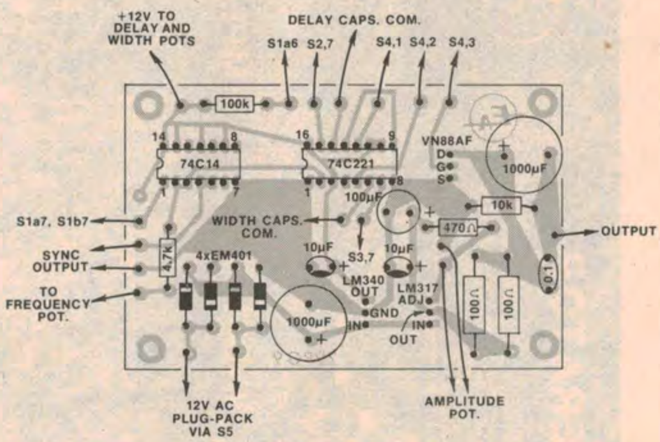


The front panel, reproduced full size. It may be cut out and used under a transparent sheet, and can also serve as a drilling template. Copies of artwork are available, and have also been distributed to label manufacturers.

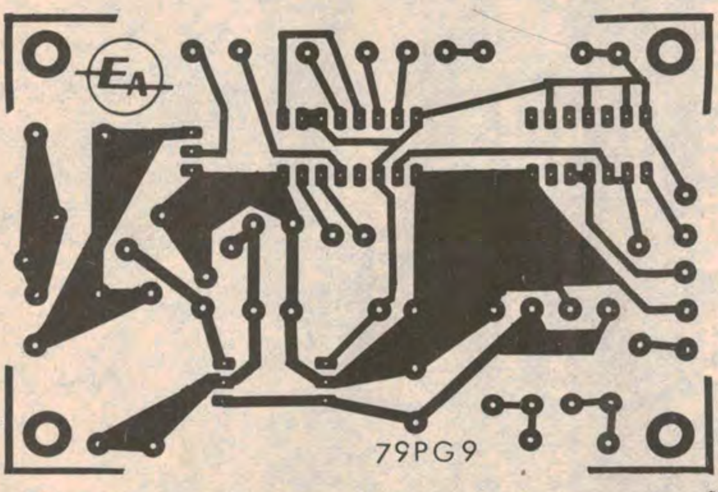
High performance pulse generator



The component side of the printed board, showing the general layout. Compare this picture with the overlay pattern below.



Overlay pattern showing placement of all components on the printed board, and identifying the leads to the panel switches and pots. Watch carefully the orientation and polarity of all components.



The printed board pattern shown exact size. Artwork has been distributed to the board manufacturers, and ready-made boards should be available by the time this article appears. Artwork is also available through our Information Service.

the same time allowing the plug-pack to be used to power a number of other instruments if desired. The AC plug-pack used with the prototype was a Ferguson type PPA12/500.

As you can see from the photographs, the prototype generator is housed in one of the low-cost plastic utility "zippy" boxes. The box we used measured 196 x 113 x 60mm. The front panel was given a professional look by means of a "Scotchcal" photosensitised sheet, and the artwork used for this is reproduced here actual size for the benefit of readers who may care to do the same.

All of the components except the various timing capacitors, the range switches and the pots are mounted on a PC board measuring 93 x 60mm and coded 79PG9. The pattern for the PCB is reproduced here again actual size, for those who may wish to trace or otherwise use it to make their own board. Patterns are also being sent to the various board manufacturers, so that ready-made boards should be available shortly.

Wiring up the PC board should be a relatively simple job, as we have produced an overlay diagram showing the parts placement and orientation. When you are wiring the board make sure that you insert the ICs and electrolytic capacitors the correct way around, and remember to observe the usual precautions when handling and soldering in the CMOS devices (including the VMOS output transistor). Make sure that the barrel and bit of your iron is connected to the "earthy" side of the PCB, and preferably solder the MOS devices into the PCB last of all.

The timing capacitors are mounted between the appropriate lugs of their respective switches and small tagstrips soldered to the backs of the pots, as you can see from the photograph. Lugs on the same tagstrips are also used to support the series resistors.

The output lead of the AC plug-pack is not provided with a plug, so we used a 2-pin DIN plug and socket of the type used for loudspeaker connections. Unfortunately while there is a cord-type socket, there is no panel-mounting plug, so we had to use a socket on the pulse generator and a plug on the input cable. This is not the best arrangement, but is probably acceptable as only low voltage is involved.

RCA phono-type sockets are used for the sync and main pulse outputs, to reduce cost. While not perhaps quite as suitable for an instrument of this type as higher-cost coaxial connectors, they are still quite satisfactory.

After completing the assembly of the generator, it is a good idea to check all components of the PCB for any errors. Similarly check the connections to the various controls, before applying the power. Having done this, the generator should spring to life as soon as power is applied.

No setting up is required, so that at this stage your new pulse generator should be ready for business.