Charge Storage in TRANSISTORS

Two unusual circuits using this effect

By K. T. Wilson

WHILE a transistor is conducting, charge is flowing between emitter and collector through the base region. The sign and direction of this charge will, of course, depend on whether the transistor is a *pnp* or a *npn* type. Some of this charge will flow to the base circuit, and the ratio of the amounts of charge flowing in the two circuits is the current gain or amplification factor, commonly represented by the symbol h_{fe}.

When forward bias is removed from the transistor, a certain amount of charge will still exist in the base region, and consequently the transistor will continue to conduct until this charge has been dissipated. If the base is sharply reverse-biased, base current will flow in the opposite direction to normal and will help to dissipate some of this excess charge.

This characteristic is used in several high-quality audio amplifiers to obtain an extended frequency response from power transistors. In such a case, using power transistors which would normally show a response 3dB down at 4kc/s, reverse base currents of 20 to 30mA may be flowing into the base of each power transistor in order to sustain a level response at 10kc/s.

STORAGE TIME

If the base is not reverse biased, however, the stored charge supports an undiminished collector current for some time until the charge is exhausted. This delay time is called the *storage time* of the transistor, and depends mainly on the current which the transistor was passing before base cut-off. Conversely, when forward bias is applied, current does not flow in the collector circuit immediately. In this case the odd phenomenon of *base-following* can occur—the collector voltage moves in phase with the base voltage until normal transistor action comes into effect.

Normally, both these effects cause considerable trouble in transistor switching circuits, and combined efforts had to be made by transistor designers and by circuit designers to give us the very fast switching arrangements which exist today.

It is possible, however, to design circuits which make deliberate use of these two charge storage effects.

A PULSE SHARPENER

Fig. 1a shows a pulse-sharpener which makes use of the switch-on time. With no input, the transistor is held cut-off by the positive bias developed by the current flow through the diode, D1 via R2 and R3. If a negative pulse is now applied to the input, the output will follow the input potential until the transistor switches on. When this happens, the output potential goes very sharply positive, cutting off the diode. In this way, a sharp spike very suitable for triggering purposes can be produced from a rather poor square wave or any other waveform with a reasonable rise time over a limited voltage. The waveforms are shown in Fig. 1b.

A DELAY CIRCUIT

The second circuit shown in Fig. 2a depends on the switch-off time and the *base-following* effect. The bias on TR1 is adjusted until roughly half the battery volts are dropped across R1. In this condition, both diodes are back-biased by about 4½ volts each and if the input pulses are less than this, they will not change the state of the transistor. If a negative pulse of greater amplitude is applied, it will appear unchanged at the output of the transistor without causing any switching action, as the diode D2 is back-biased.

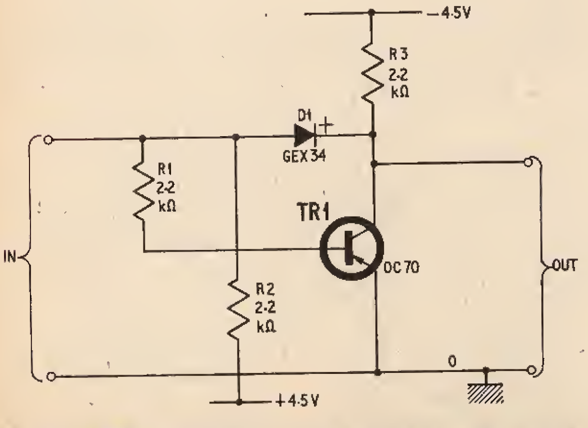

Fig. 1a. Basic circuit for a pulse-sharpener utilizing the "switch-on time" effect. The transistor and diode specified are suitable for pulses not narrower than 1μs

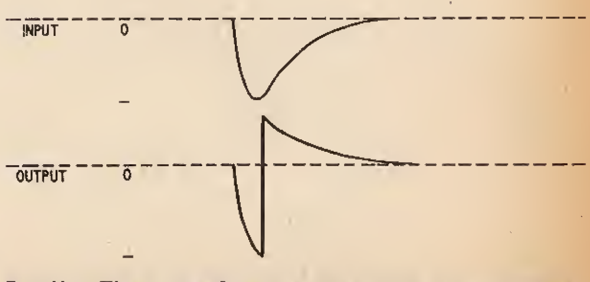

Fig. 1b. These waveforms show how the output initially follows the input, but swings very sharply positive when the transistor switches on

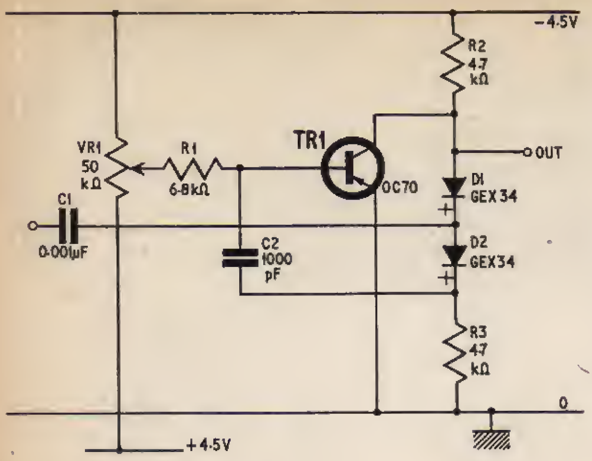

Fig. 2a. Basic circuit using the base-following effect

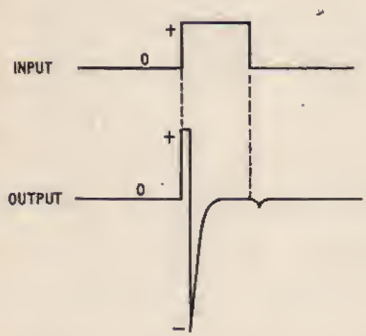

Fig. 2b. These waveforms show how sharp positive and negative pulses are obtained from a positive input pulse

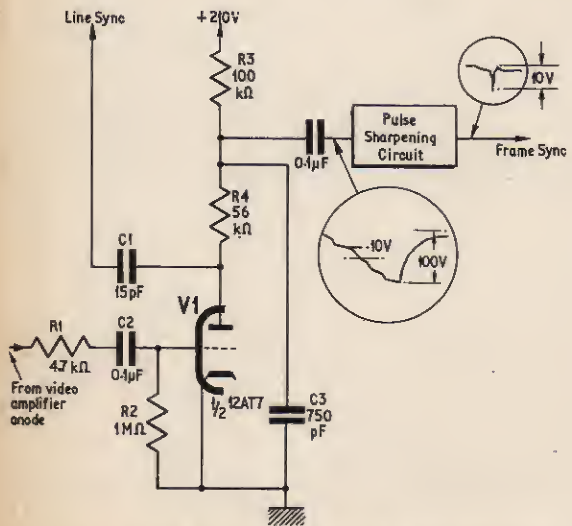

Fig. 3. A practical application of the pulse-sharpener is this arrangement to produce a sharp pulse for frame sync in a TV receiver

If a positive pulse is applied, however, D2 conducts, the pulse appears at the base of TR1 and, since the transistor does not switch off instantly, the positive pulse also appears at the collector. Both diodes D1 and D2 are now in a conducting state and the pulse at the collector serves to sharpen that at the base in *bootstrap* fashion until the transistor switches on.

This circuit can be used to discriminate between positive and negative pulses, to obtain sharp positive and negative pulses from a single positive pulse or from the leading edge of a square wave, or to obtain a pulse delay of a fixed amount. It should be noted that the values of the coupling capacitors have very little effect on the waveforms.

Some examples will now be given of practical applications of the two effects illustrated in Fig. 1 and Fig. 2.

FRAME SYNC PULSE

One use of the pulse sharpening circuit is shown in Fig. 3. On most television receivers, the frame sync pulse is obtained by integration, and the resulting waveform consists of a series of steps superimposed on a slowly rising waveform. The frame time base requires a sharp pulse for really good synchronisation, however, and the usual circuit does not provide it, so faulty interlace and even frame jitter are common faults. The use of the pulse sharpening circuit greatly improves this. Only one of the steps is sharpened, the others occurring either while the transistor is too far beyond cutoff to respond, or when the transistor is fully on. Thus one, and only one, sharp pulse is delivered to the frame time base, and perfect synchronisation is the result.

IMPROVING A SQUARE WAVE

Another use for the pulse sharpening circuit is shown in Fig. 4. In this case, the problem is a square wave generator whose output has an insufficiently sharp edge. With older type valve operated square wave generators, this usually occurred with the positive going leading edge of a positive square pulse.

This problem is tackled in a slightly different way, as the output pulse must be very considerably sharpened. The leading edge of the pulse is picked off at an earlier stage of the generator, where it is negative-going and still fairly sharp. This is differentiated and applied to the sharpening circuit which produces a negative pulse followed at once by a very sharp positive pulse. This positive pulse is picked off by a diode and added to the square wave whose positive leading edge is defective. The excess is then clipped off by a Zener diode, and the result is an excellent square wave.

OSCILLOSCOPE TRIGGERING

Fig. 5 shows how the circuit of Fig. 2 can be used to provide the facility for oscilloscope triggering in a pulse generator.

Unless the oscilloscope is triggered before the arrival of the pulse being observed, the front edge of the pulse will not be seen due to the time needed to start the time base. If the trigger for the pulse generator (whether internal or external) is sent through a delay circuit so that the original trigger is used for the oscilloscope and the delayed trigger is used for the pulse generator, then the whole of the pulse will be visible on the c.r.t. This is a useful facility which is often missing on home-made pulse generators.

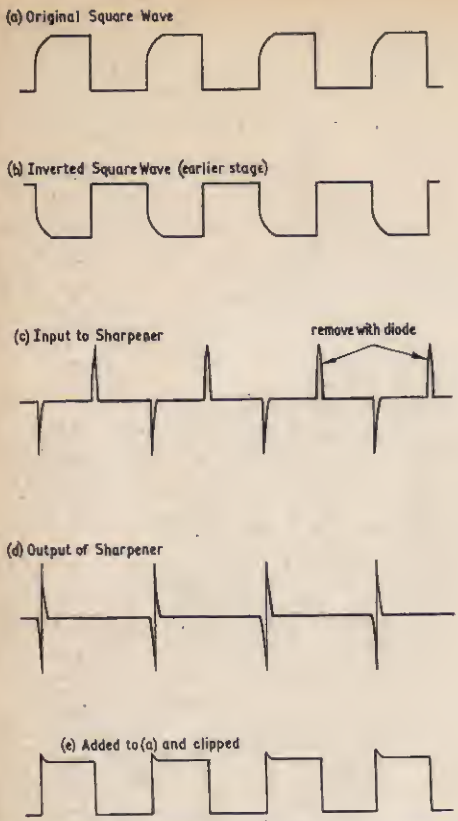

Fig. 4. Deficiency in the leading edge of a square wave can be restored by the process depicted in the waveforms (a), (b), (c), (d) and (e).

Finally, as shown in Fig. 6, the circuit of Fig. 2 can be used to generate square waves of variable width. The output of the circuit is applied to a Schmitt trigger so that a pulse applied at the input of the circuit produces a square wave whose width can be altered within limits by varying the bias on the base of the transistor TR1.

PRACTICAL NOTES

Since, in each of these circuits, the properties of the transistor rather than the external components determine the action of the circuit, almost any transistor will work.

Small a.f. transistors, with a cut-off (common-base) of a few hundred kilocycles, will give output pulses of one microsecond or better; r.f. transistors can produce pulses with extremely rapid rise and fall times and widths of down to 50 nanoseconds. The author's prototype circuits were built on "Veroboard", but any construction is suitable as long as it is remembered that stray capacitance must be kept to a minimum round the collector circuit. A rather straggly layout is often better for the purpose of reducing strays than a very neat "everything-close-to-the-baseboard" form of construction.

Some variation in performance may be noted using different diodes. The same type of switch-off problems exist for diodes as for transistors. The point contact diodes specified are suitable for use with the transistors specified, but those who aspire to very fast-rising waveforms will have to use faster diodes such as those used in computing. For most purposes, however, it is not necessary to use the ultra-fast gold-bonded type of diode; in fact the virtue of these circuits is that they enable sharp pulses to be produced with the minimum of expenditure in components. ★

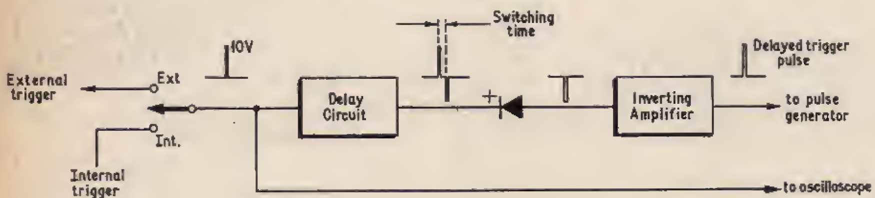

Fig. 5. An arrangement for using the base-following effect to provide a delayed triggering facility for an oscilloscope

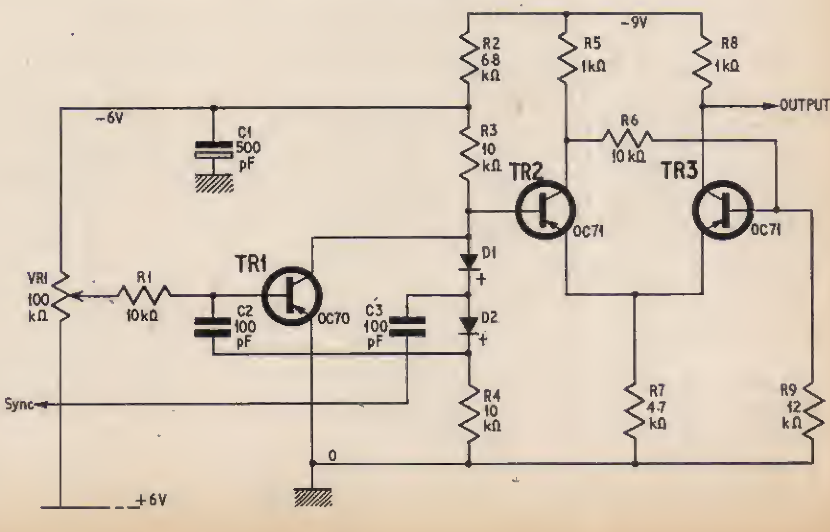

Fig. 6. This circuit provides square waves of variable width and is derived from Fig. 2