Analogue gate applications

The final background article in the series

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THE HAZY WORLD between analogue and digital systems is populated with a variety of strange and legendary creatures. One of these is the perfect switch, as hopelessly quested after as the Holy Grail as hunted as the Snark. As a long-time connoisseur of Boojums it has become obvious that we can hope for no better.

Good design is always a question of exploiting the behaviour of the available devices, of working within their limitations and not against them. The first step is to identify these limitations for the alternative devices, to see the implications and applications that follow. Consider first the on-off switch. This function can be duplicated by any device for which the resistance can be charged between two distinct levels. Ideally the resistance should be zero in one state infinite in the other and with no injected error voltages or currents. An adequate performance is possible provided the off-on resistance ratio is greater than 10^4, though useful results are obtained at ratios down to 10^2 while ratios above 10^6 are becoming commonplace.

The changeover switch presents a different kind of problem. There is no direct electronic equivalent of such a switch, and it has to be synthesized by two separate on-off switches driven antiphase. This is not easy since if the conduction periods overlap then two different e.m.fs are placed temporarily in parallel. If there is a gap between the conduction periods problems arise with any current source that is open-circuited. The problem is clearly worse in multipole systems.

So far the switches, by implication, are able to operate between any pair of points regardless of their potentials. To bring ourselves down to earth (or ground) the transistor and f.e.t. switches of Figs 1, 2 and 3 illustrate the realities. Each can be switched from an off state where the resistance is very high to an on-state of moderately low resistance – anywhere between 10Ω and 1kΩ depending on the device. In the bipolar transistor the off-state is the normal one, with a forward bias voltage/current required to bring the collector-emitter path into conduction. This base current flows on through the emitter to the supply common line. For a junction f.e.t. which is a depletion-mode device the drain-source path is normally conducting and a reverse bias on the gate is needed to switch it off.

The enhancement-mode device of Fig. 3 requires the same sense of voltage drive as for the bipolar transistor to bring it into conduction, but the gate current is vanishingly small. The advantage is clearly seen by drawing the bipolar transistor switches with non grounded terminals as in Fig. 4. The base current then has to flow in either the source or the load. Further, the required drive voltage is affected by the magnitude and sign of the signal voltage, since at one extreme the device might receive excessive bias while at the other the signal might be sufficient to hold it permanently off.

This raises the question of how the drive voltage or current is to be derived. In the junction f.e.t., for example, the gate drive voltage is of opposite polarity to the normal drain source voltage and will normally require a dual supply system. The m.o.s.f.e.t. avoids the current requirements of the bipolar transistor and the reverse voltage needs of the junction f.e.t.

To summarize the imperfections that can exist Fig. 5 shows one equivalent circuit for a bipolar transistor in its switching mode. When the switch is open (no base current) the finite R_{off} still permits some current flow. When the switch is closed there is a voltage drop that depends in part on a resistive term R_{on}, but includes a voltage V_p the

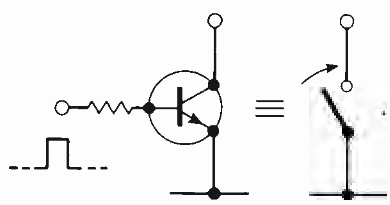

Fig. 1

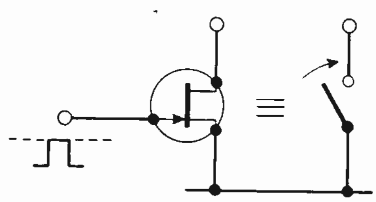

Fig. 2

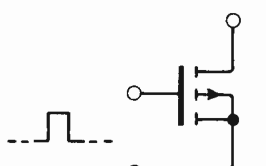

Fig. 3

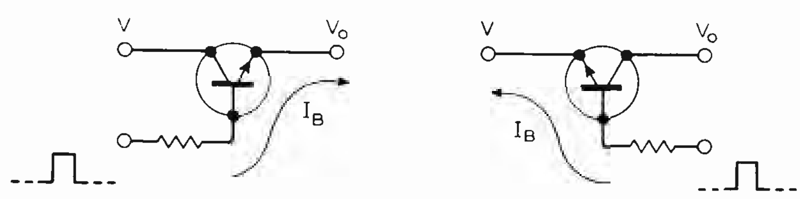

Fig. 4

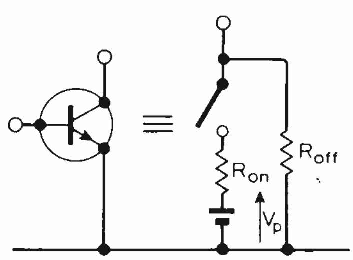

Fig. 5

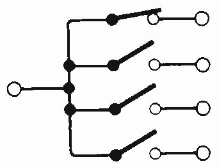

Fig. 6

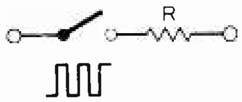

Fig. 7

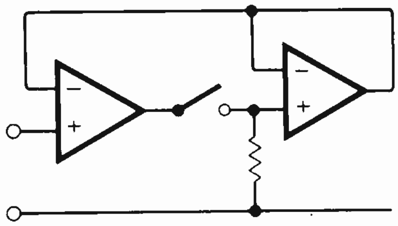

Fig. 8

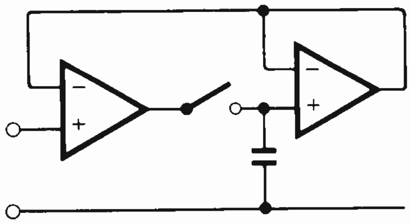

Fig. 9

pedestal voltage that is present even in the absence of current flow. This last term is absent from the equivalent circuits of both forms of f.e.ts making them preferable for low-voltage applications. The equivalent circuit is partial; it applies only to the static conditions, takes no account of the load presented to the switching voltage, and more important does not indicate the effects of the transients in the switching voltage. At high frequencies, low voltages or both these transients inject error currents into the output that can have the same overall effect as offset and drift voltages in operational amplifiers.

These limitations are very relevant to the process of multiplexing, of using a singlechannelto convey multiple sets of information. As a simple example, Fig. 6 shows a set of switches which can be used from left-to-right to transfer a single signal to one of a number of lines. Alternatively it can be used from right to left as a data selector i.e. transferring one out of a number of signals onto a single line.

A quite different application where transient properties are important is that of a switch that is periodically opened and closed (Fig. 7). If the rate at which this happens is very fast compared to any signal frequencies applied to the switch, then it is the fraction of the time for which the switch is closed that is significant. For a given voltage applied to the switch, the current remains inversely proportional to the resistance, but its average value is halved if the switch conducts for only 50% of the time; it is reduced to a quarter if the switch is closed for only 25% of the time and so on. The average current and hence the equivalent value of resistance is varied by the mark-space ratio of the switching waveform. This is an application of pulse width modulation to the control of circuit and system behaviour.

The examples quoted so far, have the switches used in open-loop systems. They can be very effective within feedback systems and two applications are shown in Figs 8 & 9. The first shows the switch at the location that would be occupied by a diode in a well-known form of precision rectifier. In fact if the switch is activated by a separate comparator that senses the input, it duplicates the function with some advantages. Replacing the resistor by a capacitor, creates a peak rectifier in the case of a diode, and a sample-and-hold circuit in the case of a switch. It is a testing application for the switch, since the speed of response should be high, the on-resistance low to allow the capacitor to sample rapidly, and the off-resistance should be high to avoid discharging the capacitor in the hold mode.

These are some of the areas in which analogue gates can be applied. Analogue gates are economically available in c.m.o.s. form. They have excellent performances in respect of drive input impedance which is virtually infinite, and an off-resistance which is also extremely large. Their on-resistance is less ideal though falling as new devices are introduced. The high-frequency behaviour is such as to permit operation to above 1MHz, while they are useful both as low-level choppers and as high-level switches. The gate-drive voltage is logic-level and the analogue signal may have any potential between the supply limits. It is for the flexibility that they add to circuit design that they are perhaps most welcome – no more need to waste time on special drive circuits, but instead use that time on applying them to a wide-range of useful functions. □

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Twenty circuit cards devoted to analogue gate uses – sets 34 & 35 – concludes the Circards circuit information service. Individual back sets are available for £2 each (ten cards minimum) inclusive of UK and surface mail (ten sets are £18) and reprinted bound volumes of sets 11 to 20 are still available for £14.50.