A SYMMETRICAL ROUTE SWITCH FOR ELECTRONICS

by Michael Soper

THE logic relation 'exactly two of *a*,*b*,*c*, are true', or ((*a*,*b*,*c*,)), can perform all standard logic functions: for example, *a* = not *b* is ((T,*a*,*b*)) where T denotes true.

This enables the consideration of a new approach to circuitry also. We can move to see how relational approaches differ from standard ones. Suppose the function '*a* implies *b*' is T = *c* is required to have implementation. We may then use the symbol in

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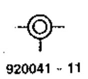

Fig. 1to denote ((*a* *b*,*c*,)).

The network in Fig. 2 will perform this task. That is, ((*a*,*d*,*e*)), ((*b*,*d*,*f*)), ((*e*,*f*,*h*)), ((*f*,*h*,*c*)), since *a* implies *b* is true, is equivalent to ((¬ *a*) v *b*) is true, the auxiliary condition *c* = 1 or T together with our NOT function above gives OR and NOT, from which all functional logic can be created. Each cell is almost equivalent to the XOR function, but, since XOR cannot create all logic alone, our relational system is simpler and more powerful, since it *can*

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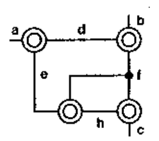

This logic system can be amended somewhat to provide a practical type of circuit element. The essence of the system consists of a symmetrical element with three wires and the rule that only two of the wires can carry current in either direction at any one time. That is, the circuit appears as a pi circuit in which exactly one of the three impedances has a low value at any one time. 'At any one time' is important. There will be some impedance to the low state, but this impedance can be relatively low. Thus, we have a dynamic new type of circuit element. The rule is that the middle voltage on the three wires is the high-impedance input. We may make the low impedance a partially linear function of high impedance voltage if required.

We may be keen on this approach for various reasons: one of them is symmetry, another is operational simplicity. The manufacture of devices that are both logic and analogue is straightforward. The devices themselves would not be suitable for very high speeds until much development work is done, but this is not often a requirement.

The increased flexibility of use is a great advantage; for example, three-phase oscillators where the high impedance rotates about the device are possible. Many other standard approaches become simpler and with the devices any active circuit function, except the diode and very high speed, can be carried out. In theory, they can also be made to have no supply lines as operational amplifiers do, but the stability of this approach requires analysis. Thus, the distinct possibility exists of a new and useful three-wire device: the Symmetrical Route Switch—SRS.

Liberation from directivity

The advantage of these devices is that they can be connected *any way* round at all. Thus, electronic methods can be non-directive in the sense that once a low-impedance link is established between two parts of the circuit, current can flow either way. This totally symmetrical property is new for an active element with three wires (the group of Symmetries is S3).

The ability to rearrange elements in this way is a very considerable advantage. The devices can be used for linear or digital applications and are, therefore, apart from speed, more powerful than transistors. The power of the system lies in the fact that only capacitors, resistors, diodes and SRSs are required for circuit implementation (the occasional use of inductance, although rare, is not ruled out).

One more factor is that the device can float at any potential and is, therefore, free from the restrictions that separate power lines to the device impose (this would be difficult to achieve at low voltages, but then SRSs with separate power lines would be used). Thus, the device defines its own relative levels and will not fail, as opamps do, when inputs are at disparate levels from the output.

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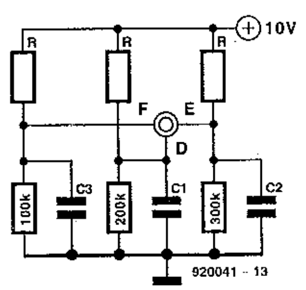

In other words, however complex the interior of the device, its behaviour is still intrinsically simple and the designer's friend.

One symmetrical route switch can serve as the active element in a circuit that oscillates while rotating the high impedance option about the centre of the device—see Fig. 3. In this circuit, on turn-on, D is high impedance so that C_1 is charged first until the voltage at D is greater than that at E, whereupon E becomes the high impedance and C_2 will be charged while the voltage across C_1 drops. If the values are chosen properly, C_3 is the next capacitor to be charged and the voltage on F increases. The cycle then begins again. In that way, a very simple one-device oscillator circuit has been designed.

One device and perhaps six resistors and three capacitors is a component count that could be reduced if a slightly different operation is required, say, not such a symmetrical wave. Therefore, although one-transistor, coil-less oscillators can be designed, the circuit in Fig. 3 has a more predictable and usable response and can thus be used as required. That done, other circuits can be completed for similar purposes.

Now, the linear use.

Continuity

In order to use a symmetrical route switch for linear applications, we must bias the middle electrode so that it remains high impedance.

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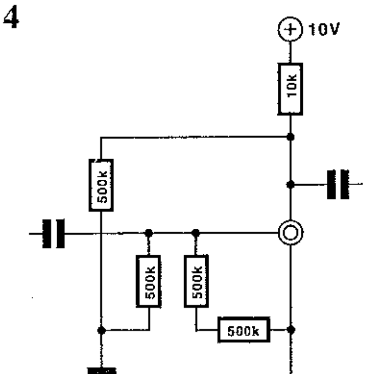

The circuit would then appear as shown in Fig. 4. Note that the low impedance is directly proportional to the input voltage and steps must, therefore, be taken to prevent positive feedback. Apart from those requirements, the circuit is standard. The main point to make here though is that this is not the best utilization of a symmetrical route switch, since the sixfold symmetry is not used But it must be said that linear amplification over the natural range of use of the device can be obtained Multi-stage amplifiers with or without feedback can be built with the device We thus already have dual types of operation: logical and linear

Promotion

The reason that such a system should be promoted is clear: simplification Although in extreme applications like very fast switching of low-noise amplifiers the SRS is probably best replaced, the neat and interesting possibilities the SRS creates suggest that it should ascend from the status of a theoretical curiosity to that of practical implementation.

One difficulty of the common transistor is that at the end of its standard range of operating conditions there is not always any discontinuous change into another mode, thus indicating a fault

The system itself can be designed economically Let U,V,W be the voltages at the three electrodes and I the current in the conducting branch Then,

$$V + W - 2U = V_1 + |I|\tanh(\alpha V_1)$$
$$U + W - 2V = |I|\tanh(\alpha V_1) - V_1$$
$$U + V - 2W = V_1 - |I|\tanh(\alpha V_1)$$

where $I = \alpha V_1 = \alpha(V-U)$ [for transistor]
or $= \alpha\{(2V-U-W)/2\}$ [for SRS]
α = gain
$\tanh(x) = (e^x - e^{-x})/(e^x + e^{-x})$

These equations are included to give some idea of how a relational law can be defined. With this approach the SRS can easily be modelled on a computer The device is non-linear over a wide range with this law but linear over a small range of signal inputs Whether or not designers wish to appreciate the flexibility of the SRS depends on how skilful they are and, of course, on the cost of the device. In order to present a unified approach of relational logic and relational amplification in one object, it may be true and it must be admitted that many extreme active circuit functions cannot be performed by this device, but the very great advantage of flexibility coupled with symmetry should not be ignored

In fact these devices can be scaled up whenever required and will prove useful at any scale Design techniques are very different and in a sense relational, not functional Also the positive feedback feature makes for more rather than fewer useful circuits

Another oscillator circuit—a relaxation type—is shown in Fig 5 This type can have an 'amplifier' positively coupled back to a shunt capacitor over any number of stages, since all stages in the SRS's 'common-emitter-like' configuration have positive feedback

The chief strength of the SRS is for current routeing, which will be reverted to later

However, the ease with which either oscillators or amplifiers can be made is encouraging and leads one to speculate on how active electronics would have turned out if active devices had originally had 'in-phase' output and input

Transformation

A transformation that mirrors the behaviour of the symmetrical route switch with one electrode at high impedance is the following: $v = v_{in}$ (between the common electrode and the high impedance electrode, where v is referred to either the mid-voltage of the output electrodes or the voltage on one of them) and $R = R_{o(ut)}$ is the (variable) resistance of the low-impedance (output) electrode and the common electrode

$$R = R_o + (1-\alpha v)u/(1+u) + \alpha v$$

where v is again referred to either the mid-voltage of the output electrodes or the voltage on of them, α is the gain and $u = (\alpha v)^{100}$

The use of a formula like this makes design work easy. The formula is chosen to have an almost perfect ramp before cut-off when the output electrode become high impedance: a change of state An explicit formula can easily be written into a computer program, after which a simulation can be run and new circuits tried out The juxtaposition and connection of many such circuits can be simulated Relational rather than functional thinking can be difficult to get accustomed to, but in the phase shift oscillator of Fig. 6 the ease of operation makes sense. Although this is a good example of the SRS used functionally, this really does not exploit the special properties of the circuit In Fig 7, however, our previous oscillator circuit produces a much better example of the use of a symmetrical route switch, since the switch is used symmetrically

However, symmetrical use does involve a switching operation in the SRS and is thus not suitable for most linear circuits An exception may be made for some class D or push-pull amplifiers The distinction between linear and non-linear operation is also usually the distinction between stable use where small inputs produce small outputs and unstable use where a change of state in the device may occur. Class D amplifiers produce quasi-linear operation out of extremely non-linear components. The ramp function of our SRS combines both modes of operation—but may the effective slope of the amplification be changed? The best linear use of any symmetrical route switch is with a constant current tail of, say, current i, when

$$V_{out} = iR = iR_o + i\alpha V_{in}$$

under these conditions of linear use—see Fig 8. Connecting a feedback impedance R_1 with feedback factor $1/n$ we find

$$dv = V_{out}/n$$

so that

$$V_{out} = i\{R_o + \alpha(V_{in} + V_{out}/n)\}$$

In other words, the output resistance and the effective transconductance are increased; the gain of the stage increases also and is usefully a function of i, the quiescent current The factor $1/n$ depends linearly on R_1 so that we may replace R_1 by another suitable SRS to obtain a stage with negative gain. Thus, when more than one SRS is used—see Fig 9—we have the capability of building an inverting stage: with constant current

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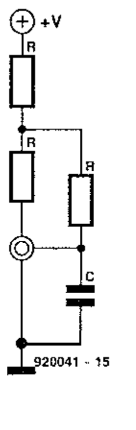

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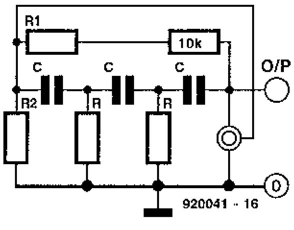

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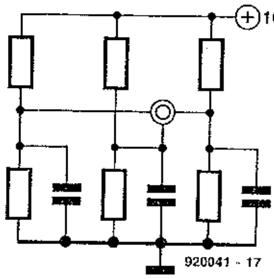

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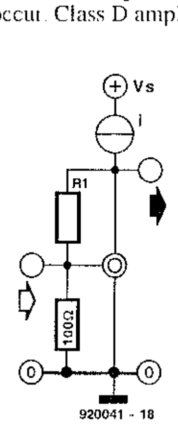

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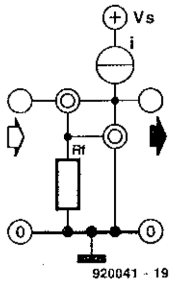

supplies, the linearity can be very good

Buffer stages

The symmetrical route switch is naturally suitable as a buffer stage when it is used linearly—but, of course, this is not the best use because the flexibility of the device is ignored. For good linearity, a constant-current stage can be used: the linearity of the SRSs is a direct function of the quality of the constant current supply. This fact and the symmetry of the high-impedance input connection means that stages can be paralleled for lower impedance or be put in series with no great problems as long as the input electrode sits at the correct point with respect to the output electrodes. Even this feature is simpler on the SRS because, as long as the voltage on the input electrode lies between the voltage of the output electrodes, the behaviour will be linear at all times (given that the voltage is 'one side' of midway).

To reduce the output impedance of a transistor stage to low values, an emitter-follower is used: a circuit with negative feedback which similarly has non-linearity. The use of negative feedback is possible for the SRS when the input voltage is nearer the more negative 'through' electrode, because the gain is then negative and a simple impedance is enough. A diagram of the series connection is given in Fig. 10.

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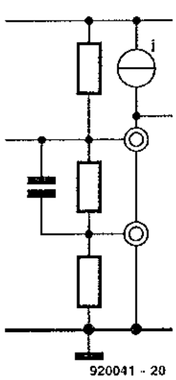

For the reason just given, a 'switching' symmetrical route switch can make an ideal method for shunting out large currents. A suitable circuit is shown in Fig. 11. Assume the left-hand side of this to be temporarily positive: as the current increases, the voltage across the low resistance increases also until the knee voltage of diode D is reached.

Since the circuit is symmetrical under

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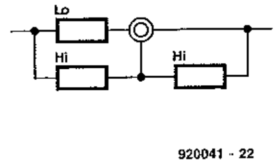

some conditions, the same approach will work for alternating current also: a simple design for use with this case when the component values are correctly chosen is shown in Fig. 12.

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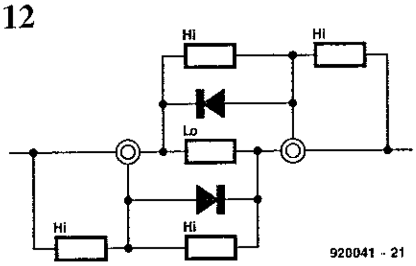

Routes

The name symmetrical route switch suggests also that they can be used for signal routeing: a task they are ideally suited for. Consider the simple arrangement in Fig. 13.

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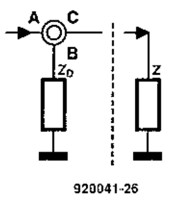

While electrode B has a voltage between that of A and C, the signal will actuate load Z. But when the voltage on electrode B is above that on A and C, the signal is dissipated in matched load Z_d. The advantage is almost perfect matching. Practical circuits for AC and DC are given in Fig. 14.

Designing a bistable from symmetrical route switches in conventional ways is possible but clumsy; a bistable based on an SRS on-impedance of 10 Ω is shown in Fig. 15. With 4.5 passive components per active device, this circuit is not very practical. The circuit in Fig. 16, however, is, mainly because it has greater natural stability.

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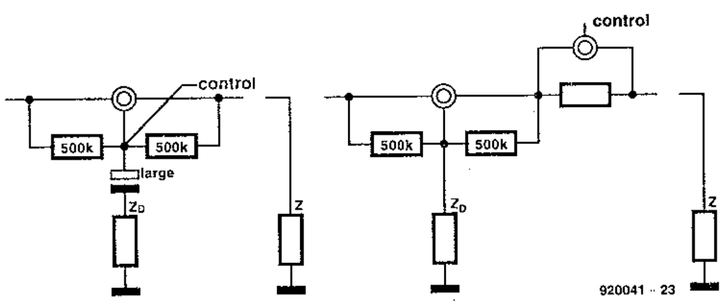

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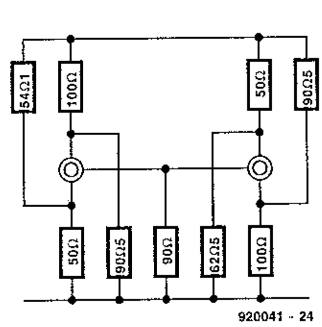

The symmetrical route switch combines a non-linear function, as required for switching and for load and power supply protection, with at least two kinds of linear function: transistor-like and symmetrical input function referred to midpoint, when required. Thus, two distinct circuit operations are combined in one circuit. Look inside many hi-fi amplifiers and you will see that until recently small relays were used for protection on overload. The symmetrical route switch combines this function also, because, although it is a three-terminal device, the control connection (at very high impedance with respect to the others) controls the output impedance. Hence, one device can perform all logic, linear action and protective switching.

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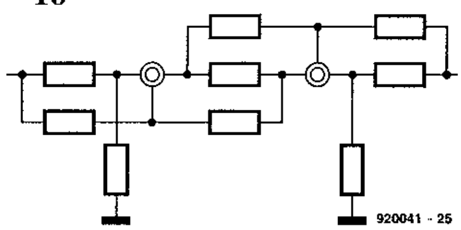

The route ahead

Integration of circuits has led to a large pin-out count on many integrated circuits, followed by a partial reduction. Some useful ICs are three-terminal devices, usually unsymmetrical and polarized, although a few are symmetrical. The symmetrical route switch is the first three-terminal device capable of logic and linear action, which can be inserted *any way* into a circuit. The power it takes is absorbed from the current through the output impedance. ■