DESIGN IDEAS

Exploring negative resistance: the lambda diode

by Samuel Dick

RESISTANCE is omnipresent in electronics A few materials (super conductors) lose their resistance at fairly low temperatures and all materials lose it completely at absolute zero However, at normal temperatures, most (conducting) materials obey Ohm s law, but some show characteristics of negative resistance Are these breaking Ohm's law? And what good is negative resistance?

Dynamics

Ohm s law must be one of the simplest (and most remembered?) equations of elementary electricity. To determine the resistance of a component. apply a voltage across it and measure how much current flows through it The resistance equals the voltage divided by the current:

$R=U/I,$

where R is in ohms, U in volts and I in amperes

For many objects, their resistance may be thought of as constant If a resistance is plotted over a wide range of voltages as in Fig 1, it will be seen to be pretty linear: the resistance is the reciprocal of the gradient But this situation is true only under certain conditions If the temperature at which the measurements are made is varied, (slightly) different values of resistance will be obtained For instance, the value of most carbon film resistors changes by 0 03% °C^{-1} However. for most purposes, the humble carbon resistor is regarded as being 'linear': the current through it is directly proportional to the voltage applied across it.

Not all devices are so well behaved and we need not look at exotic devices to find an example The wire-filament light bulb is non-linear! As the voltage applied across it is increased, the filament heats up and its resistance increases The bulb will pass a lower current at higher voltagessee Fig 2 A similar effect is seen with a diode: it passes little current as long as the applied voltage is below 700 mV (at least, in case of a silicon diode)

A device may, therefore, have different values of resistance, depending on the level of voltage applied across it The application of Ohm's law is always correct, because its answer is the resistance at the instant the measurement was made, that is with constant circuit parameters When the resistance of the light bulb or diode was measured, the voltage was kept constant when the current was measured Because the resistance was measured in this way, it is referred to as static resistance

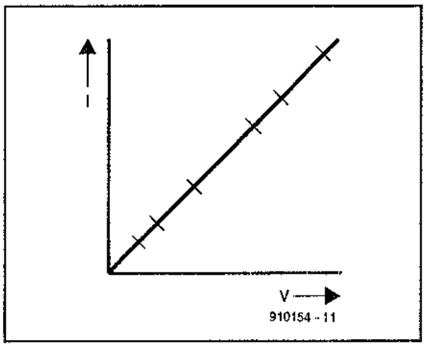

Fig.1. *V–I* curve of simple resistor.

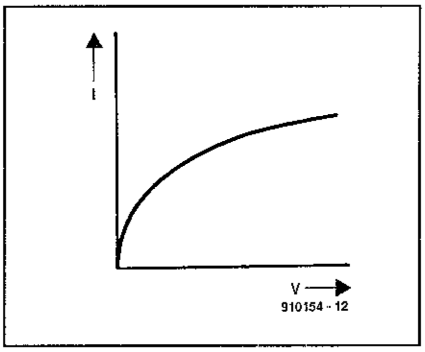

Fig. 2. *V–I* curve of electric light bulb

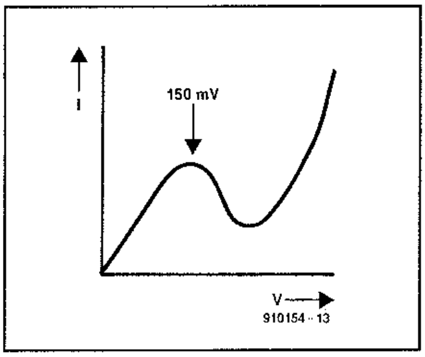

Fig. 3. *V–I* curve of tunnel diode

A more interesting notion is that of dynamic resistance If Figures 1 and 2 were plotted with the current rather than the voltage along the x–axis, the resistance at any point would be merely the gradient of the curve This is referred to as the dynamic resistance because it is measured as a resultant of changing circuit parameters.

While the static resistance is the voltage divided by the current. the dynamic resistance is defined as a change in voltage divided by the (resultant) change in current In this definition, it should also be noted at what voltage the dynamic resistance was measured In the case of a resistor, the dynamic resistance is constant and equal to the static resistance But for the light bulb or the diode, the gradient, that is the dynamic resistance of their curves is a function of the applied voltage.

If the gradient of most devices is plotted, it will be found to be invariably positive But for a few devices, part of the curve has a negative gradient, and thus a negative dynamic resistance For instance, Fig 3 shows the behaviour of a tunnel diode: at a voltage of 150 mV, the current stops increasing and decreases instead The tunnel diode, in this region, has negative resistance. Of course if you applied a voltage of, say, 200 mV (in the negative slope region) and measured the current, it would have a sensible positive value. It is not the static resistance that is negative, but the change in current is in the opposite sense (it decreases) compared with normal positive resistance devices when the voltage is increased

But how is negative resistance used? Tunnel diodes are used in oscillators monostable and

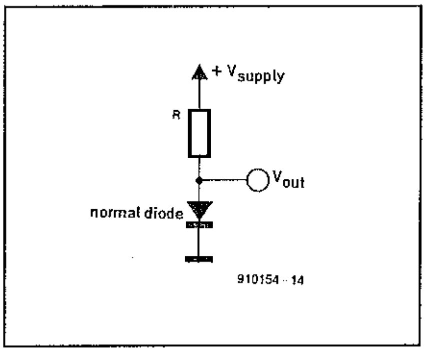

Fig. 4. Series resistor-diode network.

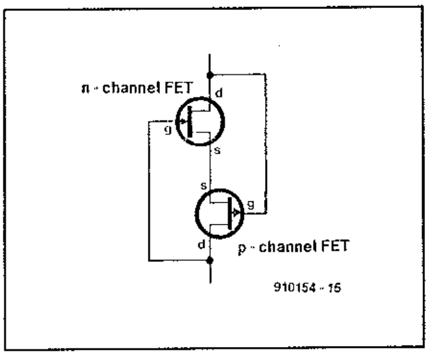

Fig. 5. The lambda diode.

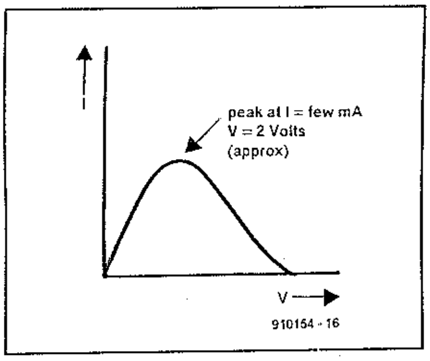

Fig. 6. *V–I* curve of the lambda diode.

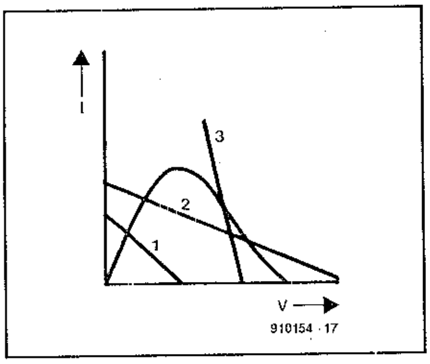

Fig. 7. Three possible load lines for the lambda diode: (1) monostable; (2) bistable; (3) oscillator.

bistable circuits. Which type of behaviour is exhibited depends on how the device is biased Biasing is merely the term for setting up the circuit around a component so that it operates correctly, but note that negative dynamic resistance devices have several correct operating modes

Load lines

To determine how to bias a device, a simple graphical approach may be used Take the example of a resistor and diode in Fig 4 How can we calculate at what voltage the anode of the diode will run? If we plot the current-voltage behaviour of the diode, a curve like that in Fig 6 would be obtained If the diode were not in the circuit the maximum voltage that could be present at the diode end of the resistor would be the supply voltage, V_s If the diode were short-circuited the maximum current that would flow would be V_s/R These two values may be taken as the two ends of a line on the same graph That line represents all the possible solutions to our problem. Since the diode must operate on its characteristic curve, too, the point at which the two curves intersect tells us (a) at what voltage and (b) at what current the anode of the diode will be These lines are known as load lines

So, by drawing the load lines, we may determine what are the operating points of any circuit. This is very simple in the case of the diode. Regardless of where we draw the load line of the resistor, it will intersect the characteristic curve of the diode in only one place. Note, however, that in the case of a tunnel diode or other device demonstrating negative resistance, there are several possible characteristics

The lambda diode

While tunnel diodes are relatively rare, *n*–channel and *p*–channel FETs are common By combining an *n*–channel and a *p*–channel FET as shown in Fig. 5, a negative resistance device is formed It is called the lambda diode, because its characteristic curve—see Fig 6—looks like the Greek upper case lambda, Λ.

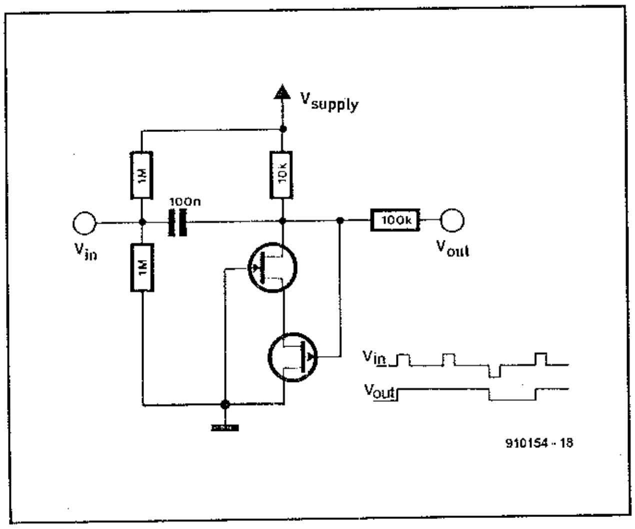

Fig. 8. Bistable circuit

Figure 7 shows three possible biasing schemes for the lambda diode In the first, the device has only one intersection or operating point Despite any perturbations, the simple resistor and lambda diode combination will settle down to operate around this point: its point of stability

In the second case, there are two points of stability: that is, the combination will work as a bistable If it is at the lower-voltage point, momentarily increasing the voltage (for instance, by a pulse fed via a capacitor—see Fig. 8) will cause the circuit to stabilize at a higher voltage point By applying a pulse in the opposite sense, the circuit will switch back to the first operating point: it is a bistable.

In the third case, there is only one operating point again but it is situated on the negative slope region of the characteristic curve Here, given the right circumstances, the circuit may be made to oscillate If a pulse is applied to the resonant *LC* circuit, the circuit will ring at a frequency given by

$$f = 1/2\pi\sqrt{LC},$$

where f is in Hz, L in H and C in F.

In an ordinary circuit the resistance in the circuit causes the energy of the oscillations to be lost and the circuit ceases to oscillate But if the resistance is countered by a negative resistance, the circuit will resonate indefinitely

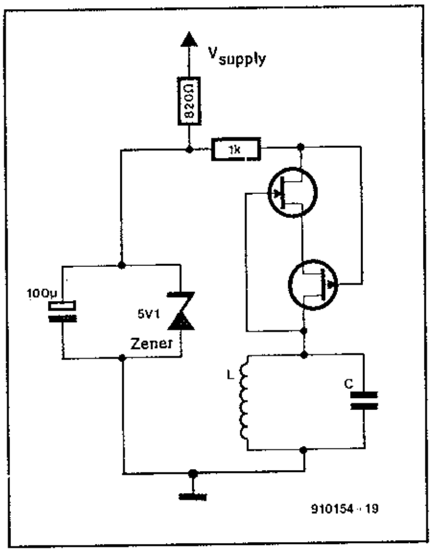

Fig. 9. Simple *LC* oscillator.

Figure 9 shows a suitable circuit for experimentation: $V_{s(upply)}$ is in all cases 12 V The circuit tends to be very stable: typically, the drift is ≤100 p.p.m. per hour. The amplitude of the oscillations is about ±2 V The output of the oscillator in any practical applications must be buffered, otherwise the load caused by the following circuitry represents additional resistance As the power of the circuit is limited by the peak current that the lambda can draw (typically a few mA), a buffer stage is invariably required

When the tuning capacitor is shunted by a varactor diode, the circuit may be tuned electronically. Note that the circuit is simplified by having only one tuning capacitor and a single, tap-less inductor, unlike the classical Hartley and Colpitts oscillators ■