Field Effect Transistors

A guide to the basics.

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Field effect transistors, or FETs, are widely used in electronic circuits today and are taking over many of the tasks for which we previously used the bipolar junction transistor. We will look at the difference between the two types, but before we can do that, we must say something about semiconductor junctions.

There are two types of semiconducting material, p-type and n- type. There is not enough space here to go into the nature of these materials, or precisely what their names mean, but the essential point is that something interesting happens when we join p-type with n-type.

The pn junction (Fig.1) is the basis of many semiconductor devices. The simplest of these is the diode which consists of a single pn junction. A diode conducts in only one direction. This is because of the nature of the pn junction. What happens is that when the two types of material are placed in contact, a potential difference appears between them. The n-type has a potential of 0.7V higher than the p-type. Further, on either side of the junction, there appears a depletion zone, a zone in the semiconductors in which there are no carriers of electric charge (*eg*, no electrons).

To make current flow across the junction we apply a voltage greater than 0.7V as in Fig.2. This overcomes the voltage between p-type and n-type, the depletion zone disappears and the diode conducts. It is said to be forward-biased. But if we apply a reverse voltage, the depletion zone simply becomes wider, as in Fig.3. There is no conduction.

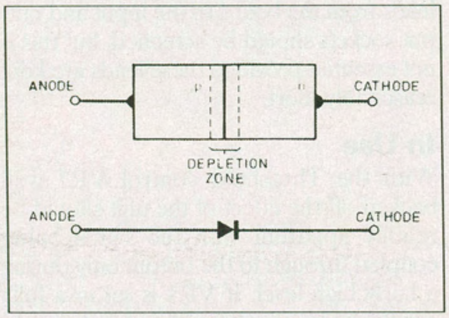


Fig.1. The Diode, diagram and circuit symbol.

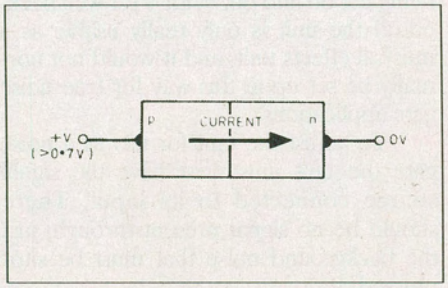


Fig.2. Forward-biased, diode conducts.

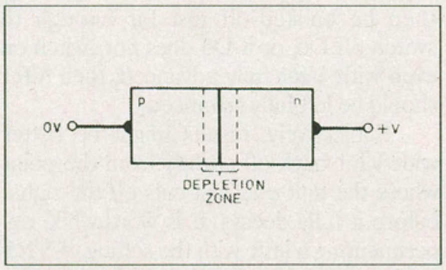


Fig.3. Reverse-biased, diode does not conduct.

Bipolar Junction Transistor

Now we are ready to look at the action of a bipolar junction transistor, Fig.4. The npn transistor (the commonest type used today) has a very thin layer of p-type (the base) sandwiched between two n-type layers (collector and emitter).

Taken together, the base and the emitter form a diode, as do the base and collector. If the base is made positive of the emitter (more than 0.7V), current flows in at the base and out at the emitter.

It might be thought that it is impossible for any current to flow from collector to emitter, since the collector-based diode would be reversed-biased. However, because the base layer is so thin, quite the opposite occurs. As Fig.4 shows, when a small base current IB flows from the base to emitter and the collector is a few volts positive of the emitter, it causes a much larger collector current IC to flow from collector to emitter.

Electronic Switch

By turning the base current on or off, we can turn the collector current on and off — the transistor works as a switch. Since the collector current is much bigger than the base current (20- 200 times) we can also use the transistor as a current amplifier.

Field Effect Transistor (FET)

The FET works in an entirely different way. Fig.5 shows it to be a single bar of semiconductor material (n-type in this example, but it could be p-type). Current flows freely along the bar of n-type material. Normally one end, the drain, is

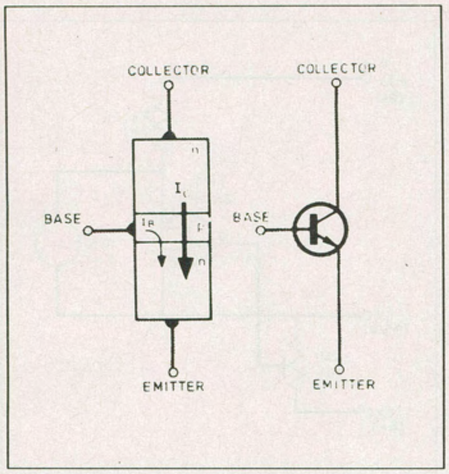


Fig.4. Bipolar junction transistor, diagram and circuit symbol.

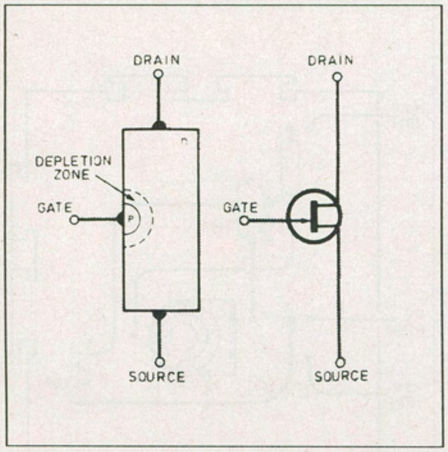


Fig.5. Junction FET, diagram and circuit symbol.

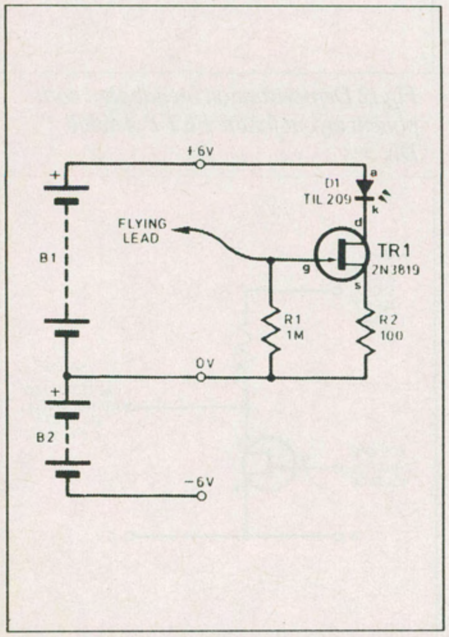


Fig.6. Circuit diagram demonstrating switching action of an FET.

made positive of the other end, the source, so electrons flow from the source to the drain.

To one side of the bar is a small region of p-type material, the gate. This is surrounded by a depletion zone , as explained above. The depletion zone insulates the gate from the drain and the source.

If the gate is at zero volts (with respect to the source) the depletion zone is small. Electrons cannot flow through this zone, so it restricts the flow of electrons along the bar, but not unduly. However, is the gate is made negative of the source, the gate and n-type material are equivalent to a reverse-biased diode. The more negative we make the gate, the wider the depletion zone becomes. The conducting region of the bar gradually becomes pinched off, reducing the current along the bar. If the gate is made negative enough, the depletion zone extends right across the bar and no current can flow.

The action of this type of transistor depends not on the flow of current (such as the base current of a bipolar transistor) but on the effect of the electric field caused by the potential of the gate. This is why it is called a field effect transistor.

FET Switch

A circuit to demonstrate the switching action of a FET is shown Fig.6. The LED D1 is used to show wether or not current is flowing through the FET. The demonstration breadboard component layout for the FET switch is shown in Fig.7.

With the flying lead unconnected,

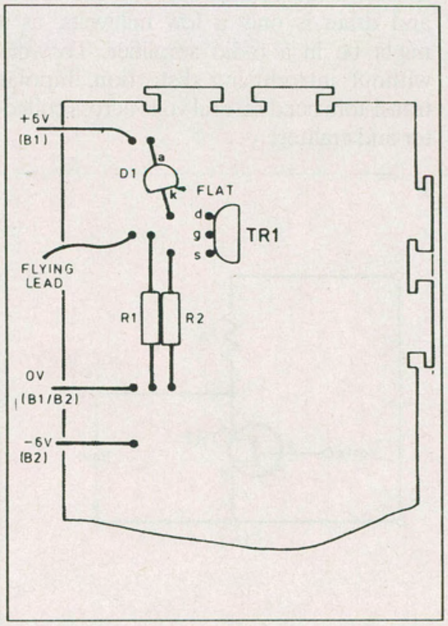


Fig.7. Demonstration breadboard component layout for the FET Switch..

resistor R1 brings the gate potential to 0V. With the lead unconnected, the LED is on.

Now touch the flying lead to the -6V terminal. The negative voltage at the gate, makes the depletion zone so wide that the drain-source current is pinched off. The LED goes out.

Like the bipolar transistor, the FET can be used as a switch. It has the advantage that its switching action is very fast. It has another advantage that becomes apparent in our next demonstration.

A simple FET Touch Switch circuit diagram is shown Fig.8. The circuit has the gate connected by a short lead to a small metallic touch plate. This could be a thumb tack pushed into a piece of wood.

The demonstration breadboard component layout for the simple FET Touch Switch is shown Fig.9. Switch on the power and note that the LED is off.

Now touch the touch-plate with your finger. It is obvious that the amount of current that passes between you and the gate is extremely minute. Yet the act of touching the plate is enough to turn the LED on.

Normally, the touch plate and the gate have a potential about 0.7V below that of the rest of the transistor. Your body has a potential somewhat higher than this. This is due to the fact that you are surrounded by electromagnetic fields generated by the alternating currents flowing in wires in your house, or in the power lines outside. Add to this the effect of friction as you move around, and you finish up with a potential relatively higher than that of the gate.

When you touch the plate, a minute current flows for an instant. The potential of the gate is raised, the depletion zone decreases and the FET becomes more conductive.

Increased current flows through resistor R1 and the potential at point A (Fig.8) rises. This causes an increased base current to flow from A to TR2, turning TR2 on and causing the LED to light.

This investigation shows that the amount of current needed to operate FET is virtually nil. Such a device is ideal for use in logic circuits where thousands of transistors have to be switched on perhaps millions of times a second. The saving of power is enormous.

Before leaving this circuit, try wiring up the touch plate with a longer lead, say 20cm long. Explain the effect of this change.

Now substitute a short piece of insulated wire, stripping at both ends, as the touch plate. Try the effect of touching the bare end. The effect of touching the insulated part of the wire. Can you explain

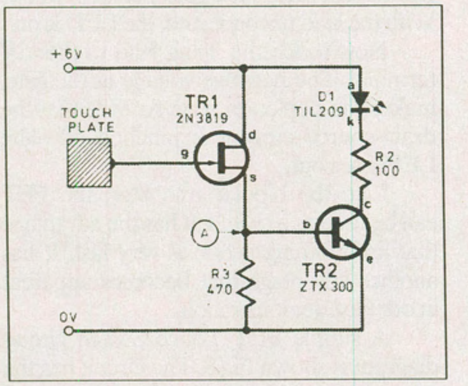


Fig.8. Circuit diagram for a simple Touch Switch. The touch plate can be a metal thumb tack or a piece of stripboard, with tracks interconnected.

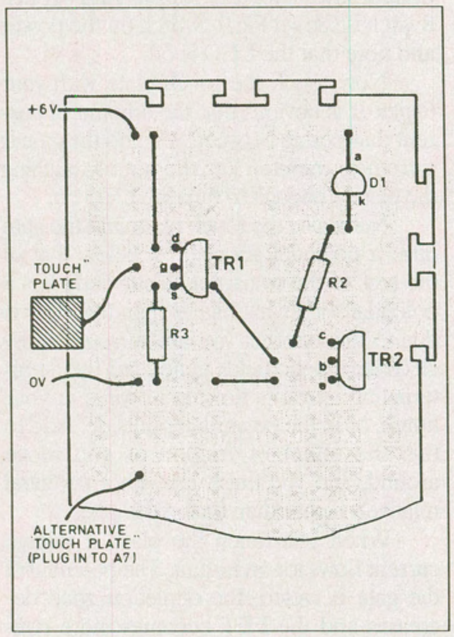


Fig.9 Demonstration breadboard component layout for the FET Touch Switch.

what is happening?

Voltage-Controlled Resistor

The bar of n-type material in FET has a resistance which varies according to the width of the depletion zone. The width depends on the gate potential. Thus we have a resistor whose resistance is controllable by its gate potential.

How this property may be used is shown in Fig.10 Fig.10a is that well known configuration of resistors—the potential divider. Vin is related to Vout like this:

$$Vout = \frac{Vin + RB}{RA + RB}$$

If either or both of the resistors are variable, Vout can be varied. Fig.10b shows a circuit using a FET in place of RB. A variable negative voltage is applied to the gate. A typical circuit diagram for a FET potential divider is shown in Fig.11. To demonstrate this circuit, connect the components on the breadboard as shown in Fig.12 and see what happens.

This type of circuit has many applications as a voltage- controlled attenuator. You have probably used a remote-controller to adjust the volume on a TV set. At some stage in the sound amplifier, the sound signal passes through such an attenuator. The attenuator is controlled by a voltage from the remote receiver IC (Fig.13).

Although it is possible to construct an attenuator from bipolar transistors, FETs are better. This is because they work just as well if the voltage between the source and drain is only a few millivolts, as it might be in a radio amplifier. To work without introducing distortion, bipolar transistors need several volts across collector and emitter.

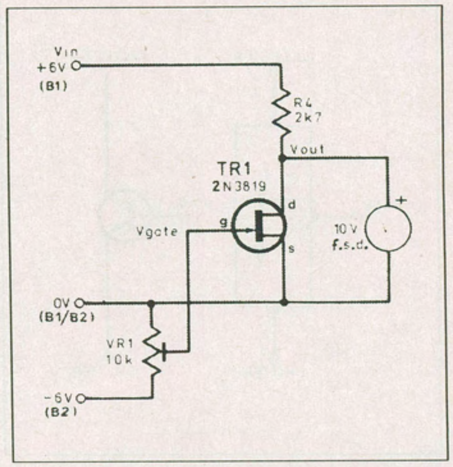


Fig.11 Demonstration FET Potential Divider circuit diagram.

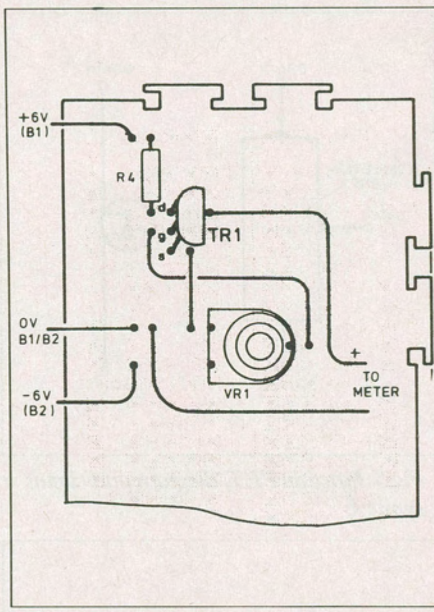


Fig.12 Demonstration breadboard component layout for the FET Potential Divider.

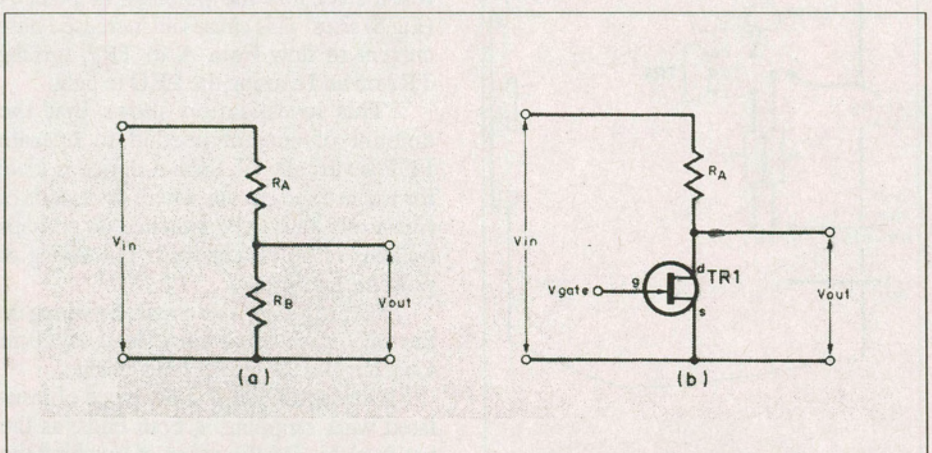


Fig.10 (a) Standard potential-divider circuit and (b) FET potential divider circuit.

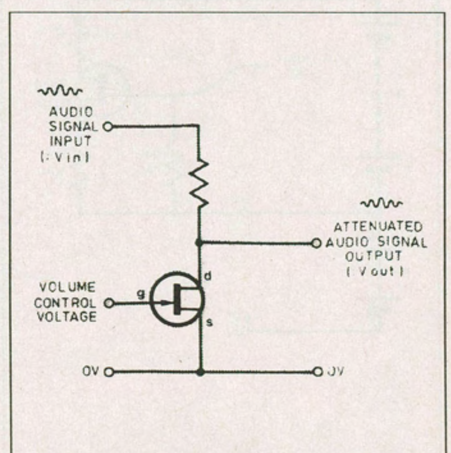


Fig.13. Using a voltage-controlled attenuator.

PARTS LIST

Resistors

R1	1M
R2	100
R3	470
R4	2k7

All 0.25W 5% carbon

Potentiometer

VR1............10k submin. horiz. trim

Semiconductors

D1	TIL209 red l.e.d.
TR1	2N3819 n-channel FET
TR2	2N3904 npn transistor

Miscellaneous

Breadboard; B1, B2 6V battery and connectors (2); materials for touch plate (see text); connecting wire and voltmeter (multimeter), set to 10V f.s.d. scale.

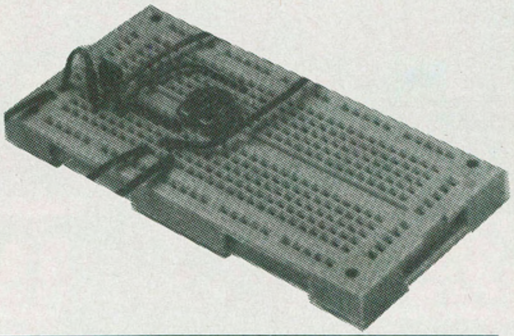
Other FETS

The MOSFETs (FETs based on CMOS technology) are widely used both as individual transistors or as integrated circuits. In the more popular types, the gate controlled by positive voltages, obviating the need to have a negative supply.

In logic circuits MOSFETs have the great advantage that they use virtually no current except when they are actually changing state from on to off. As transistor switches (used similarly to the FET in Fig.6), they can be used to switch analog signals under logic control.

Readers may have heard mention of the Darlington pair, a configuration of two bipolar transistors connected to obtain very high gain. Last, but no means least, are the VMOS transistors. These are MOSFET power transistors, capable of handling currents of several amps, up to 30A or more for the heftier members of the group.

It is obvious that FETs cover the complete spectrum of transistor functions. With the advantages that we have discussed above, it is not surprising that they are being used in an increasing number of applications. ■



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