

The junction FET

— its haunts and habits

The first in a whole family of field effect transistors, the junction FET is found in many and varied applications. If you're new to electronics or unfamiliar with the device, this article should introduce you to the haunts and habits of the JFET.

Brian Dance

THE JUNCTION Field Effect Transistor or JFET is a small electronic device much like a transistor in appearance which normally has three connections, although a fourth connection is attached to the metal case of some types for high frequency screening. Junction field effect transistors are one of the two main types of field effect transistor, the other type being known as the MOSFET (Metal Oxide Semiconductor Field Effect Transistor) or as the IGFET (Insulated Gate Field Effect Transistor).

Field effect transistors can be used as amplifiers and oscillators as well as for other applications for which an ordinary or bipolar transistor could be employed, but have particular advantages for certain applications. Field effect transistors are also used in the internal circuitry of integrated circuits.

Connections

As in the case of npn and pnp bipolar transistors, junction field effect transistors can be obtained in two polarities, these being known as n-channel and p-channel types. A far wider variety of n-channel types is manufactured than p-channel devices, since they tend to have a better performance, but devices of both polarities are readily obtainable.

The electrodes and circuit symbols for the two types are shown in Figure 1. The current flowing in a channel between the drain and the source is controlled by a voltage applied to the gate electrode. The gate is therefore the input electrode

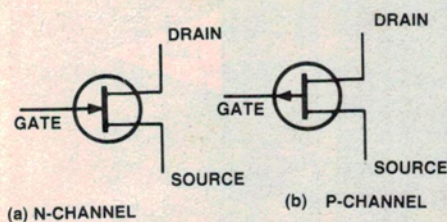


Figure 1. Symbols for n-channel (a) and p-channel (b) junction FETs.

and may be compared with the base of a conventional transistor. Similarly the drain and source may be compared with the collector and the emitter respectively.

One of the main differences between field effect transistors and bipolar transistors is that field effect transistors are essentially voltage amplifiers whereas bipolar transistors are basically current amplifiers. Thus the field effect transistor behaves more like the old thermionic valve in its circuits.

Field effect transistors tend to be more expensive than most of the common bipolar types — probably because the bipolar types are sold in much larger numbers. The economical 2N3819 n-channel field effect transistor is probably the most commonly used type and is very suitable for the readers who wish to carry out their first experiments with field effect transistors. This device is encapsulated in a black plastic or epoxy body and has the connections shown in Figure 2. The 2N3820 is a similar economical p-channel device.

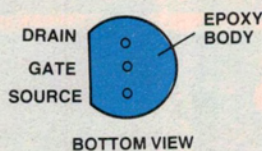


Figure 2. Connections for the common 2N3819 plastic-encapsulated n-channel JFET.

High input impedance

One of the main advantages of a field effect transistor is that it has a very high input resistance and therefore takes very little current from the circuit which feeds it — typically far less than a microamp. This means that it has very little effect on the circuit which feeds it, even if this circuit has such a high output impedance that it can deliver only a very minute current.

In order that an n-channel device shall operate correctly and have a high input impedance at its gate, it must be suitably biased with its gate negative

with respect to the other electrodes. Similarly the gate of a p-channel device has a high impedance when it is positively biased.

APPLICATIONS

Pierce oscillator

In the circuit of Figure 3 the field effect transistor is employed in a Pierce type of oscillator whose frequency is controlled by the quartz crystal shown. The advantage of using a field effect transistor in this type of circuit is that the gate imposes only a very small load from the crystal and therefore the quality factor or Q factor of the crystal is not appreciably affected, so excellent frequency stability can be obtained.

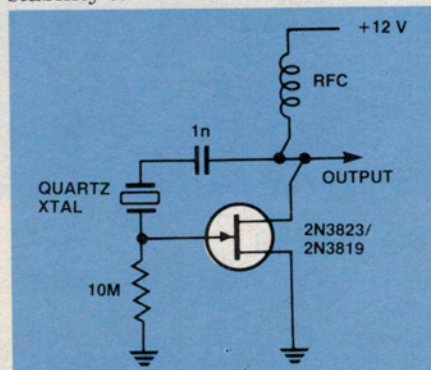


Figure 3. A Pierce crystal oscillator (National Semiconductor).

National Semiconductor recommend their 2N3823 n-channel device for use in this circuit, but the more economical 2N3819, which is made by the same type of process, is also suitable. The supply voltage is not at all critical, but the radio frequency chokes used in the supply lead should have a high impedance at the frequency of oscillation.

An advantage of this circuit is that one can change the crystal over quite a wide range of frequencies without making any other changes to the circuit and still obtain a satisfactory performance. The exact frequency range over

which the circuit will operate depends very much on the choke used and to some extent on the circuit layout.

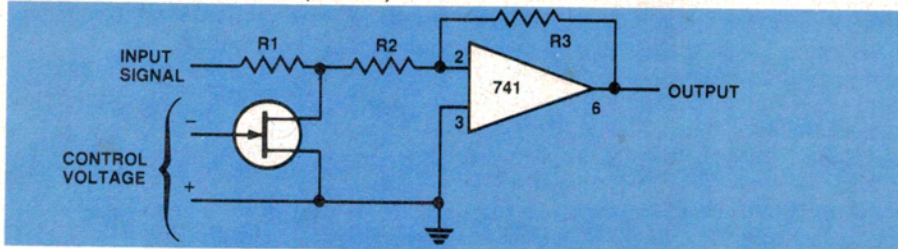
This type of circuit is suitable for use in a crystal calibrator for a receiver. If a 1 MHz crystal is employed, the output may be fed to a radio receiver to produce a signal at 1 MHz and at each multiple of 1 MHz up through the shortwave bands to provide calibration points.

Electronic attenuator

A junction field effect transistor can be used as a variable resistor, the value of which is controlled by the voltage applied to the gate electrode. As the applied bias becomes smaller, the resistance between the drain and source electrodes falls.

This property is used in the circuit of Figure 4 to design an electronic attenuator for audio signals. When the negative control voltage applied to the gate electrode is relatively large, little drain current passes through the device and the circuit behaves as if the field effect transistor were not present. However, as the control voltage falls at the gate electrode, the drain draws current from the junction of R1 and R2 so that the output signal amplitude is attenuated progressively.

Figure 4. An electronic attenuator (Siliconix).



Tone control

The circuit of Figure 5 is a tone control circuit with bass and treble boost and cut facilities. In this circuit the 2N3684 field effect transistor is used to enable the circuit to have a very high input impedance. It is used as a source follower circuit (analogous to an emitter follower) which provides a low output impedance signal coupled by a 1μ capacitor to the tone control network. This network is in the feedback circuit of the LM301A operational amplifier circuit. The 2N3684 enables a good low-noise performance to be obtained.

Lambda oscillator

A very simple sinewave oscillator is shown in Figure 6; it is essential that one n-channel and one p-channel field effect transistor are used in this circuit. The two source electrodes are connected

together and the gate of each device is connected to the drain electrode of the other device. This type of connection produces a negative resistance region in the current/voltage graph for the circuit with a peak in the graph like a Greek lambda (λ) — hence the name given to this type of circuit.

It is only necessary to connect the dual device circuit in series with a parallel tuned circuit, as shown in Figure 6, to produce oscillations at the resonant frequency of the tuned circuit used. It will oscillate at any frequency from the low audio region up to some tens of MHz, but the gate capacities of the devices used prevent operation in the regions above 100 MHz.

It is interesting to note that two separate parallel tuned circuits may be connected in series with the lambda circuit instead of the single tuned circuit shown in Figure 6. If one of these tuned circuits resonates at an audio frequency and the other at a radio frequency, the output will consist of an amplitude modulated radio frequency oscillation. This is perhaps one of the simplest possible modulated signal generators!

The output voltage from the circuit of Figure 6 is equal to twice the steady

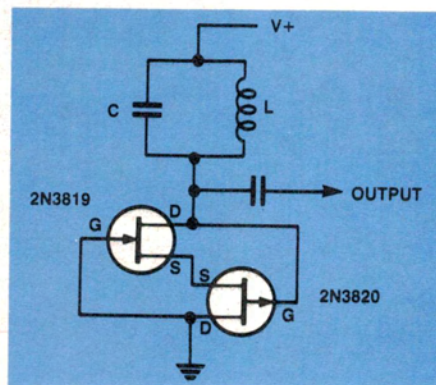


Figure 6. Sinewave oscillator using a 'Lambda' circuit.

power supply voltage applied to the circuit. Therefore this type of circuit can be very useful when one requires an output oscillation whose amplitude is accurately related to a steady applied voltage.

Complementary pairs of field effect transistors used in lambda circuits have other applications apart from simple oscillator uses.

High impedance buffer stage

The circuit of Figure 7a shows a buffer or isolating amplifier which has a very high input impedance and low input capacitance. National Semiconductor recommend a 2N4416 field effect transistor for this circuit because it has a low input capacitance, but this is further reduced by the circuit feedback. The device is used as a source follower, so the voltage gain is about unity.

Although a 2N5139 pnp transistor is specified for this circuit, the 2N3906 plastic encapsulated type is much more readily available and is fabricated by the same process, so it can be used in this application.

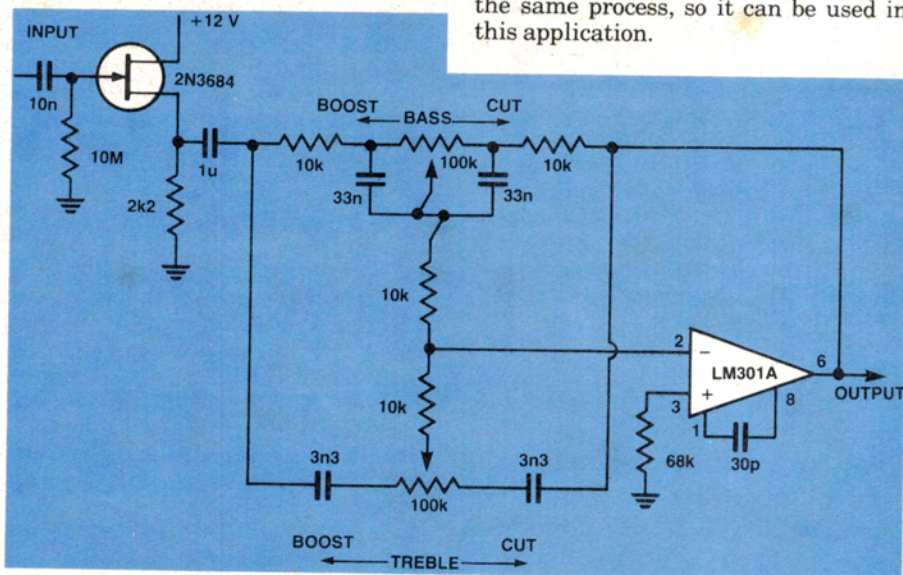


Figure 5. High input impedance tone control circuit (National Semiconductor).

High impedance amplifier

The circuit of Figure 7b is very similar to that of Figure 7a except that the feedback circuit has been modified so that a voltage gain can be obtained. The circuit provides a gain of $R2/R1$ or 10 with the component values shown. Both the circuits of Figure 7 and of Figure 8 can be operated at high frequencies into the tens of MHz region.

RF amplifiers

Junction field effect transistors are much used in the radio frequency stages of HF, VHF and UHF receivers, since they offer a noise performance equivalent to that of bipolar transistors with improved crossmodulation and intermodulation performance. Crossmodulation is the transfer of the modulation of one carrier onto the carrier of another signal. Intermodulation occurs when two or more signals outside the passband combine in the circuit to form a signal within the passband which causes interference with the wanted signal.

The better linearity of field effect transistors over bipolar transistors is responsible for this improvement. Mullard have quoted a 12 dB improvement in crossmodulation in a narrow-band FM receiver and a 20 dB improvement in a VHF broadcast receiver as having been achieved by the replacement of a bipolar mixer circuit with a junction field effect transistor circuit.

Figure 8 shows a high-performance amplifier using two JFETs connected in 'cascode' (series) with automatic gain control (AGC) applied to the gate of the upper device. The supply is applied to the 'cold' or 'ground' end of L2 via a feedthrough capacitor. Only the L-C values need be changed to operate this stage on other frequencies to the limits of the JFETs.

Simple voltmeter

The high input impedance of a junction field effect transistor is used in the circuit of Figure 9 to produce a voltmeter with an input resistance of over 10M; in some measurements this high input impedance is necessary to prevent the current taken by a conventional voltmeter from dragging down the voltage being measured.

The input voltage being measured is divided by R1 and R2 so that a voltage of +0.2 V is present at the gate electrode when the full scale input voltage is applied for the range in question. In practice R1 should consist of a fixed resistor of a value somewhat less than that shown in the table, in series with a preset potentiometer so that the sen-

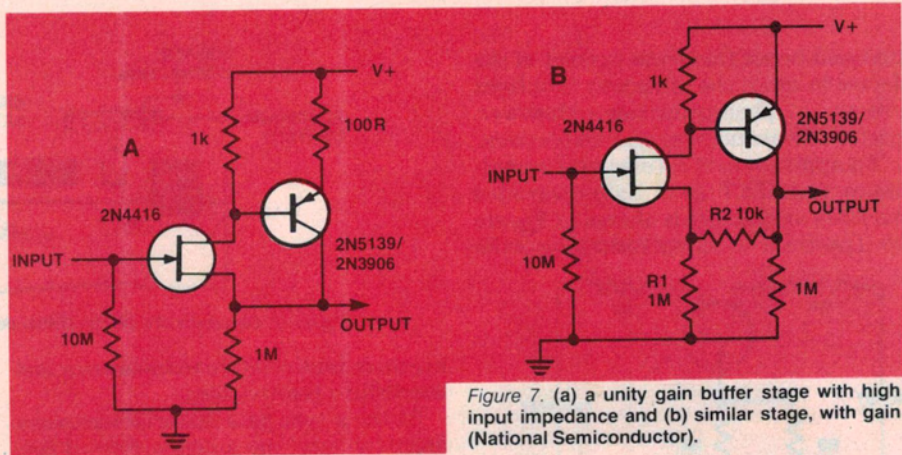


Figure 7. (a) a unity gain buffer stage with high input impedance and (b) similar stage, with gain (National Semiconductor).

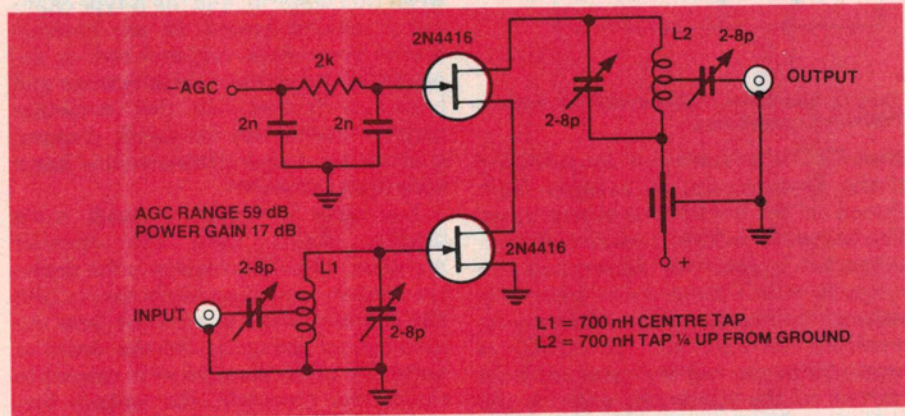


Figure 8. Typical high-performance amplifier stage employing two FETs in 'cascode'. Values given for 200 MHz. A wide variety of RF FETs may be substituted (National Semiconductor).

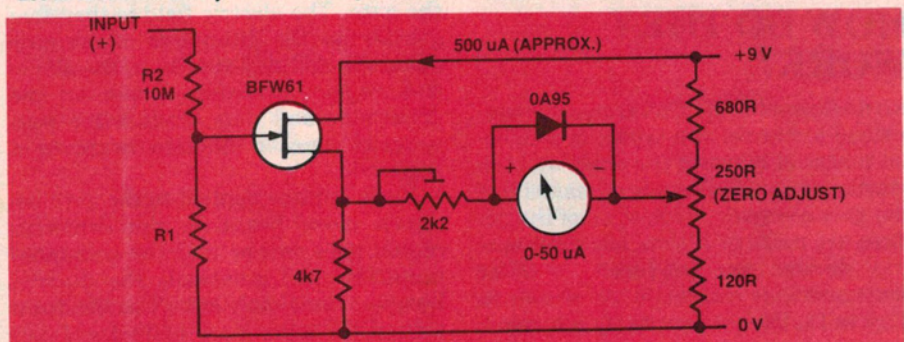


Figure 9. High input impedance voltmeter. Note that a BFW10 could substitute for the BFW61 (Mullard).

Table showing the value of R1 to be used in Figure 9 for various ranges.

Meter range	R1
250 mV	40M
500 mV	6M67
1 V	2M5
10 V	204k
50 V	40k
100 V	20k
250 V	8k
500 V	4k

sitivity of the range can be adjusted. If desired, R1 may be switched to provide a number of ranges.

No two field effect devices have exactly the same characteristics, and the 2k2 resistor in series with the meter enables the full-scale meter current to be adjusted to allow for the characteristics of the particular device used. The diode protects the meter from overloading.

PhotoFET

Photosensitive field effect transistors (photoFETs) can be made which have a window or a lens, so that any light falling on this window affects the junc-

tion and hence the drain current of the device in much the same way that light affects a phototransistor. However, photoFETs are not very common devices.

An application of a Teledyne Crystallonics photoFET as a light-controlled variable attenuator is shown in Figure 10. The drain-to-source resistance of the

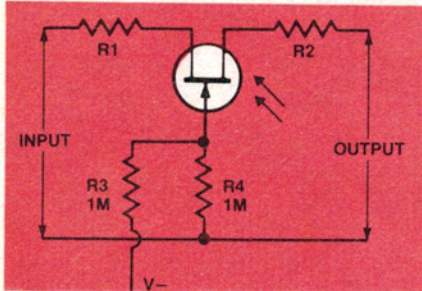


Figure 10. Example of a light-controlled attenuator (Teledyne Crystallonics).

photoFET is a function of the intensity of the illumination, so as more light shines on the device, the output rises. The negative voltage to which the resistor R3 is returned determines the range in which the drain-to-source resistance falls. Like other silicon photosensitive devices, the photoFET is sensitive to the red and near infrared regions of the spectrum, such as the radiation from an incandescent filament bulb.

HOW DO THEY WORK?

An n-channel field effect transistor consists of a channel of n-type semiconductor material between the drain and the source surrounded by p-type material of the gate electrode. Almost all of the devices are made of silicon, but a few special devices are produced in other semiconductor materials. As shown in Figure 11, the gate normally receives a

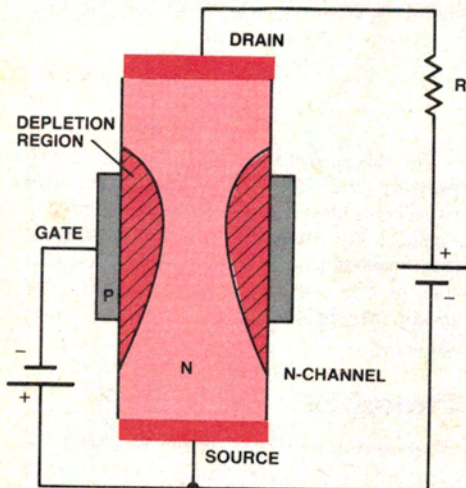


Figure 11. Control of channel width in an n-channel device.

negative bias relative to the source and the drain a positive bias.

As the p-type gate material receives a negative bias, the junction formed between this material and the n-type channel is reverse biased. In any reverse-biased junction, a region which is depleted of charge carriers (electrons and holes) is formed. As this depletion region contains very few mobile charges, it acts almost as an insulator and has a very high resistance.

The gate is normally much more heavily doped than the channel material, since this results in the depletion region spreading fairly deeply into the channel and not very far into the material of the gate. As the drain is normally made positive with respect to the source electrode, the voltage between the drain and the negative gate is larger than that between the source and the gate. The electric field is therefore greater on the drain side of the gate electrode and this results in the depletion region becoming deeper on the drain side and thus producing a narrower channel on this side, as shown in Figure 11.

If the voltage applied to the gate becomes more negative, the depletion region goes deeper into the n-channel material until eventually the channel becomes completely cut off on the drain side of the gate. Very little drain current can then flow through the device. As the gate voltage becomes less negative, the channel opens again and becomes wider as the gate voltage approaches that of the source; the widening of the channel under the control of the gate voltage results in the channel current from the drain to source increasing.

As the gate-to-channel capacitance comprises a reverse-biased pn junction, the gate has a very high input resistance and passes only a very minute current (often in the pA region). However, the gate capacitance is appreciable and therefore an appreciable alternating current may flow to this electrode at high frequencies. Even when the gate and source potentials become equal, there is still a small depletion region and the gate input resistance is high.

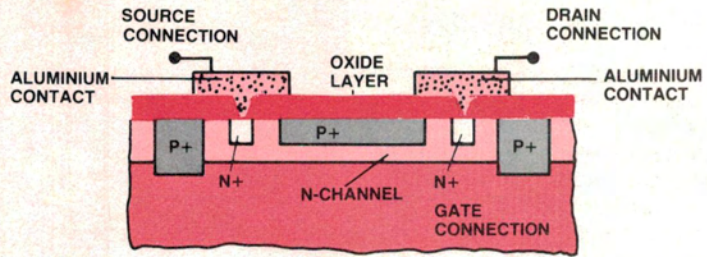


Figure 12. Structure of a silicon planar device (Mullard).

However, if the gate of an n-channel device receives a positive bias of more than about 0.65 V, current can flow in the gate circuit and this current may damage the device.

Structure

The design of a modern field effect transistor is not implemented in the form of Figure 11, which has been used for explanatory purposes, but silicon planar technology is usually employed to produce a structure such as that of the Mullard/Philips BFW11 shown in Figure 12. This has a surface or planar structure which is covered with a protective layer of silicon dioxide at all points except where electrode connections are attached. This oxide layer prevents impurities from contaminating the surface of the material and thus producing unwanted currents.

The aluminium contacts at the source and drain electrodes allow current to flow from them into the heavily doped small n+ regions, which make good contact with the n-channel region. In some devices a number of n-type channels are connected in parallel to enable a larger current to flow at the expense of an increased gate capacitance.

P-channel types

P-channel field effect transistors have the same type of structure as shown in Figures 11 and 12, but the p and n type materials are interchanged. The gate is made of n-type material and must therefore be biased positively, as shown in Figure 13. The drain is normally biased negatively.

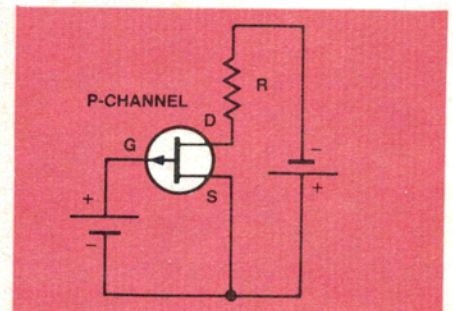


Figure 13. A p-channel device requires supplies of the opposite polarity to those used with n-channel devices.

Limiting voltages

If the bias applied to the gate is taken far beyond that required for normal operation, a point will eventually be reached at which reverse breakdown occurs. Similarly there is a limit to the voltage which should be applied between the drain and the source electrodes. However, junction devices cannot be damaged by the ordinary electrostatic charges which can accumulate on people and clothing and which can damage MOSFET devices.

Testing JFETs

It is relatively easy to check that a junction field effect transistor is able to function correctly. The circuit of Figure 14 may be used for an n-channel device and that of Figure 15 for a p-channel device.

If the gate is initially connected directly to the source (and not as shown), it will be found that the meter provides a reading of a few mA. This current is limited by the 1k resistor in the drain circuit to a safe value.

If the gate electrode is now connected to the 10M resistor as shown, the gate to channel junction is reverse biased. Thus the channel width decreases and with

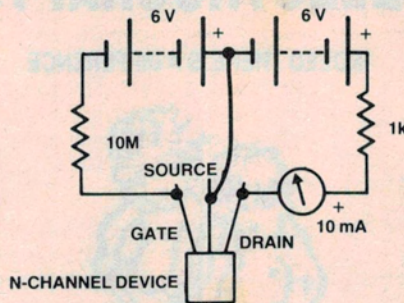


Figure 14. Testing an n-channel device.

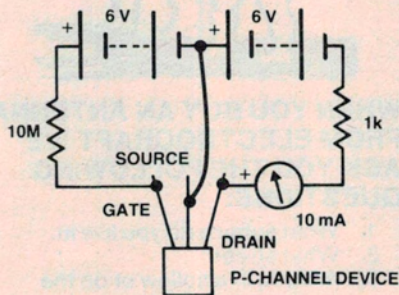


Figure 15. Testing a p-channel device.

most devices the drain current will fall to zero in the circuits shown. As the gate circuit has a very high resistance, the

voltage can be applied to it through a high-value resistor; indeed, it is interesting to note that the human body can be used in place of the 10M resistor shown when testing junction field effect devices.

If one wishes to test a device and does not know the connections, one can first find two connections in which a small current will pass in either direction. These are the source and drain connections.

A current should pass from the third electrode, the gate, only in one direction to either of the other two electrodes. If conduction takes place when the gate is positive, one has an n-channel device, whereas if conduction takes place when the gate is negative, the device is of the p-channel polarity.

One cannot easily determine which electrode is the drain and which is the source, but these electrodes are to some extent electrically interchangeable. ●

USEFUL BOOKS

Two very useful books, though difficult to obtain, are: 'FET Databook' from National Semiconductor and 'Field Effect Transistors' from Philips.