MICROELECTRONICS

INTRODUCTION

Microelectronics is a broad term used to describe the use of extremely miniaturized components and techniques, usually in transistors or other solid state devices and circuits. Use figure 3-1 in studying the following paragraphs.

INTEGRATED CIRCUITS

Up to now the various semiconductors, resistors, capacitors, etc., have been considered as separately packaged components called *discrete components*. In this section we will introduce some of the more complex devices that contain complete circuits or systems as a single packaged component. These devices are referred to as *integrated circuits*.

Integrated circuits (IC) almost eliminate the use of individual electronic parts (resistors, capacitors, transistors, etc.) as the building blocks of electronic circuits. Instead, we have tiny *chips* (tiny slides or wafers of a semiconductor crystal or insulator) whose functions are not that of a single part, but of dozens of transistors, resistors, capacitors, and other electronic elements, all interconnected to perform the task of a complex circuit. Often these comprise a number of complete conventional circuit stages, such as a multistage amplifier, in one extremely small component.

The family of integrated circuits have several advantages over conventionally wired circuits of discrete components. These advantages include:

1. A drastic reduction in size and weight,
2. A large increase in reliability,
3. Lower cost, and
4. Possible improvement in circuit performance.

However, they are composed of parts so closely associated with one another that repair becomes almost impossible. In cases of trouble, the entire circuit is replaced as a single component.

Basically, there are two general classifications of integrated circuits: *hybrid* and *monolithic*, as shown in figure 3-1. In the monolithic integrated circuit, all elements (resistors, transistors, etc.) associated with the circuit are fabricated inseparably within a continuous piece of material (called the *substrate)*, usually silicon. This type is made very much like a single transistor. While one part of the crystal is being

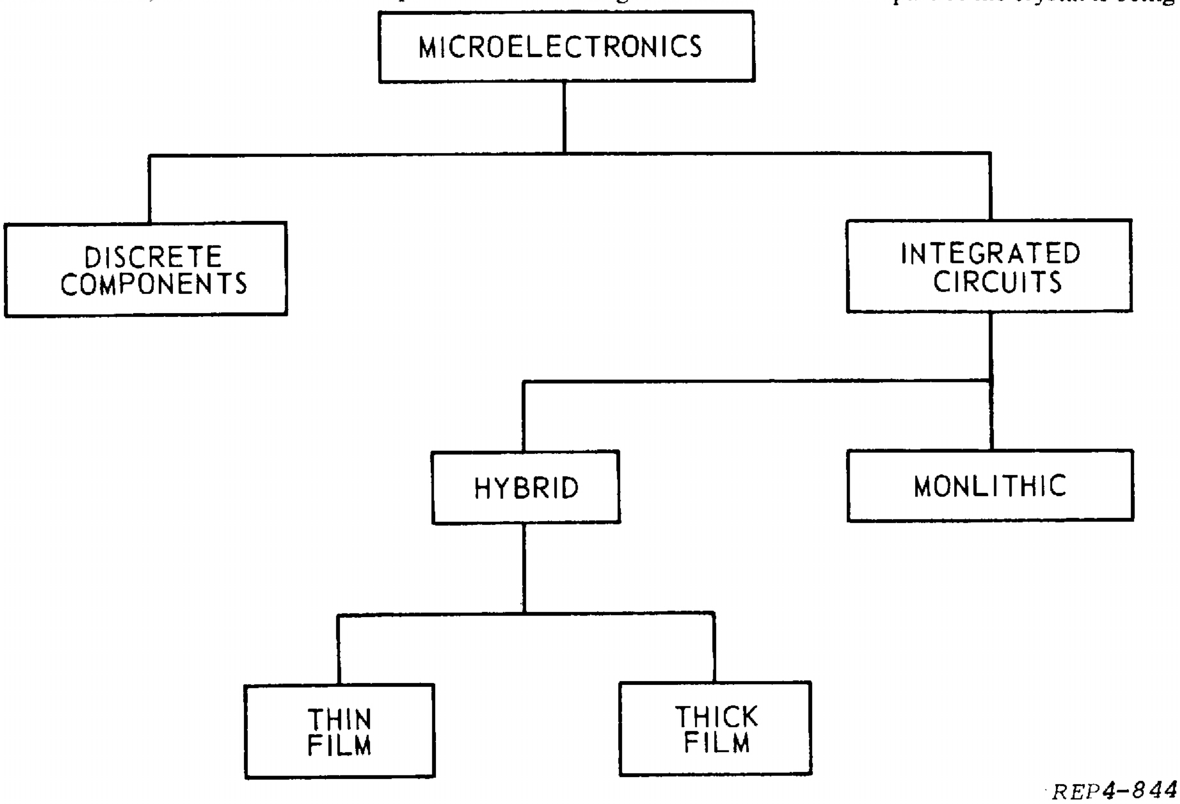


Figure 3-1. Microelectronics

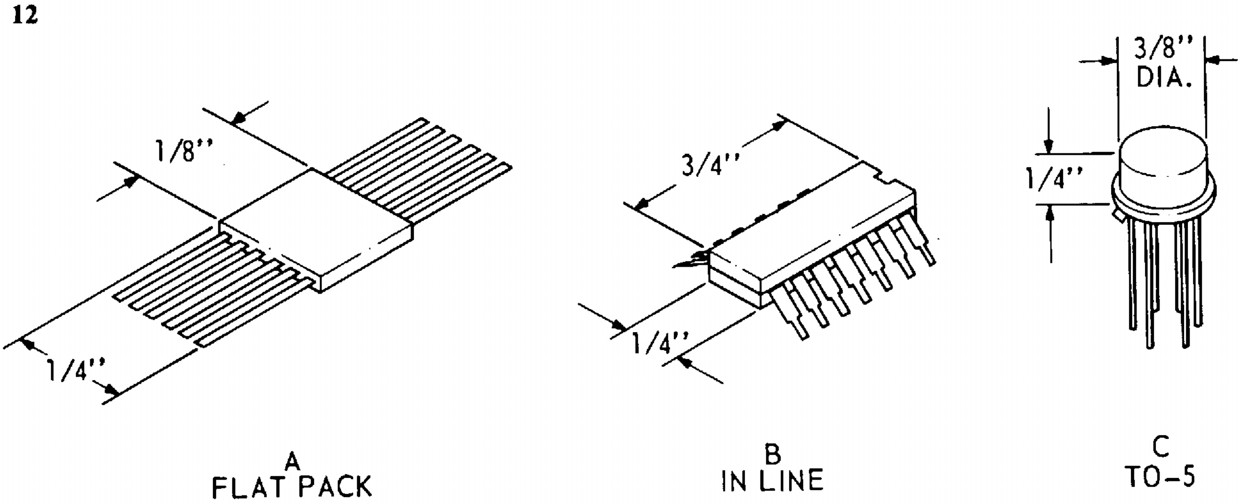


Figure 3-2. Package Styles for Integrated Circuits

doped to form a transistor, other parts of the crystal are being acted upon to form the associated resistors and capacitors. Thus, all the elements of the complete circuit are created in the crystal with the same processes and in the same time required to make a single transistor. This produces a considerable cost savings over the same circuit made with discrete components by lowering assembly costs.

Hybrid integrated circuits are constructed somewhat differently from the monolithic devices. The *passive* components (resistors, capacitors) are deposited onto a substrate (foundation) made of glass, ceramic, or other insulating material. Then the *active* components (diodes, transistors) are attached to the substrate and connected to the passive circuit components on the substrate using very fine (.001 inch) wire. The term *hybrid* refers to the fact that different processes are used to form the passive and active components of the device.

Hybrid circuits are of two general types:

1. Thin film, and
2. Thick film.

Thin and *thick* film refer to the relative thickness of the deposited material used to form the resistors and other passive components. Thick film devices are capable of dissipating more power, but are somewhat more bulky.

Integrated circuits are being used in an ever increasing variety of applications. Small size, weight and high reliability make them ideally suited for use in airborne equipment, missile systems, computers, spacecraft, and portable equipment. They are often easily recognized because of the unusual packages that contain the integrated circuit. Some of the most common package styles are shown in figure 3-2. These tiny packages protect and help dissipate heat generated in the device. One of these packages may contain one or several stages, often having several hundred components.

OPERATIONAL VOLTAGE AMPLIFIERS

An operational amplifier (monolithic integrated circuit) is basically an amplifier circuit that has an extremely high voltage gain; is directly coupled internally; has a very high input resistance; has a very low output resistance; and, when used in an actual circuit, normally has external degenerative feedback. Its versatility allows it to be used in a variety of applications; i.e., video amplifiers, RF amplifiers, voltage comparison networks, differentiation, integration, summation, and other applications. The following discussion on operational amplifiers will be devoted to the terms and modes of operation of these devices.

The schematic diagram of an operational amplifier is shown in figure 3-3. It consists of a triangle with three leads. The lead coming off the point of the triangle is the output lead. The other two leads are inputs. The one that has the plus sign is called the *noninverting* input lead. The one that has the minus sign is called the *inverting* input lead. The plus and minus signs do not represent the polarity of input signals. They are used to indicate whether or not inversion takes place between the input and output. The actual circuit arrangements inside the operational amplifier usually consist of two or more differential amplifiers and appropriate output circuitry. So the plus sign indicates that a signal applied to that lead will be amplified but will not be inverted on the output lead. Conversely, the minus sign indicates that a signal applied to the lead will be amplified and will be inverted on the output lead.

When the operational amplifier is taken as a discrete device (just as PNP, JFET, or MOSFET can be taken as discrete devices), certain characteristics can be examined. One characteristic is the *open loop* voltage gain. This term identifies the voltage gain of the operational amplifier without any feedback connected. As an example, a type 709, high performance operational amplifier, has an open loop voltage gain of 70,000. This means that when a signal is applied to one of the input leads and the output signal is observed, the output will be 70,000 times larger than the input signal. This further means that no feedback (degenerative or regenerative) is used. Another example is the type 777, precisior operational amplifier. It is listed as having an oper loop voltage gain of 250,000. Again, there is no feedback and this time the output is 250,000 times largei than the input. The phase relationship between the input and output will be determined by the input lead that is used.

In the previous discussion, only one input signal was considered at a given time. That is a signal was applied to one of the input leads and no signal was applied to the other input lead. This arrangement is referred to as *single-ended input operation.*

There will be times when one signal will be applied to the inverting lead and a second signal will be applied to the noninverting lead, and these signals will be present at the same time. This arrangement is called the *differential input* or *common mode operation.* Under this arrangement, the operational amplifier will amplify the difference between the two input signals. When the two signals are equal in amplitude and in phase, there will be no difference and the output of the operational amplifier will be zero. When the two input signals are equal in amplitude but out of phase, the difference between the two signals will be determined by their phase relationship. When they are 180° out of phase, their difference will be maximum. When they are 90° out of phase, their difference will be less than maximum. Further, if one signal is 10 millivolts, the other signal is 15 millivolts, and they are in phase, the difference between the two is 5 millivolts; and this is what the operational amplifier will amplify.

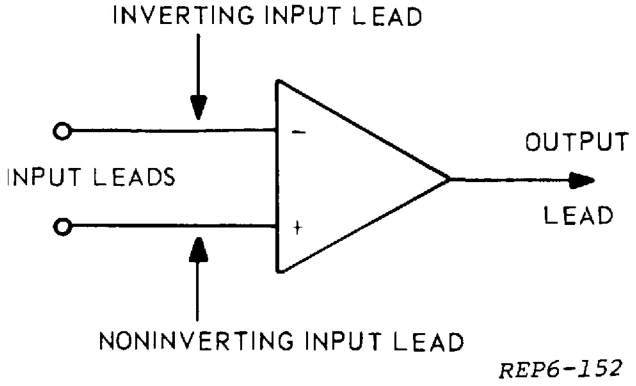


Figure 3-3. Schematic Symbol of an Operational Amplifier

Another consideration of the operational amplifier is the input and output DC levels. It is desirable that the input and output DC levels be equal. When they are not equal, the design of any required feedback networks, from the output terminal to one of the input terminals becomes complicated. To reduce this problem area, most operational amplifiers use two power sources, one a positive and one a negative, so that the input and output terminals are near zero volts. This is illustrated in figure 3-4. When a positive *Vcc* and a negative *VEE* are used, the absolute value of these source voltages will be chosen to allow both the input and output terminals to be near zero volts. This simplifies the design of feedback networks.

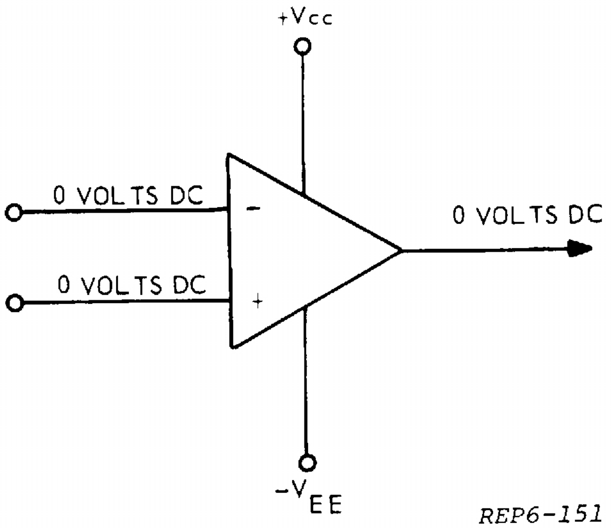


Figure 3-4. Obtaining Zero VDC on Input and Output Terminals

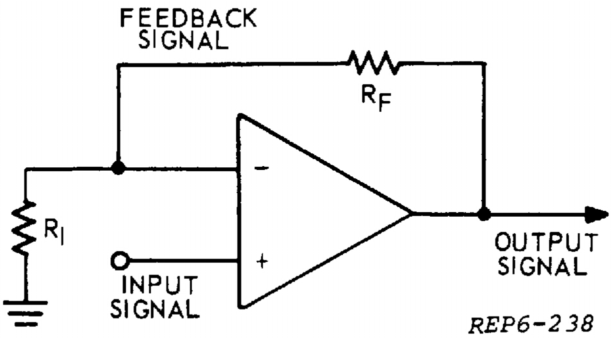


Figure 3-5. Noninverting Mode of Operation

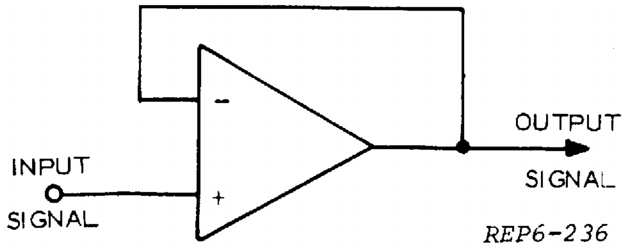


Figure 3-6. Voltage Follower: Noninverting Gain of One

Ideally, the input resistance should be infinitely large (an open) and the output resistance should be infinitely small (a short). In actual operational amplifiers, this is not possible. However, the input resistance is very high and the output resistance is very low in most operational amplifiers. As examples, the type 709 has an input resistance of 700K ohms and an output resistance of 150 ohms.The type 777 has an input resistance of 10 megohms and an output resistance of 100 ohms. These are typical values for most operational amplifiers.

One of the limitations of operational amplifiers is their instability over a wide range of input frequencies. Because of their high voltage gain characteristic, and because of phase shifting problems at the higher frequencies, some operational amplifiers will break into oscillations at various times, primarily when they are used in the open loop configuration. To obtain a high degree of stability and to provide certain other desirable features, most operational amplifiers are connected in a *closed loop* configuration. A closed loop configuration refers to the fact that degeneration is present in the circuit (feeding a portion of the output signal back to the input so that it opposes the input signal).

The first arrangement that will be discussed is the noninverting mode of operation. The circuit is shown in figure 3-5. The input signal to the circuit is applied to the noninverting lead. The output of the circuit is taken from the output lead. Also a portion of the output signal is applied through *RF* (feedback resistor) and developed across *RI* (input resistor) and is applied to the inverting input lead. The feedback signal will have the same frequency and same phase as the original input signal on the noninverting lead. In fact the only difference between the two signals will be their amplitude, and that will be controlled by the feedback network, *RF* and *RI*. Since this is degenerative feedback, the voltage gain of the circuit will be less than the open loop gain of the operational amplifier but the circuit will now be very stable.

Another possible configuration for the operational amplifier is in a circuit that provides a voltage gain of one and it does not shift the phase of the signal. This connection is called a *voltage follower* and is shown in figure 3-6. In this circuit the input signal is applied to the noninverting input lead and the degenerative feedback is present on the inverting lead. This will provide a voltage gain of one and will now invert the signal. Circuits like this are used where a high input resistance is required, and no phase shift is wanted. This can be used as a line river, or any place a common collector configuration would normally be used.

Another circuit, which is very similar, is shown in figure 3-7. This is the basic inverting mode of operation but *RF* is now equal to *RI*. In this arrangement, the voltage gain will be one (using the previous formula for the inverting mode of operation) and the output signal will be inverted. This circuit also provides a high input resistance and a low output resistance.

When an operational amplifier is connected to receive two input signals at the same time, it is said to be connected in a differential input or a *common mode* operation. A typical circuit is shown in figure 3-8.

The voltage gain, for this example, is assumed to be the same for both input signals. An example would be when R1 is 1K ohm, R2 is 1 megohm, R3 is 1K ohm, and R4 is 1 megohm. From input 1 to the output, the gain will be equal to the ratio of R2/R1 or 1000. From input 2 to the output, the gain will be equal to the attenuation of the input resistors:

(R4/R3 + R4 = approximately .999)

multiplied by the gain of the noninverting mode of operation:

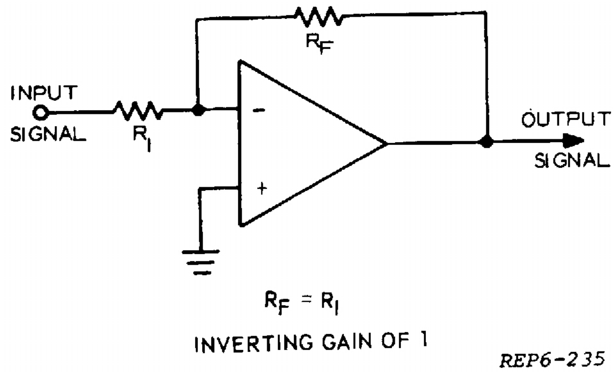


Figure 3-7. Inverting Mode of Operation: Gain of One

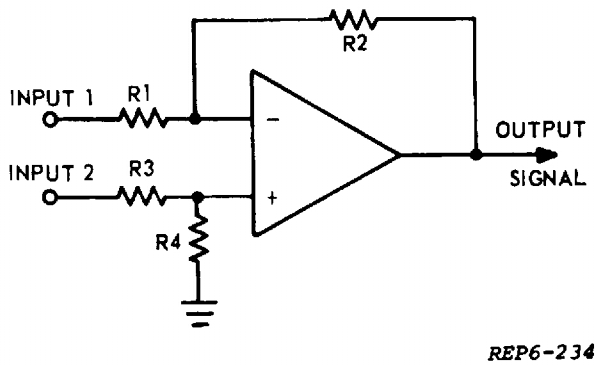


Figure 3-8. Common Mode Input (Differential Input)

(R1 + R2/R1 = 1001)

which equals a voltage gain of 1000. So the voltage gain for each input signal is the same. Of course, the number 1 input signal will be inverted and the number 2 input signal will not be inverted.

When input signals 1 and 2 are equal in amplitude and are in phase with each other, the output will be zero (the difference between the two input signals times the voltage gain).

When input 1 is 2 millivolts peak-peak and input 2 is 1.5 millivolts peak-peak, and they are in phase, the output will be the difference between the two input signals (.5 millivolts peak-peak) times the gain (1000) which produces an output voltage of 500 millivolts peak-peak.

In summary then, the output of an operational amplifier that is connected for common mode operation will be equal to the difference between the two input signals multiplied by the gain of the circuit. When the two signals are equal in amplitude and in phase, the output will be zero. The output amplitude will increase as the two input signals shift out of phase, and will be be maximum when the two signals are 180° out of phase.

Typical Characteristics MA 709 (Figure 3-9)

Supply Voltage: +18V max (positive supply) +*Voc*
-18V max (positive supply) -*Voc*

Input Voltage Range: Differential input voltage must never exceed the power supply voltage or 10 volts, whichever is less.

Output Voltage Range: From +*Vcc* to -*Vcc* depending on the value of the input signal and gain.

Input Impedance: 400K ohms (relatively high)

Output Impedance: 150 (relatively low)

Open Loop Gain: 45,000

Super High Gain: *Ri* = input resistance

Ro = output resistance

Gain = *Ro*/*Ri*

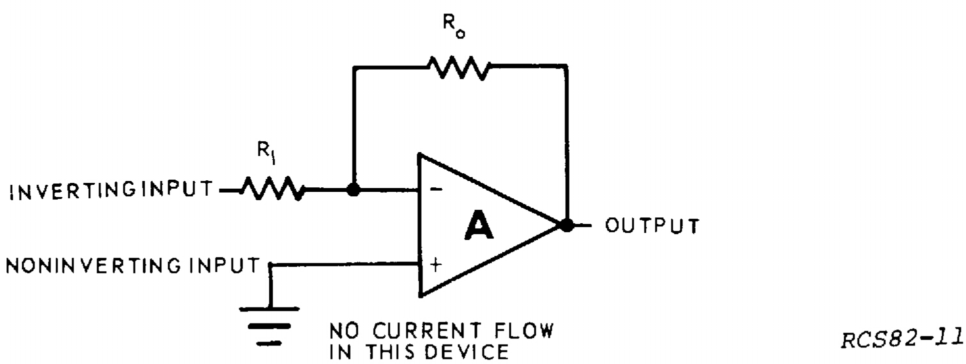
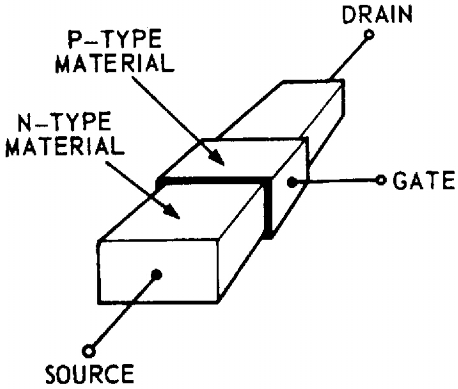
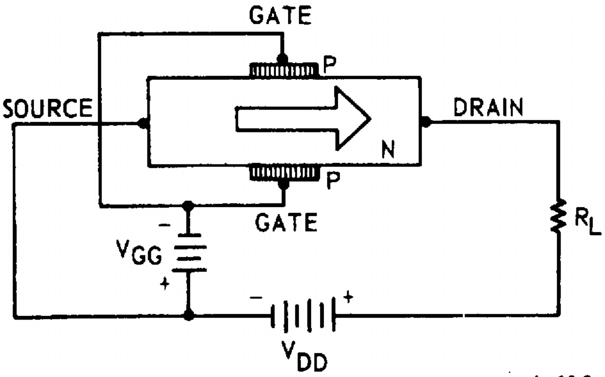


Figure 3-9. Operational Amplifier (MA 709)



A. SILICON CRYSTAL



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B. SCHEMATIC

Figure 4-1. N Type Junction Field Effect Transistor

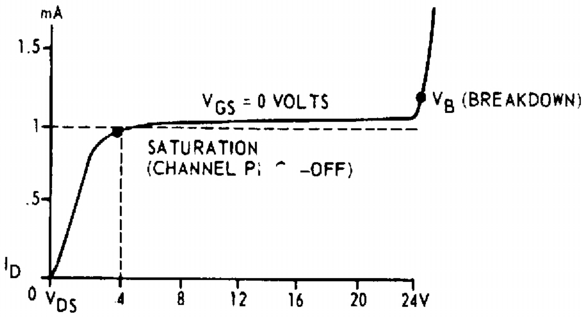

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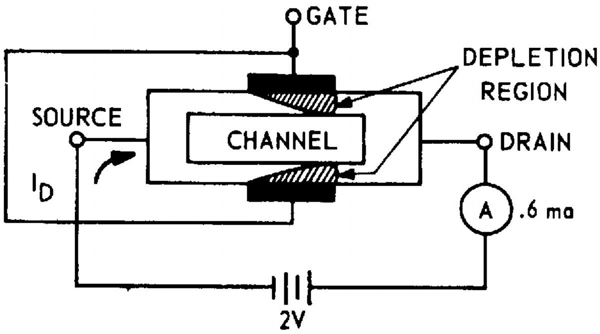
Figure 4-3. N Type JFET Characteristic Curve



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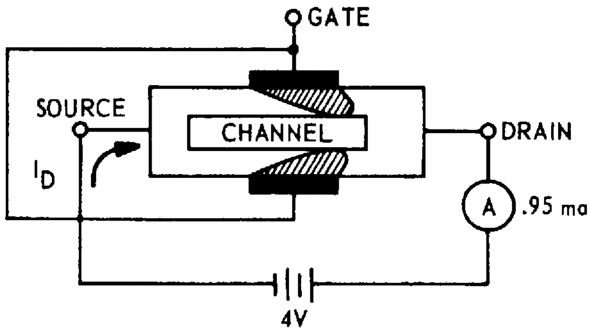

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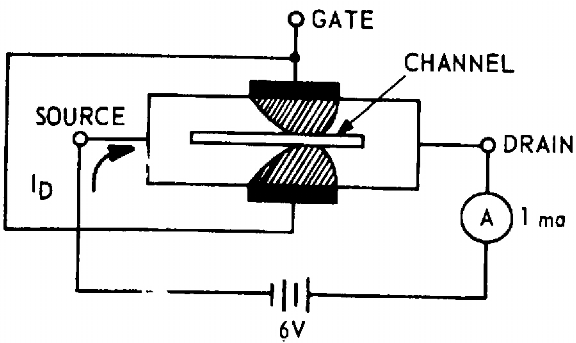

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Figure 4-2. Effects of Changing VDS on Channel and Drain Current