GENERAL:

Integrated circuits are usually simply referred to as ICs. They are responsible for the tremendous growth in electronic applications that affect all phases of our lives. Because ICs can include so much circuitry in a very small package, they are preferred in the design of most electronic equipment. They have proven to be reliable and have made miniaturization possible and practical. Without ICs, space and satellite communication systems and the modern computer would have been impossible. As technology continues, surely many more applications for ICs are yet to come.

More and more circuitry is being designed into the small IC chip. ICs began with SSI (small scale integration), where only a few components were included on the chip. Many external components were necessary to complete the circuits to make them operational. MSI (medium scale integration) followed with more internal and less external components. LSI (large scale integration) provided hundreds of internal components and many circuit operations could be completely performed within the IC. Finally VLSI (very large scale integration) became possible and practical, with thousands of internal components and complete circuit operations being performed within a piece of semiconductor material smaller than a pencil eraser.

The manufacturing of ICs involves intricate processes, which will only be basically described in this lesson. ICs may include transistors, diodes, capacitors, and resistors arranged in a wide variety of circuit configurations for use in a broad range of applications. There are IC indexes listing hundreds of types of ICs for endless applications. There are two general categories of ICs: those designed for linear operation, such as amplifiers, and those designed for non-linear operation, such as in digital and switching circuits.

In this lesson the internal circuitry of some ICs will be shown to aid in understanding ICs applications and precautions. Then these ICs will be used in circuits where their operation can be observed and tested. Then fault location methods for defective IC circuits will be explained in A later lesson.

IC FABRICATION:

The fundamental requirement of IC manufacture is that all components be processed from the same materials in a continuing process. A number of methods are used in IC manufacture, but only one method will be briefly described here.

The basic steps of this process are shown in Figures 1 through 4. The starting material is a uniform single crystal of N-type or P-type silicon (Figure 1). Diffusion processing techniques permit doping of the crystal to the desired depths and widths in the starting material.

When localized N-type regions are diffused into the P-type starting material as shown in Figure 2, isolated circuit nodes are formed. The diodes formed by the P-type material and the N-type nodes accomplish electrical isolation between the nodes. Diffusion of additional P-type and N-type regions form transistors (Figure 3).

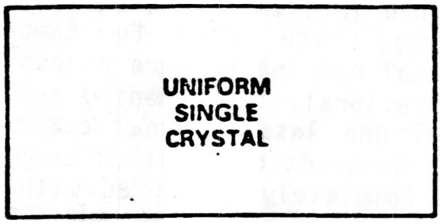


Figure 1. Silicon wafer used as starting material for integrated circuit

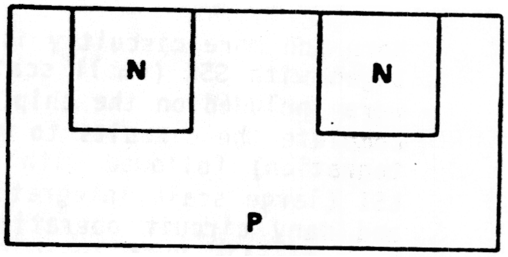


Figure 2. Diffusion of N-type areas for isolated nodes

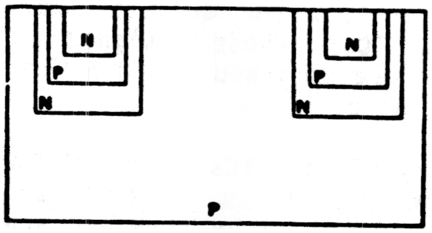


Figure 3. Diffusion of additional P-type and N-type regions for transistors

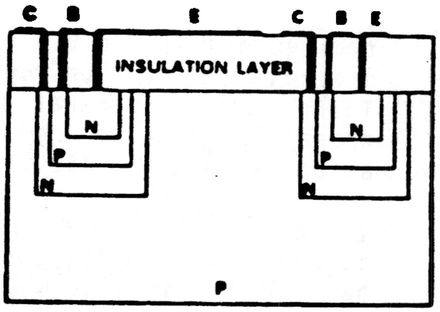


Figure 4. Addition of metallized contacts to transmitter elements

The silicon wafer is then coated with an insulating layer, which is opened selectively to permit connections (Figure 4). When resistors are required, the N-type emitter diffusion is omitted and two ohmic contacts are made to a P-type region formed simultaneously with the base diffusion (figure 5). When capacitors are required, the insulation itself is used as a dielectric (Figure 6). Figure 7 shows the combination of the three types of elements on a single wafer and the equivalent circuit.

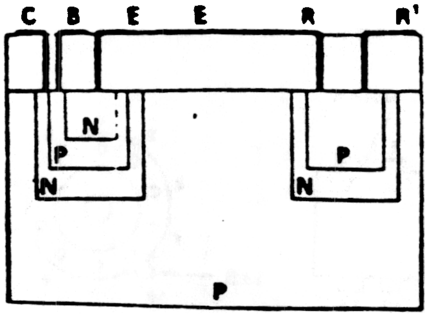


Figure 5. Connection of contacts to P-type region for integrated circuit, with resistors

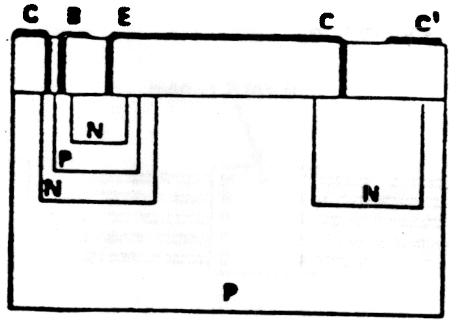


Figure 6. Use of oxide as dielectric for integrated capacitor

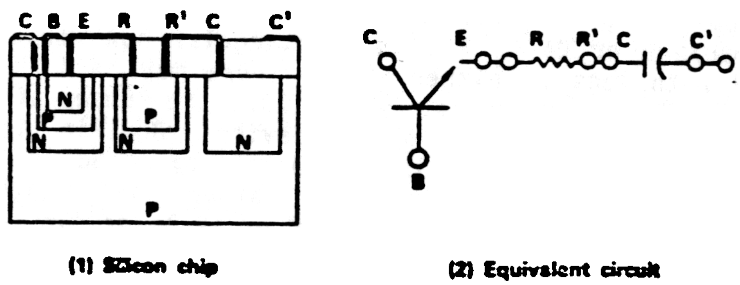


Figure 7. Completed silicon chip containing transistor, resistor, and capacitor, with equivalent circuit.

It is not practical for manufacturers to make the simple IC described here. Modern ICs have many times this number of components on the chip. Figures 1 through 7 simply demonstrate the basic processes used to form the different components on the chip during manufacture. ICs are placed in a variety of packages containing a variety of pin arrangements.

Integrated circuits come in a number of standardized package types. Some are enclosed in round plastic, or metal cans. Figure 8 shows three of the most common IC packages these are the flat pack, dual-in-line package (DIP) and the TO-5 can.

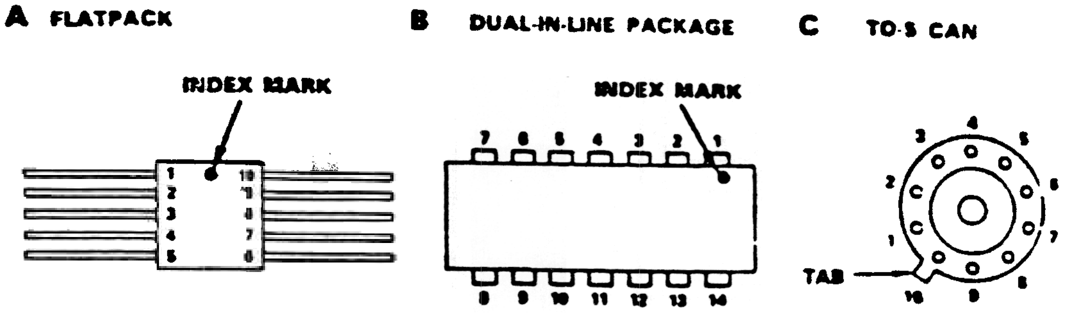


Figure 8. IC pin numbering

A flatpack, shown in Figure 8a, is a form of packaging for integrated circuits. The flatpack is characterized by physical thinness with the pins protruding straight outward from the package. The entire package is smaller than a penny. Flatpack integrated circuits are used in situations where space is restricted. The devices are normally soldered directly to the circuit boards. Figure 8b is an illustration of another common type of housing for integrated circuits, it is the dual-in-line package or DIP. A flat, rectangular box containing the chip is fitted with lugs on either side. There may be just a few pins on each side or there may be 15, 20, or 30. the number of pins is generally the same on either side of the device. Dual-in-line packages are convenient for installation in sockets. Figure 8c is a TO-5 can can type package. These devices look rather like slightly oversized transistors, except they often have 10 or 12 leads, instead of just 3.

The leads from the various packages are numbered counterclockwise (CCW) from the key when viewed from the top. The key may be a tab, a notch, a colored dot or a difference in the space between two leads. If any measurements are made at the IC pins, use extreme care not to short any pins together with the probe. Shorting the pins could cause damage to the IC and make the circuit inoperative.

Operational amplifiers, commonly called op maps, are the basic building block for many more complex circuits. They can perform the mathematical operations of amplification, addition, subtraction, integration, and differentiation. They can be used in both linear and non-linear applications. Op amps are most commonly found in IC form. Some of the op amp capabilities will be observed in this lesson.

Op amps are represented schematically by a triangle on which the input and output terminals are designated. The basic symbol is shown in Figure 11. Two inputs are shown: one labeled (-) and one labeled (+). External components are usually connected to provide the desired operation. Although the internal circuitry of the IC is not usually available, it will prove helpful at this time in understanding op amp operation. Figure 13 shows the equivalent circuit of IC UA741, which is similar to many IC op amps.

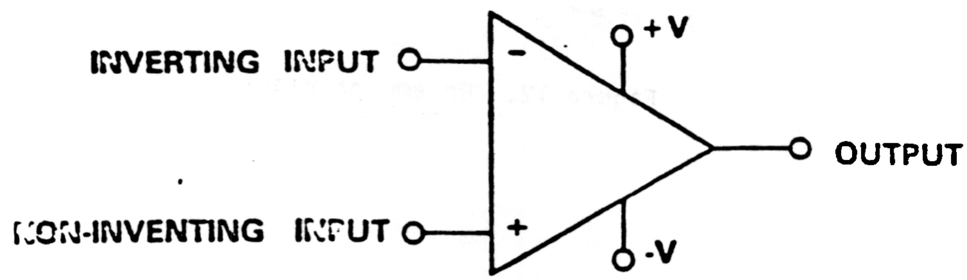


Figure 11. Op amp schematic symbol

The basic op amp has several high-gain stages. Gain may be in the thousands, but is usually reduced by an external feedback network. By using various types of feedback networks, the op amp can be adapted to a wide range of applications. Some of the feedback networks will be described later.

The equivalent circuit of the op amp in Figure 13 contains 20 transistors (both NPN and PNP), 11 resistors, and one capacitor, all formed on a single silicon chip. There are no diodes, but some transistors are connected as diodes. Resistors use more space on the chip than transistors, so some transistors are used as resistors. A transistor has internal resistance between emitter and collector. As forward bias increases, emitter-collector current decreases. Reducing forward bias decreases current, increases resistance, and increases the voltage drop. With constant bias, current and resistance remain constant. Thus, a transistor can be used as a fixed or variable resistance.

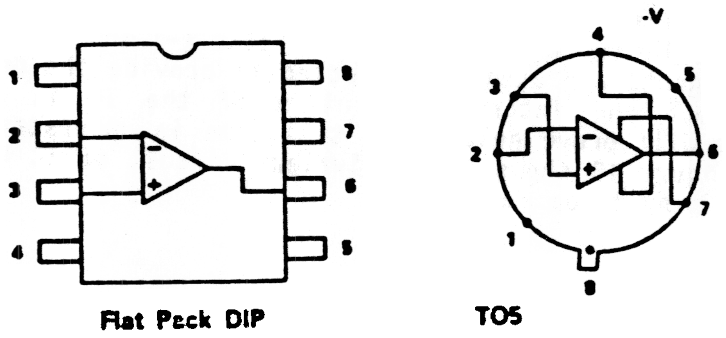


Figure 12. Op amp packages

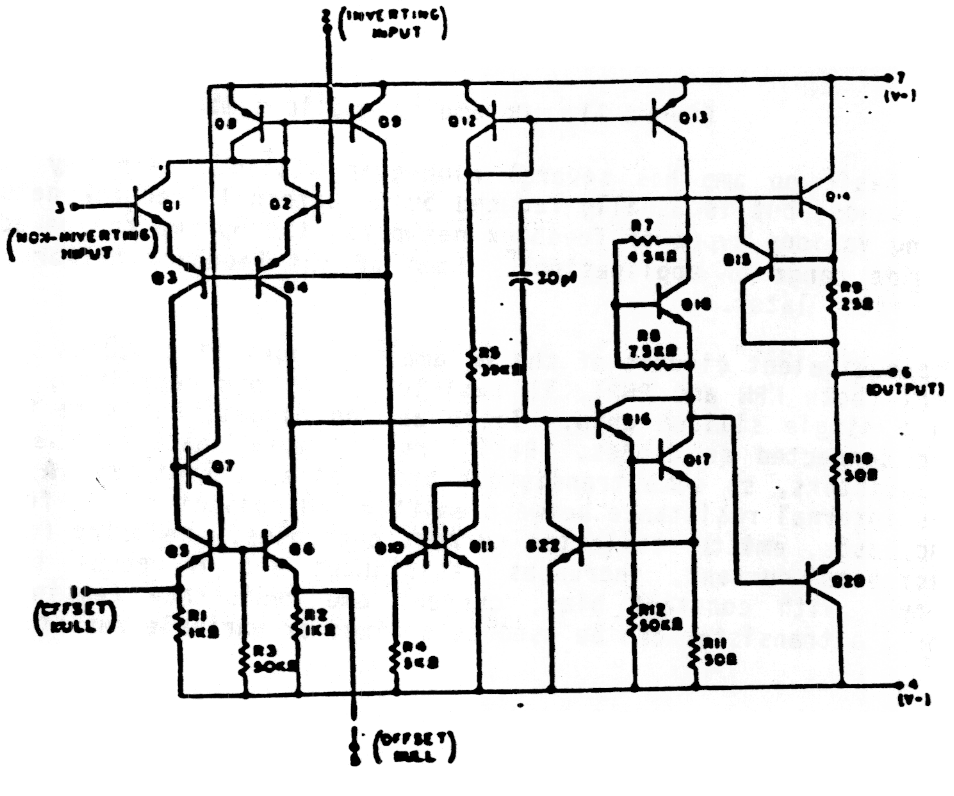
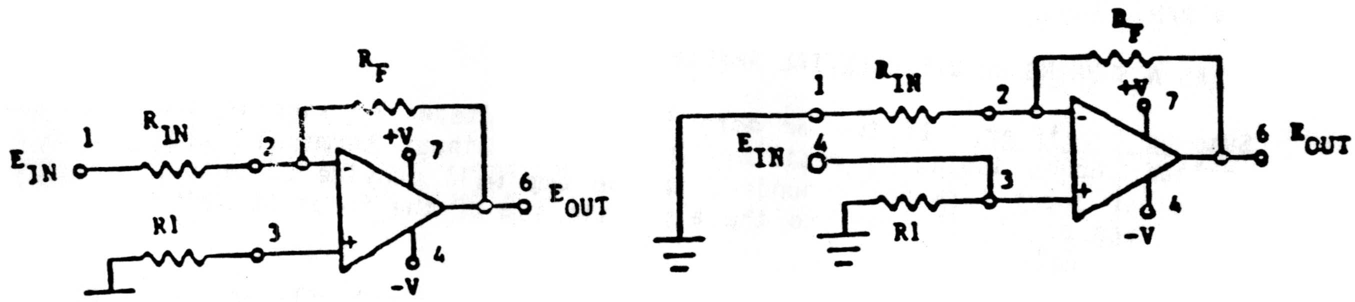


Figure 13. Internal circuit of op amp A741. (Equivalent)

The op amp can be used in the following operating modes: inverting, noninverting, summing, differential, and common mode rejection. External feedback networks are used to control the overall gain as well as to provide additional operations, such as integration and differentiation. The versatility of the op. amp makes it useful in many circuit application.



(1) (2)

Figure 14. Gain control feedback network

Gain in an op amp is controlled by a feedback network. The open loop gain of op amps is very high (in the thousands). Open-loop gain will result in distortion of the output signal. Gain is normally controlled by using negative feedback. The output voltage is opposite in polarity (inverted phase for an AC signal) when an input is applied to the inverting terminal. The output voltage has the same polarity (same phase for an AC signal) when an input is applied to the non-inverting terminal. Negative feedback is achieved by connecting a resistor between the output terminal and the input terminal as shown in Figure 14(1). The input resistor, Rin, is in the circuit to provide a ratio between the input resistance and the feedback resistance. This ratio is the voltage gain of the circuit.

The op amp in figure 14(1) is connected as an inverting amplifier. The voltage gain of this circuit is calculated by the formula AV = RF/Rin. The output voltage is calculated by the formula Eout = RF/Rin X Ein.

The negative sign indicates opposite polarity (inverted phase for an AC signal). For a DC input voltage, assume RF = 20K, Rin = 10K, and + 1 V DC. The output voltage is Eout = -20K/10K X (1 V DC) = - DC. For an AC signal, assume RF = 20K, Rin = 10K and Ein = 1 V Eout = - 20K/10K X (1 V P/P) = 2 V P/P inverted.

When the op amp in Figure 14(2) is connected as a non-inverting amplifier the input signal is applied to terminal 3. Rin is connected to ground at terminal 1. The voltage gain is calculated by the formula AV = 1 + RF/Rin. The output voltage is calculated by the formula Eout = (1 + RF/Rin) X Ein. The output DC voltage is the same polarity as the input (same phase for an AC signal). For a DC input voltage, assume RF = 10K, Rin = 5K and Ein = + 1VDC. Eout = (1 + 10K/5K) X 1 V DC = + 3 V DC. For an AC signal, assume RF = 10K, Rin = 5K and Ein = 1 V P/P. Eout = (1 + 10K/5K) X 1 V P/P = 3 V P/P in phase.

OP AMP AS A SUMMING OR DIFFERENTIAL AMPLIFIER:

Summing amplifier. If two or more input DC voltages or signals are applied though isolating resistors to the same input terminal, with the other input terminal grounded, the op amp will provide an output DC voltage or signal equal to the algebraic sum of the input DC voltages or signals.

DC voltage. DC voltages applied to the inverting terminal will provide an output DC voltage of the opposite polarity from the input. DC voltages applied to the non-inverting terminal will provide an output DC voltage of the same polarity as the input. Usually all the input DC voltages to a summing amplifier are the same polarity, either positive or negative. Refer to Figures 15A(1) and (2) for examples.

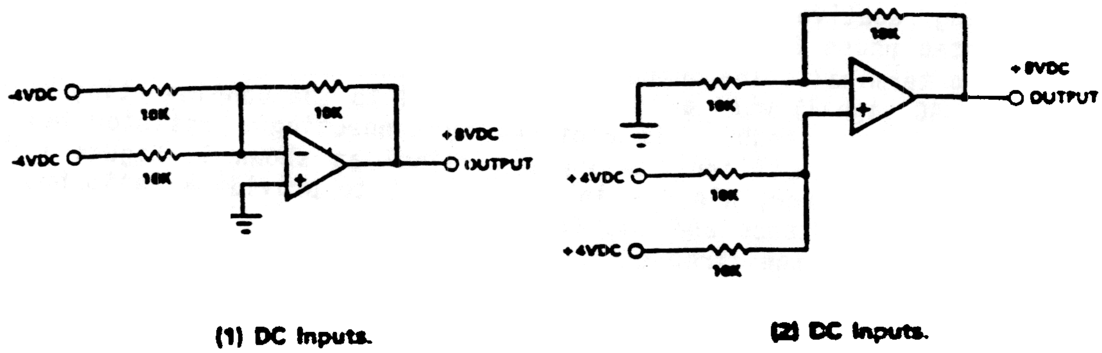


Figure 15A. Summing amplifiers

AC signals. AC signals applied to the inverting input terminal will provide an output AC signal that is 180 degrees out of phase from the input. AC signals applied to the non-inverting input terminal will provide an output AC signal that is in phase with the input. Usually all the input AC signals to a summing amplifier are the same phase, either 0 degrees or 180 degrees. Refer to Figures 15B(3) and (4) for examples.

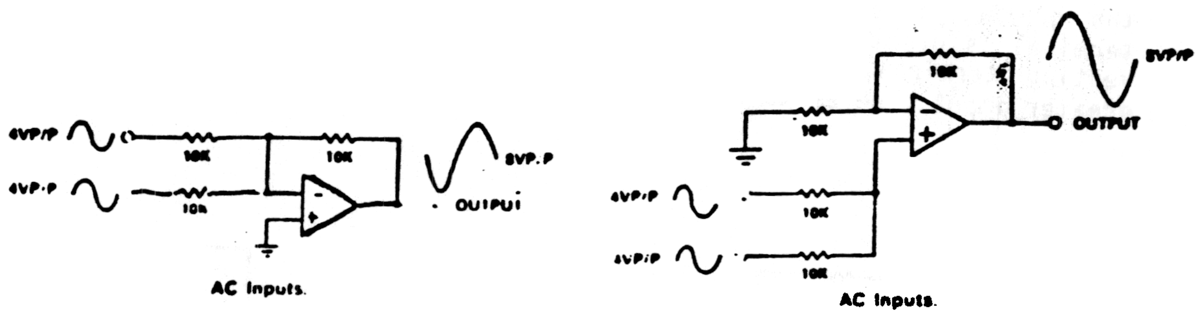


Figure 15B. Summing amplifiers

<u>Differential amplifier</u>. If two unequal DC voltages are applied, one to each input terminal, the op amp will provide an output DC voltage equal to the algebraic difference of the two DC voltages. If two unequal amplitude in phase AC signals are applied, on to each input terminal, the op amp will provide an output AC signal equal to the algebraic difference of the two AC signals.

<u>DC voltages</u>. If the DC voltage applied to inverting terminal is greater in magnitude than the DC voltage applied to the non-inverting terminal, the polarity of the output DC voltage will be opposite the polarity of the greater input. If the DC voltage applied to the non-inverting terminal is greater in magnitude than the magnitude of the DC voltage applied to the inverting terminal, the polarity of the output DC voltage will be the same as the polarity of the greater input. Refer to Figures 16A(1) and (2) for examples.

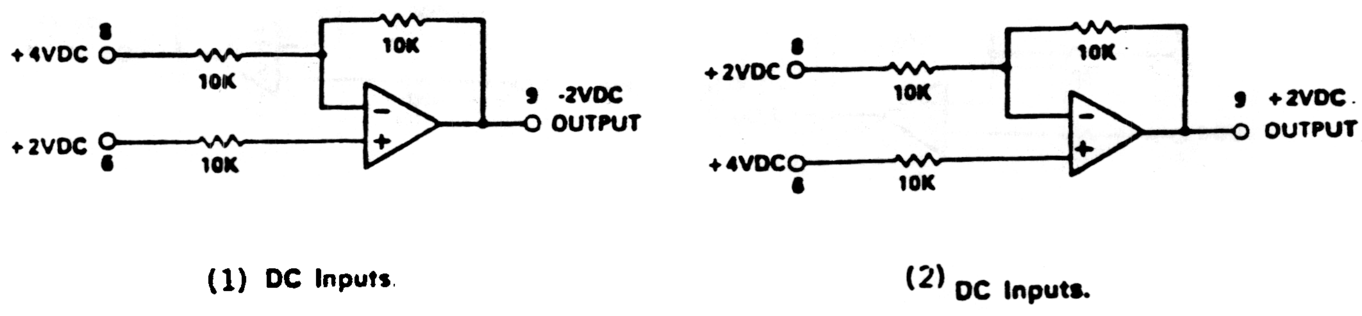


Figure 16A. Differential amplifiers

AC voltages. If the AC signal applied to the inverting terminal is greater in amplitude than the AC signal applied to the non-inverting terminal, the output AC signal will be 180 degrees out of phase from the greater input. If the AC signal applied to the non-inverting terminal is greater in amplitude than the AC signal applied to the inverting terminal, the output AC signal will be in phase with the greater input. Refer to Figure 16B(3) and (4) for examples.

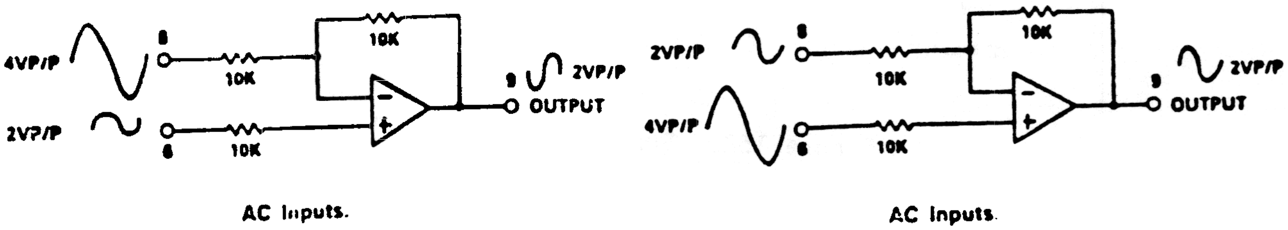


Figure 16B. Differential amplifiers

Common-mode rejection. This is a null operation of the differential amplifier. This is a special case. If two DC voltages of the same polarity and equal magnitudes are applied to the input terminal of an op amp, no output DC voltage will be developed. If two AC signals of the same phase and equal amplitudes are applied to the input terminals of an op amp, no output AC signal will be developed. Refer to 17 (1) and (2) for examples.

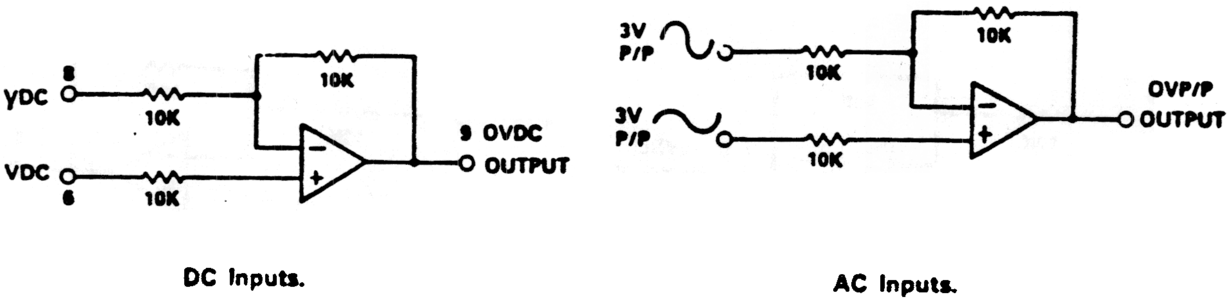


Figure 17. Common-mode rejection

Integrated circuits can be used in other modes of operation, in addition to op amps in summing amplifier circuits and in differential amplifier circuits. The op amp can be used in integrator and differentiator circuits. These two modes are used for integrating and differentiating rectangular waves and for providing 90 degree phase shifts on sinewaves. These two modes are briefly described in Figure 18.

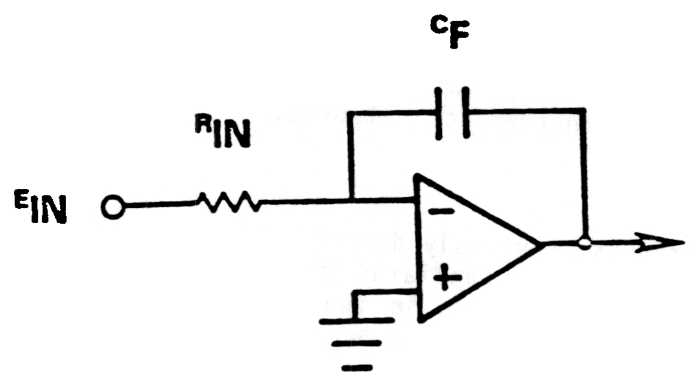


Figure 18. Op amp integrator

The feedback resistor has been replaced by a feedback capacitor in Figure 18. This is the configuration used to integrate the input. The time constant (t) of CF and Rin is approximately equal to the period of the input signal.

The input signal would normally be a rectangular waveform. If a sinewave is applied to the input, the output sinewave will be shifted in phase by exactly 90 degrees (leading).

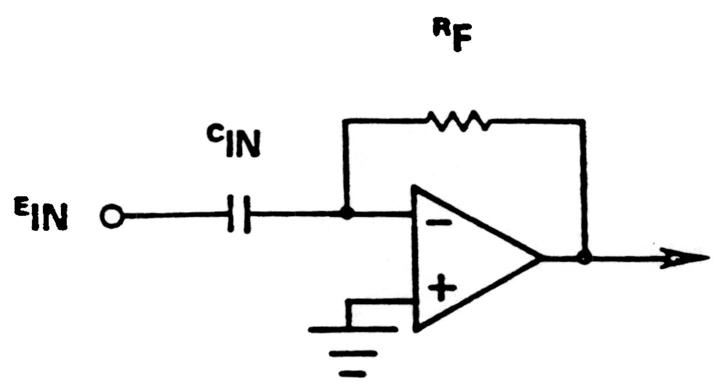


Figure 19. Op amp differentiator

In Figure 19 the resistor and capacitor of Figure 18 have been interchanged to convert the op amp to a differentiator. The time constant (t) of RF and Cin is approximately equal to the rise-time of the signal to be differentiated. The input waveform would normally b rectangular. If a sinewave is applied to the input, the sinewave will be shifted exactly 90 degrees (lagging).

There are other variations that may be used that provide other operating characteristics of op amps, but those shown in this lesson are the most common. How the op amp will operate is primarily determined by the external input an feedback networks.

NON-LINEAR OPERATION:

The op amp circuits previously described are all linear circuits except the integrator and differentiator circuits. A linear circuit should not introduce any distortion in the signal waveform. Linear circuits are commonly used for amplifying and signal processing amplifications.

Non-linear operation produces non-linear outputs. Non-linear outputs are developed through switching action of the circuit. The stage may be either conducting at saturation to provide a low output voltage level, or cutoff to provide a high output voltage level. This type of operation is associated with digital circuits, where a high output represents one and a low output represents zero. Collectively, these circuits are called logic circuits. Other non-linear circuits such as integrators and differentiators have a resistor and a capacitor as input and feedback components. These circuits produce non-linear outputs.

SUMMARY:

During this lesson, you were introduced to integrated circuits. You saw how an integrated circuit is made from a single N or P-type crystal and all of its components processed simultaneously. You then analyzed an operational amplifiers that utilized IC chips. Because of the increasing applications of integrated circuits in all phases of electronics, the proficient technician must be able to analyze circuits containing integrated circuits and be able to make valid tests to determine normal or abnormal conditions.