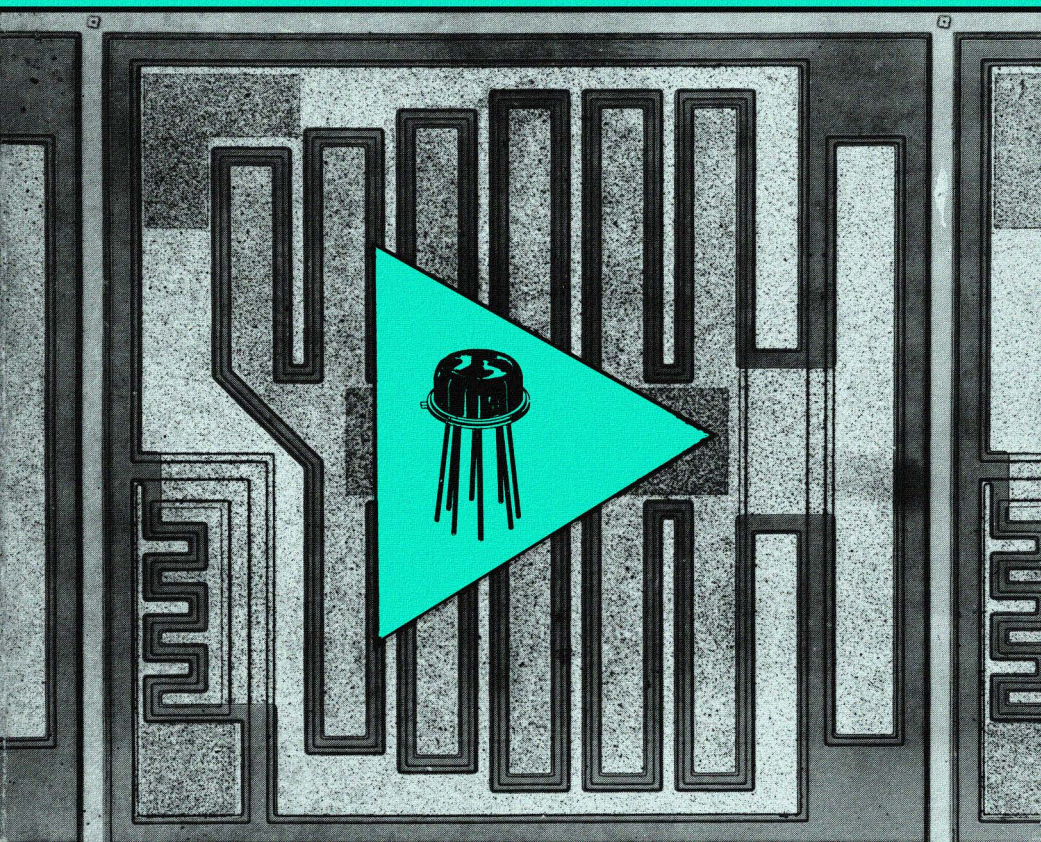


# *abc's of* **INTEGRATED CIRCUITS**

*By Rufus P. Turner*



# abc's of Integrated Circuits

By

Rufus P. Turner, Ph. D.



**HOWARD W. SAMS & CO., INC.**  
**THE BOBBS-MERRILL CO., INC.**  
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# Preface

This book offers an elementary introduction to integrated circuits. It is addressed to students, hobbyists, electronics advertising and merchandising personnel, and others who desire an essentially nonmathematical survey of the IC and its typical applications. The approach therefore is descriptive and practical, rather than theoretical and analytical.

No space is devoted to basic semiconductor theory, since the reader is assumed to be familiar already with n- and p-type materials and with transistors, diodes, and other familiar semiconductor devices. If he lacks this knowledge, he can easily find it in other Sams books. He will need some general familiarity with pn junctions, diffusion, alloying, and deposition techniques, and with the photoetching of circuits. And, of course, a knowledge of basic electronics is presupposed.

I am indebted to several IC manufacturers for illustrations and data: Fairchild Semiconductor Division of Fairchild Camera and Instrument Corp., Motorola Semiconductor Products, Inc., Radio Corporation of America (Electronic Components and Devices), Sylvania Electric Products, Inc., and Texas Instruments, Inc.

RUFUS P. TURNER

# Contents

## CHAPTER 1

FUNDAMENTALS OF THE INTEGRATED CIRCUIT . . . .	7
--	---

1.1 What is the IC? 1.2 Inside the IC. 1.3 Classification of ICs. 1.4 IC Symbols. 1.5 Characteristics. 1.6 Installation Mechanics. 1.7 Typical IC Setups. 1.8 Large-Scale Integration (LSI). 1.9 Typical IC Applications.

## CHAPTER 2

AMPLIFIERS . . . . .	29
----------------------	----

2.1 Amplification Potentialities. 2.2 Simplest AF Amplifier. 2.3 High-Gain Preamplifier. 2.4 Audio Driver. 2.5 Complete AF Amplifier. 2.6 Bandpass AF Amplifier (RC Type). 2.7 Bandpass AF Amplifier (LC Type). 2.8 Bandstop AF Amplifier (RC Type). 2.9 Bandstop AF Amplifier (LC Type). 2.10 Cascaded-IC AF Amplifiers. 2.11 Stereo Preamplifier. 2.12 DC Voltage Amplifier. 2.13 RF Amplifier. 2.14 IC as Untuned RF Amplifier. 2.15 I-F Amplifier. 2.16 Video Amplifiers.

## CHAPTER 3

OSCILLATORS . . . . .	44
-----------------------	----

3.1 Twin-T RC AF Oscillator. 3.2 Phase-Shift RC AF Oscillator. 3.3 Wien-Bridge RC AF Oscillator. 3.4 Transformer-Feedback AF Oscillator. 3.5 Transformer-Feedback RF Oscillator. 3.6 Combination AF/RF Oscillator. 3.7 Crystal-Controlled RF Oscillator.

## CHAPTER 4

CONTROLS . . . . .	54
4.1 Sensitive DC Relay. 4.2 Sensitive AF/RF Relay. 4.3 Selective AF Relay. 4.4 Sound-Operated Relay. 4.5 Proximity Relay. 4.6 Photocell Amplifier. 4.7 Simple Latch. 4.8 Threshold Circuit. 4.9 Control Amplifier-Limiter. 4.10 Interval Timer.	

## CHAPTER 5

COMMUNICATIONS . . . . .	66
5.1 Simple Radio Receiver. 5.2 IC Superhet Receiver. 5.3 Untuned RF Amplifier for Receivers. 5.4 IC FM Receiver Stages. 5.5 IC TV Sound I-F Amplifier and Detector. 5.6 Product Detector. 5.7 Balanced Modulator. 5.8 Miscellaneous Receiver and Transmitter Applications.	

## CHAPTER 6

TEST INSTRUMENTS . . . . .	75
6.1 IC as Instrument Amplifier. 6.2 Basic Electronic Voltmeter. 6.3 DC Voltmeter/Millivoltmeter. 6.4 AC Voltmeter/Millivoltmeter. 6.5 Square-Wave Multivibrator. 6.6 AF/RF Signal Tracer. 6.7 Secondary Frequency Standard. 6.8 Test Oscillators. 6.9 Null Detectors. 6.10 Distortion Meter.	

## CHAPTER 7

SUPPLEMENTARY APPLICATIONS . . . . .	85
7.1 Integrator. 7.2 Differentiator. 7.3 Inverting Adder. 7.4 Combination Adder and Subtractor. 7.5 Logarithmic Converter. 7.6 Voltage Regulator.	

MANUFACTURERS OF ICs SHOWN IN SCHEMATICS IN THIS BOOK . . . . .	91
---	----

INDEX . . . . .	93
-----------------	----

# Fundamentals of the Integrated Circuit

In 1957, a revolutionary incident occurred in the world of electronics: the invention of the *integrated circuit* (abbreviated *IC*) by Jack S. Kilby at Texas Instruments, Inc. (In 1969, Mr. Kilby received the National Medal of Science.) The IC ushered in the present age of microelectronics by offering on a single, tiny, semiconductor wafer an entire circuit including diodes, transistors, resistors, capacitors, and internal “wiring.” In the decade that followed its relatively quiet introduction, the IC found application in all kinds of electronic equipment, from space vehicles to TV receivers. An entire circuit can now be plugged in and out of a system in the same way that a single transistor formerly was. Sometimes, an external component or two will be needed, but often only a dc supply is required to make an IC work.

This chapter describes the IC and explains in simple language the highlights of IC fabrication and operation.

## ***1.1 WHAT IS THE IC?***

In many respects, the IC is a refined and subminiaturized version of the early electronic *module*. The reader will recall that the module was a complete circuit (such as an amplifier,

flip-flop, oscillator, or detector stage) made as small as possible and provided with a plug-in base so that it might quickly be inserted into or removed from a larger circuit or system (receiver, transmitter, test instrument, computer, etc.). Modules enable an experimenter or designer to breadboard a large setup with a minimum of effort, since they provide ready-made stages; they also speed up maintenance, by allowing an entire defective stage to be replaced quickly and repaired at leisure.

The first modules used tubes and were monstrous by present-day standards of size. Then came transistorized modules, which were much smaller. Next, printed-circuit techniques resulted in further size reduction and improved uniformity. Finally, the IC took the stage as a microminiature module. An IC no larger than a small-signal transistor, and even resembling the latter in size and shape, can contain a number of diodes, transistors, capacitors, and resistors, plus all of the interconnections between these components needed to provide a complete circuit. Various input, output, depower, and auxiliary connections are made to appropriate points in the tiny circuit and are run to pigtails or lugs for external connection. In the design of the early tube- or transistor-type modules, the goal was to make components as small as possible, wiring as compact and simple as practicable (even fastening the terminals of some components together to avoid interconnecting leads), and packing the components together as tightly as practicable. In the IC, however, all of the components and interconnections are fabricated by processing appropriate areas of a single-crystal semiconductor chip or wafer, the whole being kept to microminiature size.

It is beyond the scope of this introductory book to explain in extensive detail how a commercial integrated circuit is manufactured; however, a reasonably clear idea of the general process and of the final structure can be gained from the following section.

## ***1.2 INSIDE THE IC***

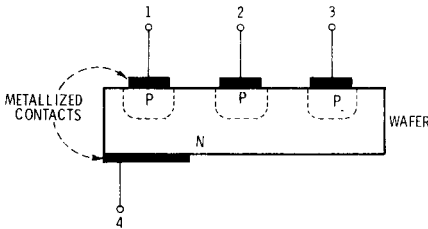
For a picture of the general nature and fabrication of the IC, refer to Figs. 1-1 to 1-4. In each instance, the wafer is



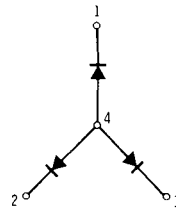
doped silicon, which provides the substrate into which the various components are produced by diffusion, and the bold black areas represent metallic contacts that are deposited on the surface.

### ***Integrated Diodes***

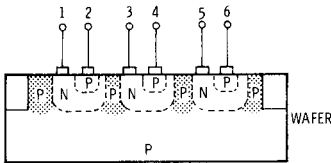
In Fig. 1-1A, the wafer contains three diodes. Each of these consists of a small diffused p-type region forming a junction with the n material of the wafer. Each of the p regions thus makes a diode with the common n region supplied by the substrate. Thus, the n-type wafer not only supplies the substrate which supports the diodes, but also acts as a common cathode for all three diodes (see the equivalent circuit in Fig. 1-1B). Although, for easy illustration here, the metallized contacts are shown as having simply been deposited on the surface of the wafer over the proper areas, the arrangement usually is not this simple. Instead, as shown in Figs. 1-3 and 1-4, a thin oxide layer or film is formed over the diffused areas to protect them; then this film is properly etched to allow contact with the specific areas, and finally the metal is deposited on top of the oxide.



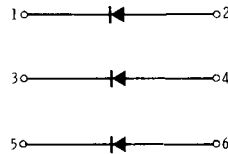
(A) *3-diode IC (common anode).*



(B) *Equivalent circuit.*



(C) *3-diode IC (isolated sections).*

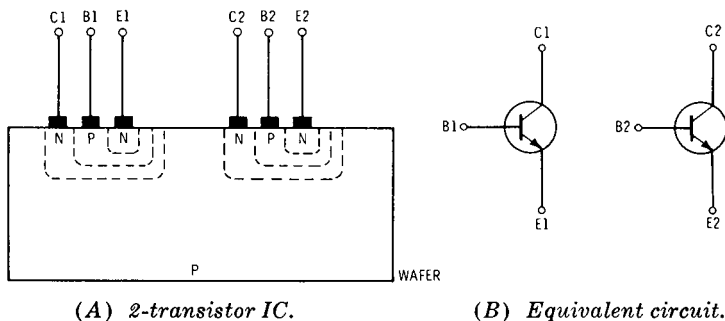


(D) *Equivalent circuit.*

***Fig. 1-1. Basic integration: diodes.***

(Note in Fig. 1-4A, for example, how the metal has penetrated through etched slits in the oxide at points 6 and 7 to make contact with the n and p regions, respectively, of the diode underneath.)

In a structure such as that shown in Fig. 1-1A, some leakage of current will occur through the substrate between the components (diodes here). However, the resistivity of the substrate is high, and the leakage currents are consequently low. Nevertheless, techniques for isolation of integrated components have been worked out. One such arrangement is shown in Fig. 1-1C, in which a high-resistance p region has been diffused into the wafer between diodes.



**Fig. 1-2. Basic integration: transistors.**

Unlike the common-anode arrangement of Fig. 1-1A, the three diodes in Fig. 1-1C have individual, separated anodes. For each diode, an n region (for the cathode) first is diffused into the wafer, and then a p region (for the anode) is diffused into the n region. The three diodes (see equivalent circuit in Fig. 1-1D) then may be connected in any way the user desires.

### ***Integrated Transistors***

Fig. 1-2A shows how the technique just described is extended to produce transistors in the substrate. Here, an n region first is diffused (for the collector electrode of the transistor) into the substrate. Next, a p region (for the base) is diffused into this n region. And finally, an n region (for the emitter) is diffused into this base p region. The result is an npn transistor. When the collector is situated

adjacent to the substrate, as it is in Fig. 1-2A, the substrate bulk can aid in the removal of heat from the collector.

While, for easy illustration, the metallized contacts are shown as having simply been deposited on the surface of the wafer over the collector, base, and emitter areas, the arrangement usually is not this simple. Instead, as shown in Figs. 1-3 and 1-4, a thin oxide layer or film is formed over the surface of the wafer for protection; then this layer is properly etched to allow contact with the specific areas, and finally the metal is deposited on top of the oxide. (Notice in Fig. 1-4A, for example, how the metal has penetrated through etched slits in the oxide—at points 8, 9, and 10—to make contact with the n-, p-, and n-type regions that constitute the transistor underneath.)

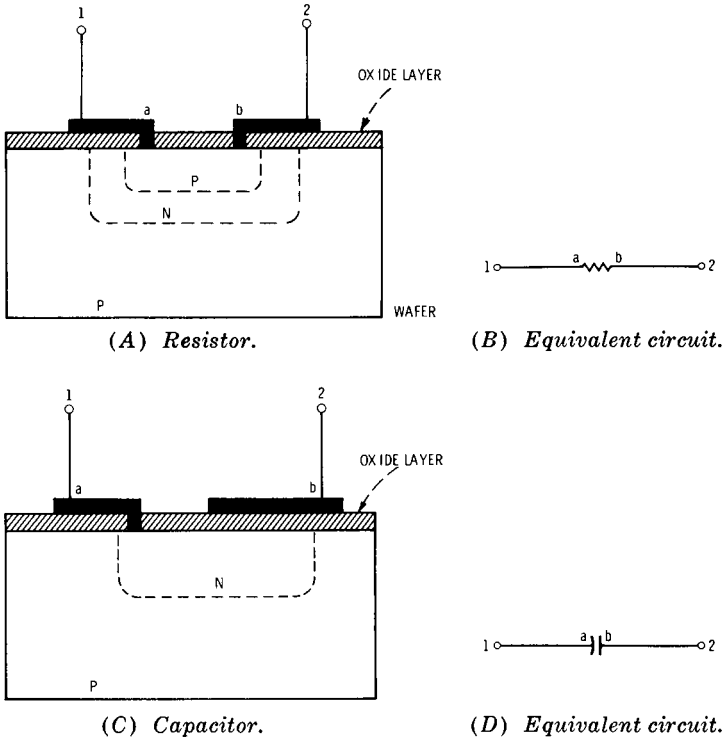
A number of transistors might be processed into the wafer, consistent with the size of the wafer, but for simplicity only two isolated ones are shown in Fig. 1-2A. The equivalent circuit is given in Fig. 1-2B.

Although simple bipolar transistors are shown here, FETs and MOSFETs also are found in integrated circuits, and power transistors are found as well as small-signal ones.

### ***Integrated Passive Components***

Resistors and capacitors also may be processed into the IC wafer. Fig. 1-3A shows the formation of a resistor. Here, the metallic electrodes (a, b) make contact with the diffused p region that constitutes the resistor “material.” (Suitable control of the chemical composition of this p region determines the amount of resistance.) The surrounding diffused n region forms a diode with the resistive p region to isolate the integrated resistor from other components integrated into the same substrate. Fig. 1-3B shows the equivalent circuit.

Fig. 1-3C shows the formation of a capacitor. Here, one metallic electrode (a) makes contact with the diffused n region, which acts as one plate of the capacitor. The other metallic electrode (b) is deposited on top of the oxide layer, directly over and facing most of the n-region area, but not extending through to that area, and forms the second plate of the capacitor. The oxide layer between electrode b and the n region serves as the dielectric separator of the capacitor.



**Fig. 1-3. Basic integration: passive components.**

As in other capacitors, the capacitance depends upon plate area, dielectric thickness, and dielectric constant. Fig. 1-3D shows the equivalent circuit.

At this writing, techniques for the microminiaturization and integration of inductors have not been completely successful. Therefore, external coils, transformers, and chokes are now being used with ICs. Some promise is offered, however, by the *gyrator*, an active device which under certain circumstances can make a capacitor (which, of course, can be integrated) look like an inductor. The gyrator is essentially a special, multitransistor, direct-coupled, negative-feedback amplifier (itself easily capable of integration).

**Integrated Complete Circuit**

Fig. 1-4 shows a full circuit containing both active and passive components integrated into a single p-type wafer.

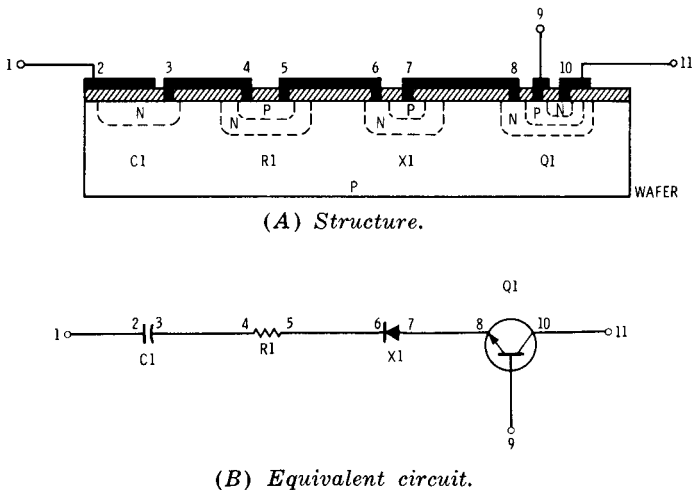
While this circuit is not necessarily functional, consisting as it does of three components connected in series, it is illustrative of the method and configuration of the integrated *circuit*.

The individual components (from left to right in Fig. 1-4A: 1 capacitor, 1 resistor, 1 diode, and 1 transistor) were separately described in the preceding discussion. The components are "wired" in series by having the deposited metallic electrodes run between, and make contact with, the individual components. Fig. 1-4B shows the equivalent circuit, with the identifying numbers matching those in Fig. 1-4A.

From this rudimentary illustration, it should be easy to visualize a multistage amplifier circuit consisting of several properly connected transistors, bias resistors, coupling capacitors, load resistors, and voltage-stabilizing diodes, all integrated into a single wafer.

### **Typical ICs**

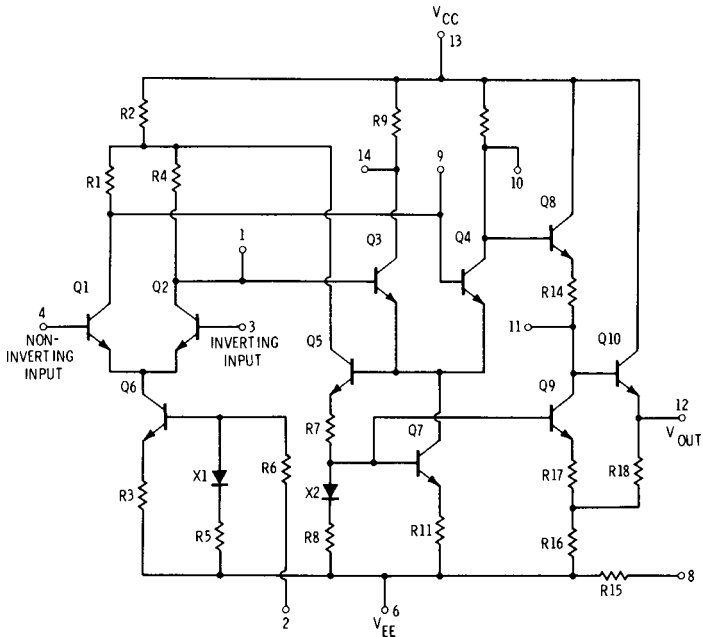
For some idea as to the component content of a typical integrated circuit, see Fig. 1-5. This is the internal circuit of the RCA Type CA3030 operational amplifier IC. In this unit, there are 10 transistors, 2 diodes, and 18 resistors (30 components and all the internal "wiring" on a chip a few mils square). This IC has two inputs (terminals 3 and 4) and one output (terminal 12). Its frequency range is dc to 50



**Fig. 1-4. Basic integration: complete circuit.**

MHz, and its voltage gain is 70 dB. As is seen from Fig. 1-5, a number of terminals are provided. This enables the user to use a part of the internal circuit, as well as the entire IC.

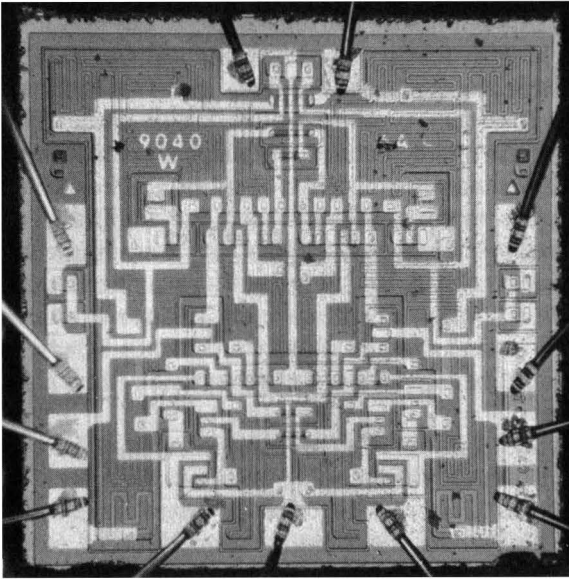
For some idea of the appearance of an IC chip, see Fig. 1-6. In this photograph, the monolithic chip has been magnified approximately 30 times. This IC is a Fairchild Type



*Fig. 1-5. Typical integrated circuit: RCA Type CA3030.*

LPDT $\mu$ L 9040 clocked flip-flop containing 16 transistors, 16 diodes, and 22 resistors, and is used in counters, shift registers, and other computer and calculator devices. Notice the wire leads running out from various circuit points. When this IC is packaged, its plastic housing is only approximately  $\frac{1}{4}$  inch square and less than  $\frac{1}{16}$  inch thick.

From the foregoing descriptions in this section, the reader will find the Electronic Industries Association's definition of the integrated circuit a relevant one: "The physical realization of a number of electrical elements inseparably associated on or within a continuous body of semiconductor material to perform the functions of a circuit."



Courtesy Fairchild Semiconductor

**Fig. 1-6.** A monolith IC chip magnified approximately 30 times. The IC is a clocked flip-flop circuit containing 16 transistors, 16 diodes, and 22 resistors.

### **1.3 CLASSIFICATION OF ICs**

Integrated circuits may be classified in a number of ways. The most useful classifications are (1) according to construction, (2) according to operating mode, and (3) according to packaging. These are discussed separately in the following paragraphs.

#### ***According to Construction***

Depending upon construction, ICs are described as *monolithic*, *thin film*, or *hybrid*.

The monolithic IC is the most common type and is described in the foregoing discussions. All of its components and interconnections are formed in a single chip or wafer of semiconductor material. Throughout its body, however, the chip is one material, various small areas of it having been processed to afford diode, transistor, capacitor, or resistor action. It is this feature that suggests the term *monolithic*

(from the Greek *monolithos*, "made from one stone"). Because of this one-material/one-block construction, high uniformity and reliability are obtainable (e. g., the user is easily guaranteed matched diodes and transistors).

In the thin-film type of IC, suitable materials (such as semiconductors and metals) are deposited in thin-film form on the semiconductor chip as substrate. Then the resulting special areas are processed to achieve complete integration and desired electrical characteristics. It is somewhat as if the circuit, components, and wiring were printed on the semiconductor substrate and then blended into the latter. Transistors, however, are not usually formed in ICs by this process. It should be mentioned here that thick films also are used sometimes.

The hybrid type of IC combines features of both the monolithic and film types. Sometimes, the term *hybrid* is applied also to units that contain two or more interconnected IC chips. Other terms occasionally used to refer to one or another of the hybrid configurations include *mono-brid* (from MONOLithic and hyBRID) and *multiple chip*. Whereas the reliability of the hybrid type is low, compared with that of the monolithic IC, transistors, diodes, and passive components may be optimized in hybrid ICs.

### ***According to Operating Mode***

Depending upon mode of operation, ICs are described as either *linear or digital* (or *nonlinear*).

Linear operation is the mode in which the output of the circuit is proportional to the input and usually varies linearly with the input. This type of operation is also usually sinusoidal. Linear ICs include the following types: af amplifier, analog multiplier, balanced modulator, buffer, Darlington amplifier, dc amplifier, differential amplifier, diode array, follower, i-f amplifier, modulator, operational amplifier, power amplifier, rf amplifier, sense amplifier, transistor array, video amplifier, voltage comparator, and voltage regulator.

Digital, or nonlinear, operation is the mode that is common to computer circuitry and components. It involves bistable action and/or nonsinusoidal waveforms. Digital ICs include the following types: adder, buffer, counter, data dis-

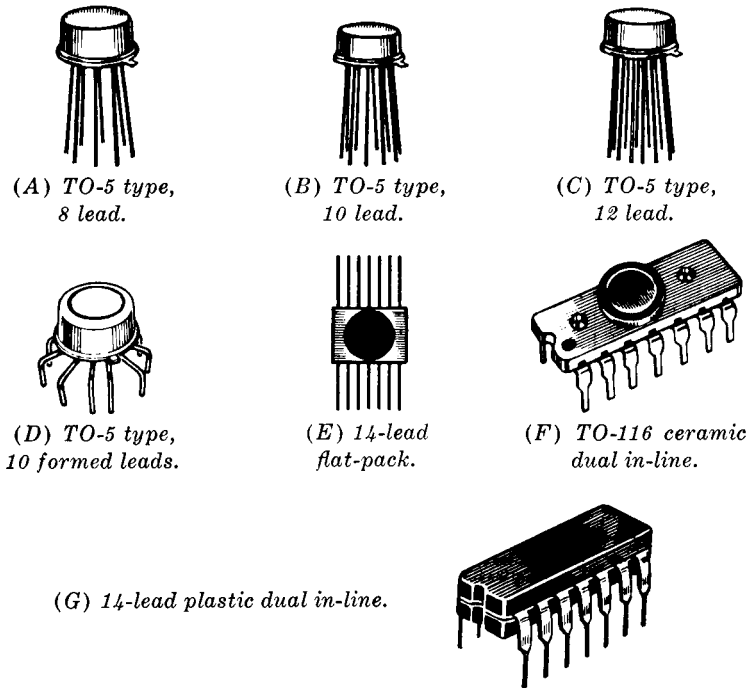


tributor, data selector, decoder, driver, expander, flip-flop, frequency divider, gate, gate expander, half-adder, inverter, latch, line receiver, logic element (all types), memory cell, multiplexer, parity tree, register, Schmitt trigger, shift register, subtracter, and translator.

Linear and digital ICs are made for specific applications, but improvisers often use an IC for some purpose other than that for which it was designed. For example, a hi-fi experimenter might employ a 3-input gate (a digital IC) as a microphone mixer amplifier (a linear application). Similarly, an operational amplifier (linear IC) might be operated as a multivibrator (nonlinear application).

### ***According to Packaging***

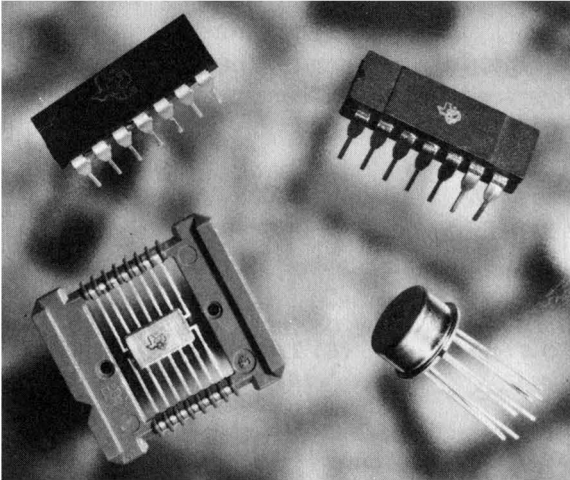
Integrated circuits are sometimes described in terms of package type. In a few years, the number of IC types has grown tremendously, and these units are mounted in many different kinds of housings (more than 100 styles of case or



**Fig. 1-7. Typical IC packages.**

envelope, at this writing). There are several common packages, however, and these are shown in Figs. 1-7 and 1-8.

The small TO-5 type cans (seen in Figs. 1-7A, B, C, and D, and lower right in Fig. 1-8) resemble small-signal transistors and are of the same size. The somewhat larger TO-8 can also is used, as is also the TO-3 “power-transistor-type” package. The flat-pack type (Fig. 1-7E, and lower left in Fig. 1-8) resembles somewhat the old plastic-molded resistor-capacitor networks. But the *dual in-line* packages (ceramic: Fig. 1-7F and upper right Fig. 1-8—plastic: Fig. 1-7G and upper left Fig. 1-8) are “new looks” in electronic components. All of these are tiny units.



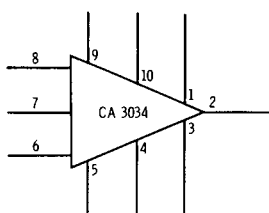
Courtesy Texas Instruments, Inc.

**Fig. 1-8. Typical IC packages.**

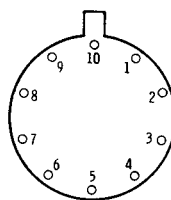
## **1.4 IC SYMBOLS**

It would be tedious to draw most complete IC circuits (see, for example, Fig. 1-5), especially if several ICs are to appear in a schematic. The symbols shown in Fig. 1-9 and 1-10 represent complete ICs and greatly simplify draftsmanship.

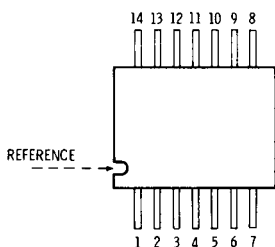
The symbol for the linear IC is shown in Fig. 1-9; symbols for digital ICs are shown in Fig. 1-10. In each instance, the lines representing leads running to the IC terminals are numbered to agree with the actual terminal numbering of



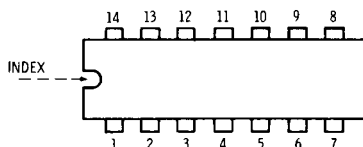
(A) *Symbol.*



(B) *Bottom view of TO-5 package.*



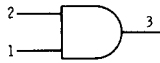
(C) *Top view of 14-lead ceramic flat-pack.*



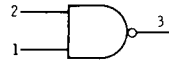
(D) *Top view of 14-lead dual in-line plastic package.*

**Fig. 1-9. Linear IC symbol and terminal layouts.**

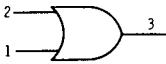
the IC. See, for example, the correspondence between the symbol (Fig. 1-9A) for the Type CA3034 IC and the pigtail numbering of this IC (Fig. 1-9B). It is not in every schematic that the numbering along the symbol follows the same sequence as the numbering of terminals on the actual IC; the sequence on the symbol is often a matter of drafting convenience. However, the terminals along the left vertical edge of the symbol (e. g., 6, 7, and 8 in Fig. 1-9A; 1 and 2 in Fig. 1-10A, B, C, and D; and 1, 2, and 3 in Fig. 1-10E) are usually input terminals, and the terminal(s) at the point of the symbol (e. g., 2 in Fig. 1-9A; 3 in Figs. 1-10A, B, C, and D; and 4 and 5 in Fig. 1-10E) are usually reserved for the output. (Sometimes, some other terminal near the right end of the symbol, along the top or bottom edge, may be the output. For example, two such terminals, such as 1 and 3 in Fig. 1-9A may indicate the outputs of an IC having balanced or push-pull output. In Figs. 1-9A and B, correspondence is shown between the conventional triangular symbol and the numbering on the corresponding 10-lead TO-5 package. The



(A) AND gate.



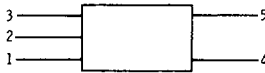
(B) NAND gate.



(C) OR gate.



(D) NOR gate.



(E) Flip-flop.

**Fig. 1-10. Typical digital-IC symbols.**

numbering is not the same, however, on other packages. Figs. 1-9C and D, for example, show the actual terminal numbering on ceramic flat-pack and in-line plastic packages, respectively. In the latter instance, where these 14 numbers are placed on the triangular symbol depends upon how the schematic is arranged (with the exception, of course, of the special places for input and output terminals, as explained above).

Fig. 1-10 shows some common digital-IC symbols. Some reference was made to these in the preceding paragraph. In the gates (Figs. 1-10A to D), two inputs (terminals 1 and 2) and one output (terminal 3) are shown, but some gates have more than two inputs. In the flip-flop (Fig. 1-10E), three inputs (terminals 1, 2, and 3) and two outputs (terminals 4 and 5) are shown. Besides these input and output terminals, the digital IC, like the linear IC, has other terminals, but these have been omitted for simplicity in Fig. 1-10.

Some draftsmen use the triangular symbol (Fig. 1-9A) for all ICs, whether digital or linear. This simplifies matters, often considerably, and so long as the terminal numbering on the symbol corresponds to that on the IC package, no harm is done. In hobbyist-type schematics, the actual base diagram (Figs. 1-9B, C, D) often is used instead of the conventional symbol.

## **1.5 IC CHARACTERISTICS**

Since most ICs are circuits, not single components, IC electrical characteristics are those of a circuit. In most

instances, therefore, performance of the IC is specified not by some single parameter (such as  $\beta$  of a transistor or  $G_m$  of a vacuum tube), but by a series of parameters and ratings that describe operation of the particular integrated *circuit*. An exception, of course, is the IC that consists only of two or more separate transistors or diodes; here, the usual transistor or diode characteristics are given.

The following list defines characteristics for which numerical data are found in the IC manufacturer's literature.

**Amplification.** See *Gain*.

**Bandwidth.** See *Frequency Range*.

**Bias Current.** Also called *input bias current*. The current into the IC input terminals in response to application of a signal voltage. Expressed in  $\mu\text{A}$ .

**Common-Mode Gain.** The voltage gain for common-mode input (see Fig. 1-12G).

**Common-Mode Impedance.** The input impedance (see *Input Impedance*) between either input of a differential-amplifier IC (Fig. 1-12B to G) and ground. Expressed in ohms.

**Common-Mode Rejection Ratio.** The ratio of open-loop gain (Fig. 1-12F) to common-mode gain (Fig. 1-12G). Expressed in dB.

**Differential-Input Impedance.** The input impedance measured between the differential input terminals (INPUT 1 and INPUT 2 in Fig. 1-12F). Expressed in ohms.

**Differential-Input Voltage Range.** The range set by the maximum signal voltage that may be applied between differential input terminals (Fig. 1-12F) without overdriving the IC amplifier.

**Drift, Input-Voltage.** The (usually slow) variation in output-signal voltage divided by the open-loop voltage gain of the IC. This drift is a function of time, temperature, and other factors. Expressed in  $\text{mV}/^\circ\text{C}$ .

**Frequency Range.** The band of frequencies within which the IC will give specified performance. Expressed as *dc to a specified high-frequency limit* (e.g., dc to 50 MHz) or as the *band width* (e.g., 30 MHz).

**Gain.** The overall voltage gain of an amplifier-type IC. Fig. 1-12 shows the various modes of operation, with the cor-

responding voltage-gain formula given in each instance. Note that in Fig. 1-12F, the input signal is applied between the INPUT 1 and INPUT 2 terminals, and the output is taken between the OUTPUT 1 and OUTPUT 2 terminals. Note also that in Fig. 1-12G, the input signal is applied to the INPUT 1 and INPUT 2 terminals in parallel, and the output is taken between the OUTPUT 1 and OUTPUT 2 terminals. Expressed in dB. See also *Common-Mode Gain* and *Open-Loop Voltage Gain*.

**Harmonic Distortion.** In the output signal of an IC handling a sinusoidal signal, the ratio of total harmonic voltage to the fundamental-frequency voltage. Expressed in percent (along a 100% scale) at the test frequency.

**Input Bias Current.** See *Bias Current*.

**Input Impedance.** The impedance presented by the IC to the input signal. For ICs operated by a dc signal, this impedance is the input resistance. Expressed in ohms (dc or at the specified test frequency).

**Input-Voltage Drift.** See *Drift, Input-Voltage*.

**Input-Voltage Offset.** See *Offset, Input-Voltage*.

**Noise Figure.** The maximum intensity, or amplitude, of noise present in the output signal delivered by the IC. Expressed in dB.

**Offset.** The unbalance between the two halves of a symmetrical unit, such as the IC shown in Figs. 1-12B to G.

**Offset, Input-Voltage.** The value of dc input-signal voltage at the differential input (e.g., INPUT 1, INPUT 2, Fig. 1-12F) required to produce an output-signal voltage of zero. Expressed in mV.

**Open-Loop Bandwidth.** When an IC amplifier is operated without feedback, this is the band of frequencies within which the gain (see formulas in Fig. 1-12) is within 3 dB of a specified low-frequency value.

**Open-Loop Voltage Gain.** The gain of an IC amplifier operated without feedback. See also *Gain* and Fig. 1-12.

**Output Impedance.** The impedance "seen" at the output terminals of the IC. For ICs delivering a dc output signal, this is the output resistance. Expressed in ohms (dc or at a specified test frequency).

**Output Swing.** The maximum output-signal amplitude (with a given dc supply) which may be attained without IC over-

load. Expressed in dcV or peak acV for a stated load resistance.

**Power Dissipation.** The maximum power which may be handled safely by the IC. Usually expressed in mW, but may be expressed in W for ICs containing a power output stage.

**Power Output.** The output-signal power delivered by an IC having a power output stage. Expressed in mW or W, at a specified load resistance.

**Slew Rate.** The maximum rate of change of the output signal of the IC, with respect to time. Usually expressed in volts per microsecond.

**Supply Current.** The dc operating current of the IC. For a single-supply IC (Fig. 1-11A), this is  $I_{cc}$ . For a dual-supply IC (Fig. 1-11B), this is  $I_{cc}$  from the "collector-end" supply, and  $I_{ee}$  from the "emitter-end" supply. Maximum and typical supply-current values are given in the IC manufacturer's literature. Expressed in mA or  $\mu$ A.

**Supply Voltage.** The dc voltage required to operate the IC. Some ICs may be operated from a single voltage source,  $V_{cc}$ , as in Fig. 1-11A; others require a dual supply  $V_{cc}$  and  $V_{ee}$ , as in Fig. 1-11B. In the dual circuit,  $V_{cc}$  is connected to the "collector end" of the IC, and  $V_{ee}$  to the "emitter end." Maximum and typical supply-voltage values are given in the IC manufacturer's literature. Expressed in Vdc.

**Temperature.** The maximum temperature at which the IC may be operated safely. Expressed in  $^{\circ}$ C.

## **1.6 INSTALLATION MECHANICS**

ICs may be installed into larger circuits by the same means used for single transistors: (1) sockets, (2) contact clips or springs, (3) contact screws, and (4) direct soldering. In temporary experimental setups, flexible clip leads may be used.

Because of their small size and numerous contacts, ICs often require deft handling. A TO-5 unit (see Fig. 1-7C), for example, can have 12 flexible pigtailed spaced around a circle less than  $\frac{1}{4}$  inch in diameter (considerably more crowding than that found in the 3-pigtail transistor), and this arrangement demands patient handling to prevent bends and

short circuits. The dual in-line packages (see Figs. 1-7F and G) have rigid lugs instead of pigtails, but 7 of these lugs are spaced along each edge of the housing in a line less than  $\frac{3}{4}$  inch long.

## 1.7 TYPICAL IC SETUPS

Most ICs offer considerable flexibility. Because of the numerous terminals at various parts of the internal circuit, the user may employ either the entire circuit or only those parts he needs, the unused portion of the IC simply idling or

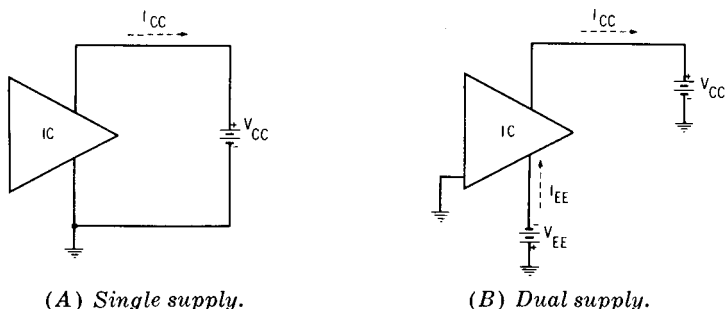


Fig. 1-11. Dc supply for IC.

floating. This will be clear from an inspection of the operational-amplifier IC shown in Fig. 1-5. This entire IC may be used by applying an input signal to either INPUT terminal 3 or INPUT terminal 4, and taking the output signal from the single OUTPUT terminal 12. (A signal applied to 3 will appear amplified, but inverted in polarity, at 12, whereas the same signal applied instead to 4 will appear amplified and uninverted at 12. That is, 3 positive = 12 minus, and 4 positive = 12 positive. The inverting input terminal (here, 3) sometimes is labelled *negative*, and the noninverting one (here, 4) *positive*. The entire IC thus offers two separate, identical-gain amplifiers, with a common, low-impedance (emitter-follower) output. And either amplifier can be placed into operation simply by applying dc voltages  $V_{cc}$  and  $V_{ee}$  and the input signal; no external components are needed. Diodes X1 and X2; transistors Q5, Q6, and Q7; and resistors R3, R5, R6, R7, R8, and R11 form current sinks for stabilization of operation.



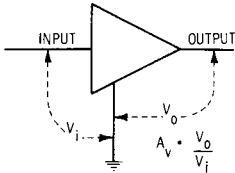
Sometimes, the entire circuit is not needed. For example, the input signal may be applied to 11, and only the output transistor (Q10) is used—as an emitter follower. Similarly, the input signal may be applied to 9, whereupon Q4 acts as a common-emitter amplifier direct coupled through Q8 to the emitter-follower output transistor, Q10. Also, a single input stage may be employed as a common-emitter amplifier by applying the input signal to 3 and taking the output signal from 1, or by applying the input to 4 and taking the output from 9. Other ways of going into this IC and coming out of it will suggest themselves to the reader.

The differential operational amplifier (abbreviated *op-amp*) thus is one of the most useful linear ICs. The type of full-IC operation discussed above is illustrated by Fig. 1-13A. There being no overall feedback in this instance, the open-loop voltage gain of the IC is realized. Open-loop operation is depicted also by all of the arrangements in Fig. 1-12.

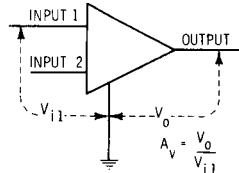
But overall feedback may be used. This is illustrated by Figs. 1-13B to D. In Fig. 1-13B, external resistor R1 provides a feedback path from the output terminal to the inverting input terminal. The feedback therefore is negative. In Fig. 1-13C, external voltage divider R1-R2 divides the output-signal voltage and applies the resulting voltage as feedback to the noninverting input terminal. This feedback therefore is positive. (When the positive-feedback amplitude is high enough, the opamp becomes an oscillator.) In Fig. 1-13D, both negative and positive feedback are obtained with external resistors R1 (negative), and R2 and R3 (positive).

Opamps usually provide high gain. When the overall gain of a single IC is insufficient, however, two or more ICs may be cascaded, as shown in Fig. 1-13E. If required, feedback may be provided around each IC individually or around the entire cascade. In cascades, individual and combined phase shifts must be considered when feedback paths are planned. In the two-IC cascade in Fig. 1-13E with IC<sub>1</sub> and IC<sub>2</sub> connected output-to-negative as shown, for example, a signal applied to the negative INPUT terminal, as shown, is *uninverted* at the cascade OUTPUT terminal, whereas a signal applied to the positive INPUT is *inverted* at the cascade OUTPUT (both of these effects are the opposite of those obtained with a *single* IC). In a three-IC cascade, the phase

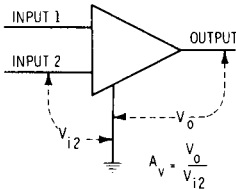
relations of the single IC apply to the cascade. Thus, when identical ICs are employed and are connected together as shown in Fig. 1-13E, negative (inverting) and positive (non-inverting) input labels must be interchanged in even-numbered cascades, but may remain unaltered in odd-numbered cascades.



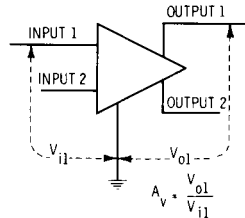
(A) Single-ended amplifier.



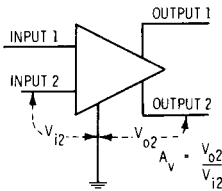
(B) Single-output differential amplifier (input 1 used).



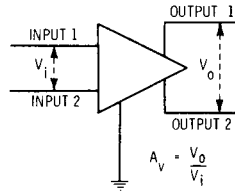
(C) Single-output differential amplifier (input 2 used).



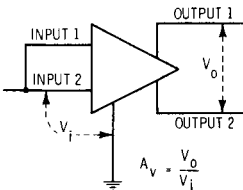
(D) Dual-output differential amplifier (side 1 used).



(E) Dual-output differential amplifier (side 2 used).

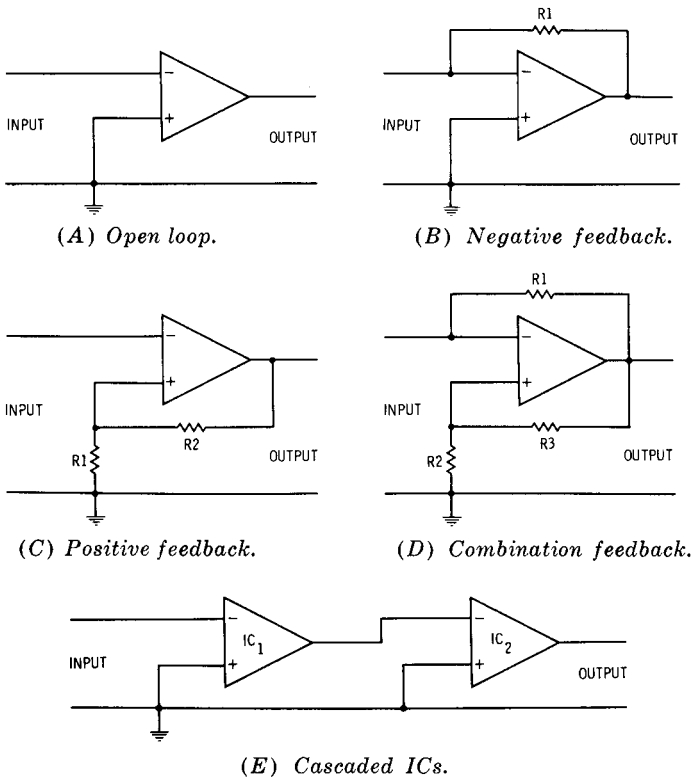


(F) Differential amplifier (both sides used).



(G) Differential amplifier (common-mode input).

**Fig. 1-12. IC amplifier input/output relationships.**



**Fig. 1-13. Opamp operation.**

For simplicity, only resistors are shown in the feedback paths in Figs. 1-13B to D, and this sometimes is the case. Often, however, capacitors also are included—for isolation, RC tuning, etc. Similarly, coils, transformers, transistors, and other active and passive devices serve, where needed, as external (“outboard”) components.

### 1.8 LARGE-SCALE INTEGRATION (LSI)

Fig. 1-13E suggests that complicated systems may be built up comparatively easily by putting together the proper linear and/or digital ICs and adding any required external components. And this method is indeed employed in the design and fabrication of a number of modern electronic systems.

The practice goes further, however, than simple implementations—the assembly of ICs and external discrete components into a larger circuit. A number of separate ICs and external components, together with all “wiring” may now be processed into a single wafer. This practice is referred to as *large-scale integration* (abbreviated LSI), and it will be increasingly responsible for dramatic size and weight reductions in all kinds of electronic equipment, especially computers, calculators, radar, and television.

A striking instance of size reduction through LSI is seen in the new mini-calculators that seem destined eventually to replace the engineer’s slide rule. One model is smaller than a cigar box, weighs only 2.2 pounds, and performs the following operations: addition, subtraction, multiplication, division, chain multiplication and division, raising to a power, calculations by a constant, and mixed calculations. Another example is a recently announced solid-state wrist watch. This regular-size timepiece contains more than 40 ICs—equivalent to about 3500 transistors.

## **1.9 TYPICAL IC APPLICATIONS**

The following chapters show typical applications of integrated circuits, in most instances single ICs. This presentation includes amplifiers (af, dc, rf, video), oscillators, controls, receiver applications, transmitter applications, power-supply applications, test instruments, and analog-computer applications.

The wide range of IC service is illustrated by this list, but the applications given here do not nearly exhaust the range of possibilities. The newcomer to ICs doubtless will be intrigued with the versatility and extended service of what appears to be a *single* component, the IC.

In some instances, power-supply connections have been omitted for simplicity and clarity. If the reader wishes to duplicate these setups, he need only connect the dc supply to the IC terminals shown in the manufacturer’s data. While specific IC’s are shown in many instances and the values are given for outboard components, other schematics show only a class of operation and have no values. In the latter case, the user may adapt an IC he has to the indicated service.

## CHAPTER 2

# Amplifiers

Countless newcomers will have their first experience with the IC as a microminiature multistage amplifier. Indeed, many experimenters will already be accustomed to the “unit” amplifier in the form of a module, and they will regard the IC as nothing more than a tiny module. Some designers who must include an entire amplifier into other equipment will be intrigued with the convenience of the IC for this purpose. In whichever category the user falls, he will appreciate the utility of the ready-made, miniature, IC amplifier.

This chapter presents 15 representative applications of ICs in amplifiers of the following types: af, dc, rf, i-f, and video.

Unless shown otherwise in the text or schematic, resistances are in ohms and capacitances are in microfarads, and electrolytic capacitors are rated at 50 Vdcw.

### ***2.1 AMPLIFICATION POTENTIALITIES***

As an amplifier, the IC offers a considerable range of possibilities. Depending upon model and configuration, the IC may provide operation from dc signals up to those at frequencies of several hundred MHz, voltage gain of more than 100 dB, single-ended or balanced output, voltage or power output, inverted and/or uninverted output, and low dc power

drain. In many instances, either the entire internal circuit or a portion of it may be used at will. In systems planning, the IC may be handled as a versatile black box having specified input and output characteristics.

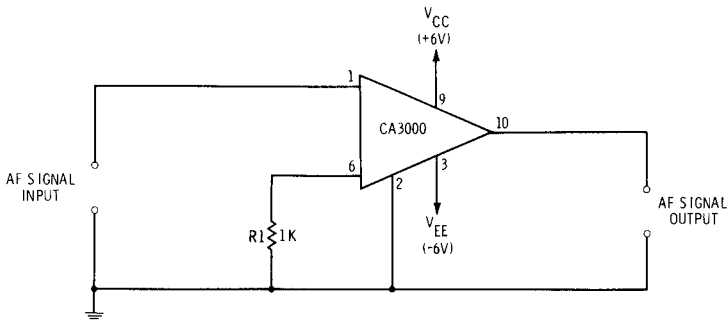
While simultaneously providing voltage gain, with or without phase inversion, the IC may also function as a high-to-low impedance converter. Additionally, the accessibility of various circuit points, via external terminals, enables the amplifier operation to be modified, as desired, through connection of external components and feedback networks.

In all amplifier applications, the IC thus saves the user a great deal of design effort and, at the same time, reduces the labor and time required for the assembly of amplifier systems.

## 2.2 SIMPLEST AF AMPLIFIER

The simplest possible IC audio-frequency amplifier is the IC itself with the minimum of external components. Fig. 2-1 shows such an arrangement. Here, a Type CA3000 unit is used with only one external 1k resistor ( $R_1$ ).

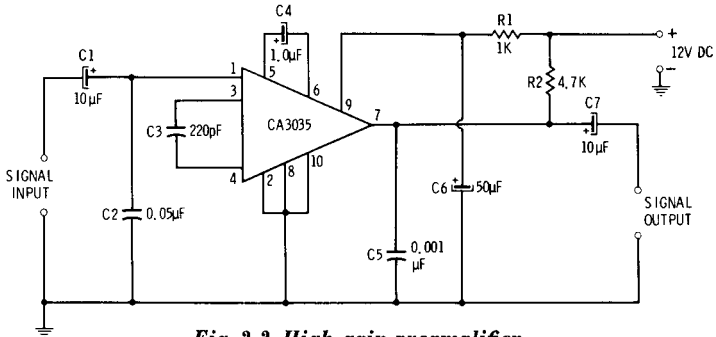
The CA3000 contains two direct-coupled amplifier stages, each consisting of an input emitter follower plus an output common emitter. In the connection shown in Fig. 2-1, only one of these amplifiers is used; the other floats. The voltage gain of this connection is 30 dB. Without any external compensating components, the frequency response is dc to 1 MHz. Input impedance is 0.1 megohm, and output impedance is 8k. Both amplifiers may be used in cascade, with corre-



*Fig. 2-1. Simplest af amplifier.*

sponding increase in gain, by connecting an interstage coupling capacitor externally between IC terminals 10 and 6 and taking the output from terminal 8, instead of terminal 10.

Gain control (by means of a potentiometer) and dc isolation of input and output circuits (by means of blocking capacitors) may readily be achieved, if required, through the connection of external components.



*Fig. 2-2. High-gain preamplifier.*

### 2.3 HIGH-GAIN PREAMPLIFIER

Fig. 2-2 shows the connections for a high-gain af preamplifier employing a Type CA3035 IC. This circuit, designed by R. M. Marston, uses a single 12-volt dc supply.

The CA3035 contains three separate amplifiers, and all of them are used in cascade in the connection shown here. External capacitor C3 provides coupling between amplifier stages 1 and 2, and C4 provides coupling between stages 2 and 3. The voltage gain is 80 dB. The  $-3$  dB bandwidth of the entire CA3035 is approximately 500 kHz.

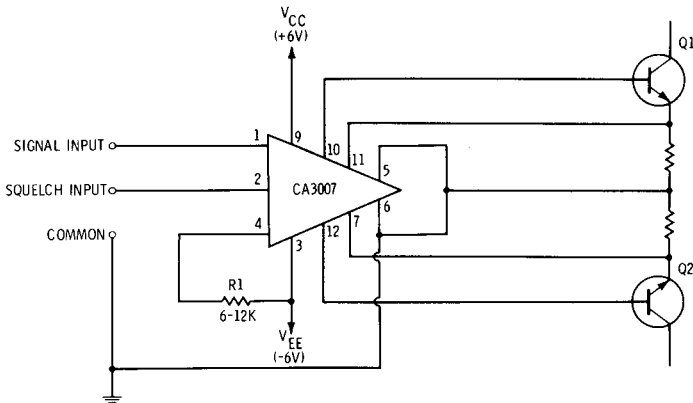
If a gain-control potentiometer is employed, it must be connected at the output terminals or between amplifier stages (e.g., at terminal 4 or 6), since the high gain of this IC (10,000) would cause potentiometer noise to be amplified if the gain control were installed at the input.

### 2.4 AUDIO DRIVER

The symmetrical output of the Type CA3007 IC is employed in Fig. 2-3 to drive the bases of a push-pull transistor,

Class-B, af, power-output stage (Q1-Q2). This circuit, due to RCA, requires two 6-volt dc supplies and as shown here is direct coupled to the Q1-Q2 stage, which can deliver 300 milliwatts output.

The CA3007 provides a typical power gain of 22 dB and has an input impedance of 4k ohms. A squelch voltage of +5 V presented to terminal 2 will cut off the amplifier.



**Fig. 2-3. Audio driver.**

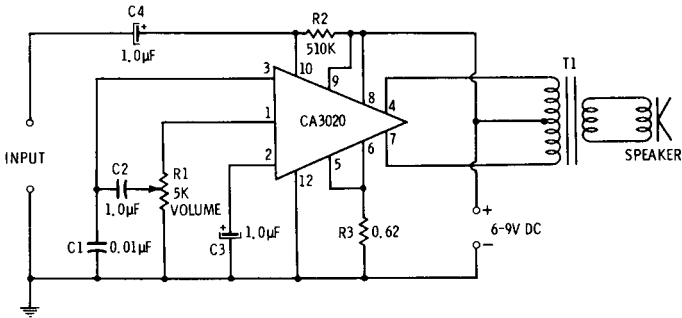
A driver of this type offers considerable simplification and size reduction, since the 12-lead TO-5 package of the CA3007 IC is smaller than the miniature coupling transformer alone required in most transistorized driver stages.

## 2.5 COMPLETE AF AMPLIFIER

Fig. 2-4 shows the connections for a complete af amplifier delivering  $\frac{1}{2}$  watt to a loudspeaker. The Type CA3020 IC employed here contains input amplifier, phase inverter, and push-pull Class-B power-output stages, as well as a 3-diode-type voltage regulator. Internally, direct coupling is employed between all stages. The IC is housed in a 12-lead TO-5 package.

Operated from a single 6- to 9-volt dc supply, this IC draws a zero-signal current of 7 mA and a maximum-signal current of 47 mA. The required input-signal amplitude is 35 mV. A heat sink is required.





**Fig. 2-4. Complete af amplifier.**

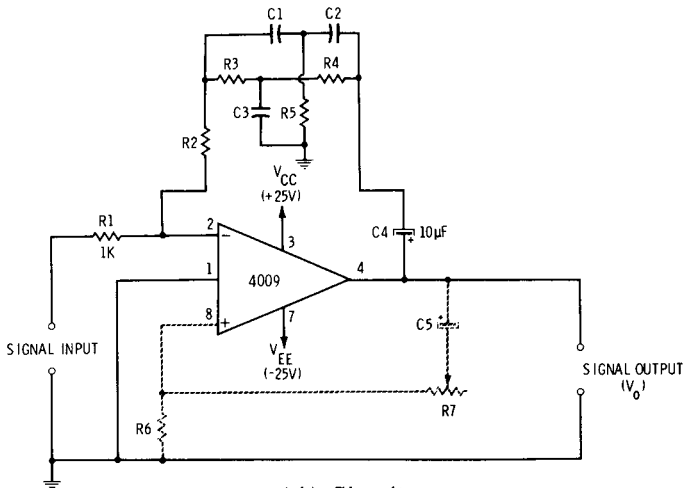
The required external components are four capacitors (C1 to C4), two 2-watt fixed resistors (R2, R3), one 5k volume-control potentiometer (R1), and one miniature output transformer (T1: 125 ohms center tapped to 3.2 ohms). Two of these amplifiers, each no larger than a small-signal transistor and requiring only 9 external components including a loudspeaker, will supply the complete channels for a stereo phonograph.

Like other small-sized amplifiers having the same gain and power output, this amplifier is useful for purposes other than audio reproduction. It finds application, for example, in test equipment, alarm and signaling devices, modulators for low-powered transmitters, etc.

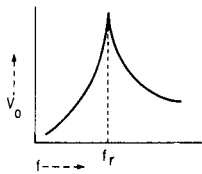
## **2.6 BANDPASS AF AMPLIFIER (RC TYPE)**

External resistance-capacitance tuning is used in Fig. 2-5A to peak the frequency response of a high-gain af amplifier. This is the familiar arrangement in which a twin-T null network (C1-C2-C3-R3-R4-R5) is connected in the negative-feedback path of the amplifier. Fig. 2-5B shows the frequency response. A Type 4009 IC is used. Capacitor C4 provides dc blocking, and resistor R2 minimizes IC loading of the RC network, but neither of these components is a part of the tuned RC network.

In this arrangement, the negative feedback (back to inverting input terminal 2) ideally cancels the gain of the amplifier at all frequencies but the one that is nulled out by the twin-T network. The amplifier accordingly transmits this



(A) Circuit.



(B) Response.

Fig. 2-5. Bandpass of amplifier (RC type).

frequency (actually a narrow band of frequencies, as shown in Fig. 2-5B). The peak frequency  $f_r$  is found from the formula:

$$f_r = 1 / (2\pi R_3 C_1)$$

where,

- $f_r$  is in hertz,
- $C_1$  is in farads,
- $R_3$  is in ohms.

Also,  $C_1 = C_2 = \frac{1}{2}C_3$ , and  $R_3 = R_4 = 2R_5$ . The response may be sharpened by providing positive feedback (back to non-inverting input terminal 8) through the adjustable signal-divider,  $R_6$ - $R_7$ . Sharpest peaking occurs when the positive feedback is set just below the point at which the amplifier oscillates. The amplifier tuning may be made continuously variable (say, from 20 Hz to 20 kHz) by using a 3-gang tuning potentiometer for  $R_3$ - $R_4$ - $R_5$ , and switching  $C_1$ ,  $C_2$ , and  $C_3$  in trios to change bands.

The obvious advantage of this type of tuned amplifier is its ability to operate without bulky iron-core inductors, and to provide tuning at low audio frequencies. However, two difficulties have always accompanied actualization of the circuit. One is the need that the amplifier have sufficient gain to overcome the losses of the feedback network. The other is that the gain of the basic amplifier be constant over a wide frequency range if the tuned amplifier is to be used throughout the audio spectrum. The IC overcomes both of these difficulties, providing high gain (through cascaded internal stages) and wideband operation (through direct interstage coupling).

## **2.7 BANDPASS AF AMPLIFIER (LC TYPE)**

Although the bandpass amplifier described in preceding Section 2.6 is divorced from all inductors, there are instances in which sharper response is needed than that afforded by RC tuning. The higher Q available with inductor-capacitor tuning provides the narrower passband that is required.

Fig. 2-6A shows essentially the same circuit with an inductor-capacitor null circuit (L1-C1) in the negative-feedback path. The corresponding frequency response is illustrated by Fig. 2-6B. The mode of operation of this tuned amplifier (employing a Type 4009 IC) is the same as that explained in the preceding section, except that L1 and C1 (instead of a twin-T RC network), acting as a wavetrap, remove the feedback frequency to which this combination is resonant; accordingly, this frequency is the one that the amplifier transmits. The resonant frequency  $f_r$  is found by the formula:

$$f_r = 1 / (2\pi\sqrt{L_1C_1})$$

where,

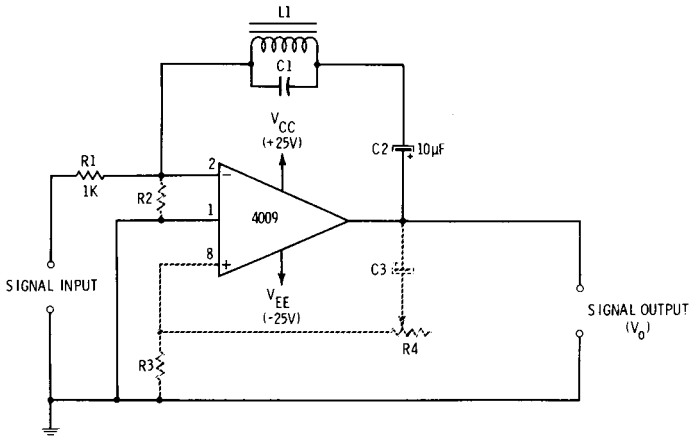
- $f_r$  is in hertz,
- L1 is in henrys,
- C1 is in farads.

Also, from the preceding formula,  $C_1 = 1 / (4\pi^2 f_r^2 L_1)$ , and  $L_1 = 1 / (4\pi^2 f_r^2 C_1)$ .

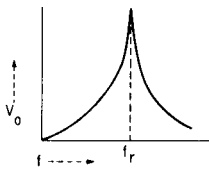
As in the preceding amplifier, the response may be sharpened still further by means of positive feedback obtained

through the R3-R4 signal divider and adjusted just short of the point of oscillation.

The LC-type bandpass amplifier has the obvious disadvantage that it cannot easily be continuously tuned, since L1 and C1 ordinarily are too large to be made continuously variable. However, a small amount of tuning is possible by employing one of the adjustable-core (screwdriver-tuned), high-Q inductors that are commercially available.



(A) Circuit.



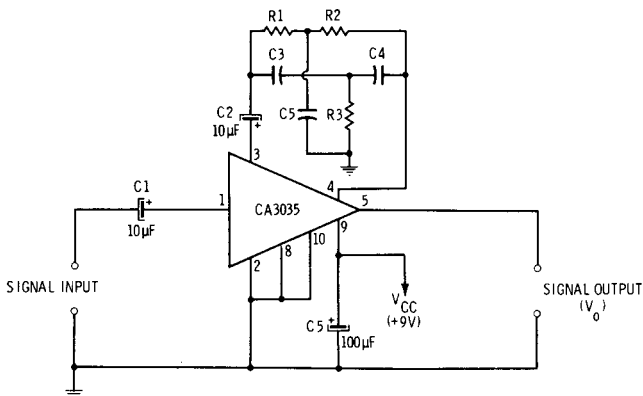
(B) Response.

Fig. 2-6. Bandpass of amplifier (LC type).

## 2.8 BANDSTOP AF AMPLIFIER (RC TYPE)

Fig. 2-7A shows the connections for a bandstop amplifier employing a Type CA3035 IC. Ideally, this amplifier removes one frequency (actually a narrow band of frequencies, as shown in Fig. 2-7B), transmitting all other frequencies with little attenuation.

The frequency that is nulled out is determined by the resistance and capacitance values in a twin-T RC network



(A) Circuit.

(B) Response.

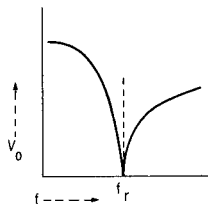


Fig. 2-7. Bandstop of amplifier (RC type).

(R1-R2-R3-C3-C4-C5) connected between amplifier stages 1 and 2 of the IC. The null frequency  $f_r$  is found by the formula:

$$f_r = 1 / (2\pi R1 C3)$$

where,

- $f_r$  is in hertz,
- R1 is in ohms,
- C3 is in farads.

Also,  $C3 = C4 = \frac{1}{2}C5$ , and  $R1 = R2 = 2R3$ .

As in the bandpass amplifier described in Section 2.6, the tuning may be made continuously variable (e.g., from 20 Hz to 20 kHz) by using a 3-gang tuning potentiometer for R1-R2-R3, and switching C3, C4, and C5 in trios to change bands.

## 2.9 BANDSTOP AF AMPLIFIER (LC TYPE)

Although the bandstop amplifier described in preceding Section 2.8 offers the advantage of operation without induc-

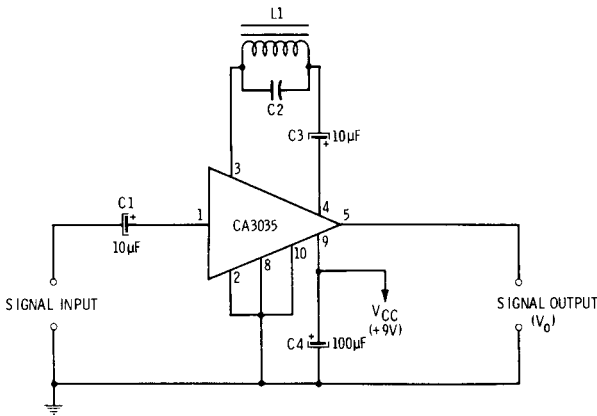
tors, there are instances in which sharper tuning and a deeper null are needed than are obtainable with RC tuning. The higher  $Q$  obtainable with inductor-capacitor tuning provides the narrower passband required under such circumstances.

Fig. 2-8A shows essentially the same circuit with an inductor-capacitor null circuit (L1-C1) connected between amplifier stages 1 and 2 of the Type CA3035 IC. The corresponding frequency response is illustrated by Fig. 2-8B. The mode of operation of this amplifier is the same as that explained in Section 2.8, except that here L1 and C1 (instead of a twin-T RC network), acting as a wavetrapp, remove the frequency to which this combination is resonant. The null frequency  $f_r$  is found by the formula :

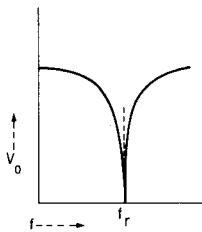
$$f_r = 1 / (2\pi\sqrt{L1C1})$$

where,

$f_r$  is in hertz,  
 L1 is in henrys,  
 C1 is in farads.



(A) Circuit.



(B) Response.

Fig. 2-8. Bandstop of amplifier (LC type).

Also,  $C1 = 1/(4\pi^2f^2L_1)$ , and  $L1 = 1/(4\pi^2f^2C_1)$ . The 10- $\mu$ F capacitor, C3, serves only for dc blocking and does not enter into the frequency determination.

The LC-type bandstop amplifier has the obvious disadvantage that it cannot easily be continuously tuned, since L1 and C1 ordinarily are too large to be made continuously variable. However, a small amount of tuning is possible by employing one of the adjustable-core (screwdriver-tuned), high-Q inductors that are commercially available.

## **2.10 CASCADED-IC AF AMPLIFIERS**

Although ultrahigh-gain ICs are available, there are af applications demanding higher gain than that afforded by a single IC. For higher gain, ICs may be cascaded (see Fig. 1-13E and Section 1.7, Chapter 1).

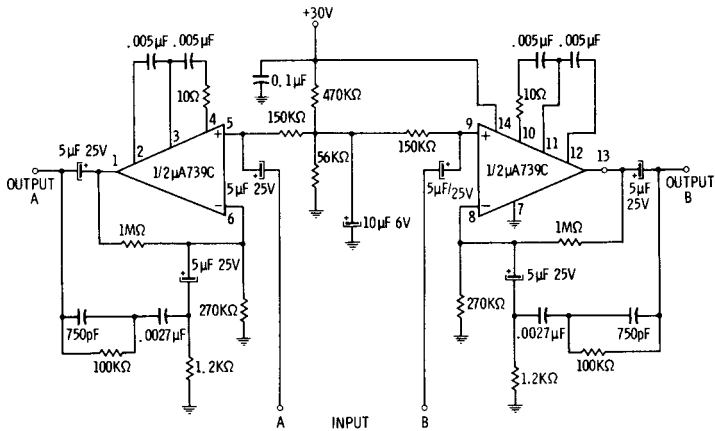
In general, recommended practices for cascading ICs are the same as those for cascading other types of npn transistor amplifiers. Important considerations, for example, are (1) noise amplification, (2) cumulative drift effects, (3) overdriving, (4) decoupling requirements, and (4) overall phase shift.

Cascading of high-gain ICs is common practice where extremely high sensitivity is desired. In most instances, however, available lower-gain ICs will be cascaded in order to approximate the capabilities of an ultrahigh-gain IC that is not immediately available.

## **2.11 STEREO PREAMPLIFIER**

Fig. 2-9 shows the connections for a 2-channel preamplifier for stereo phonographs. This circuit is RIAA equalized and is a design by Fairchild Semiconductors. For the two channels, the two halves of a  $\mu$ A739C IC are used (two separate IC symbols are shown, as this reduces crowding in the schematic, but all of the terminals could have been shown on one triangle).

Each channel provides a voltage gain of 40 dB at 1 kHz. The RIAA-equalized input overload point is 80 mV rms. The signal-to-noise ratio is 74 dB below 10 mV, and the channel separation is 80 dB at 1 kHz.



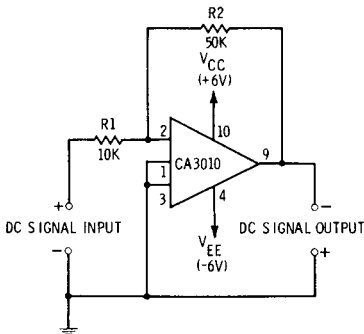
**Fig. 2-9. Stereo preamplifier.**

## 2.12 DC VOLTAGE AMPLIFIER

Because of its direct coupling and stability, the operational-amplifier IC works well with dc signals. Fig. 2-10 shows the connections for a dc voltage amplifier employing a Type CA3010 IC. This arrangement has an input resistance in excess of 15k and an output resistance of 200 ohms.

Operated from a dual dc supply ( $V_{cc} = +6\text{ V}$ ;  $V_{ee} = -6\text{ V}$ ), this arrangement has a voltage gain of 4, for a maximum dc input signal of 1 volt. Negative feedback is provided by the 50k resistor, R2, connected from output terminal 9 to inverting input terminal 2.

Dc amplifier ICs may be cascaded, provided the precautions necessary in the cascading of any direct-coupled transistor amplifiers are heeded. It is necessary also in the case



**Fig. 2-10. Dc voltage amplifier.**



of cascaded IC dc amplifiers to take into account the effects of individual offset and slew in the entire setup, and to compensate for these when they are significant.

### 2.13 RF AMPLIFIER

Fig. 2-11 shows the connections for a tuned radio-frequency amplifier based upon a Type CA3005 IC. This circuit is adapted from the original RCA version. If the amplifier is used for standard broadcast-band service, T1 may be a ferrite loopstick antenna of the two-coil variety, and T2 will be a matching trf “coil.”

The CA3005 contains two amplifiers (a differential arrangement) and a stabilizing circuit. This unit has a useful frequency range of dc to 120 MHz and is housed in a 12-lead TO-5 package. It can provide a power gain of 16 dB in the differential arrangement shown in Fig. 2-11.

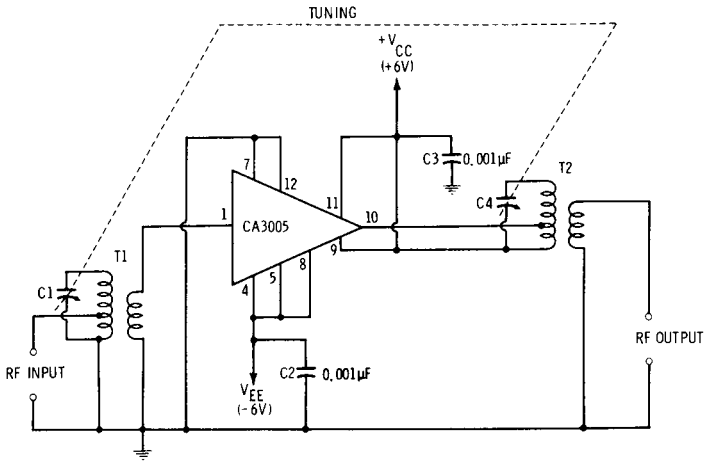


Fig. 2-11. Rf amplifier.

### 2.14 IC AS UNTUNED RF AMPLIFIER

In applications in which selectivity is not demanded, a wideband IC amplifier may be used as an untuned rf amplifier. For applications of this type, many ICs have suitable frequency specifications. The following are a few examples: CA3000 (dc–30 MHz), CA3001 (dc–20 MHz), CA3004 (dc–

120 MHz), CA3005 (dc–120 MHz), CA3013 (100 kHz–20 MHz), CA3020 (dc–8 MHz), CA3021 (dc–6 MHz), CA3023 (dc–40 MHz), CA3028 (dc–120 MHz), CA3034 (dc–100 MHz), and 4009 (dc–30 MHz).

A common use of an untuned rf amplifier is the aperiodic preamplifier or booster found in some test instruments and radio receivers. The numerous well-known precautions that ordinarily are important in the construction and use of such amplifiers must be observed also when ICs are used.

### 2.15 I-F AMPLIFIER

Fig. 2-12 shows the connections for a single intermediate-frequency amplifier stage based upon an RCA design for the CA3012 IC. The frequency response of this IC extends from 0.1 MHz to more than 20 MHz, and the single-battery arrangement shown in Fig. 2-12 is effective at the 10.7-MHz fm intermediate frequency.

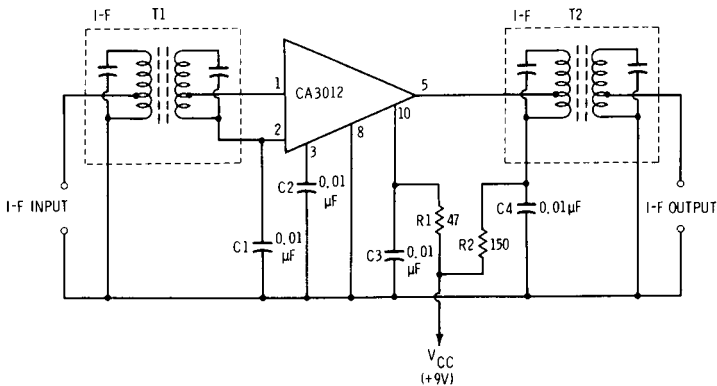
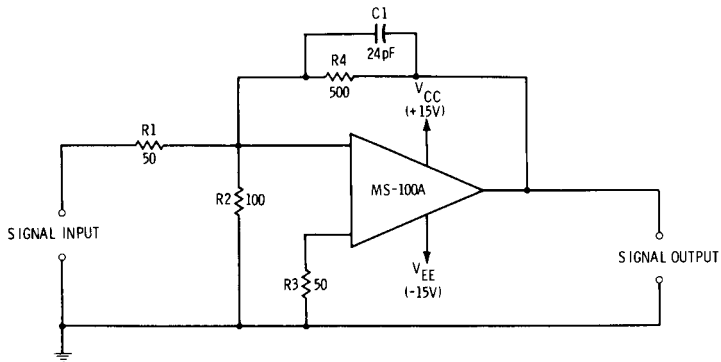


Fig. 2-12. I-f amplifier.

The tapped transformers allow improved impedance matching at the input and the output of the IC. The IC manufacturer shows a voltage gain of 65 dB between terminals 1 and 5 of the IC in this i-f amplifier circuit (based upon a 3.5- $\mu$ v signal at terminal 1).

Two such stages usually are employed in a superhet receiver. Transformer-coupled stages of this type usually can be cascaded without difficulty.



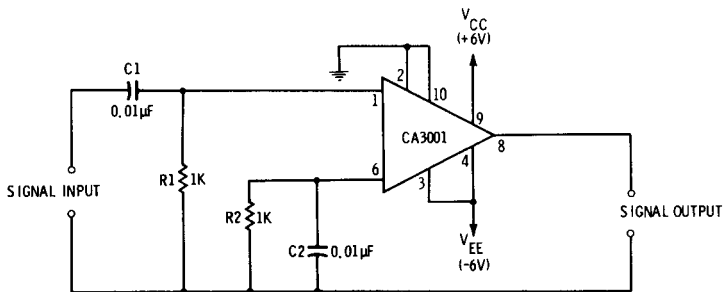
**Fig. 2-13. Video amplifier (1).**

## 2.16 VIDEO AMPLIFIERS

The extended bandwidth of many linear ICs suits these units for video amplifier service. Fig. 2-13 shows the connections for a video power amplifier, due to Sylvania. Employing an MS-100A IC, this amplifier works between a 50-ohm source and a 50-ohm load. (The output impedance of the MS-100A itself is less than 2 ohms.)

The voltage gain is 10 dB, and the 3-dB bandpass is dc to 18 MHz.

A second video amplifier, shown in Fig. 2-14, is based upon the CA3001 video-amplifier IC and follows the original RCA design. Driven by a 50-ohm source, this amplifier provides voltage gain in excess of 15 dB from dc to 5 MHz. At approximately 18 MHz, the gain is 3 dB down from that figure. Typical input resistance of the CA3001 is 50 ohms, and output resistance is 70 ohms.



**Fig. 2-14. Video amplifier (2).**

# Oscillators

The high-gain and wide passband of the operational-amplifier-type IC enable this device to operate as an oscillator over a wide frequency range. The IC oscillates readily when feedback is applied to its noninverting input and adjusted to the proper amplitude.

The IC is especially useful in resistance-capacitance-tuned oscillators, since its overall gain is more than adequate to offset the attenuation of the RC network. Also, the dual input of the differential IC permits not only positive feedback (for oscillation), but also negative feedback in some circuits (for improving the output waveform).

This chapter describes seven IC oscillators—three RC arrangements, three LC arrangements, and one crystal arrangement. These are generalized circuits that may be used with practically any high-gain operational-amplifier IC. Specific terminal designations therefore are not given except for inverting input, noninverting input, input ground (common), and output. Dc supply connections are not shown, since these (and the particular  $V_{cc}$  and  $V_{ee}$  voltage values) will vary with the individual IC. Where possible, as much practical operating information as practicable is given for these general illustrations.

### 3.1 TWIN-T RC AF OSCILLATOR

Fig. 3-1 shows the circuit of a resistance-capacitance-tuned af oscillator employing a twin-T null network (C1-C2-C3-R2-R3-R4) to determine the frequency. The IC should have a voltage gain of 60 dB.

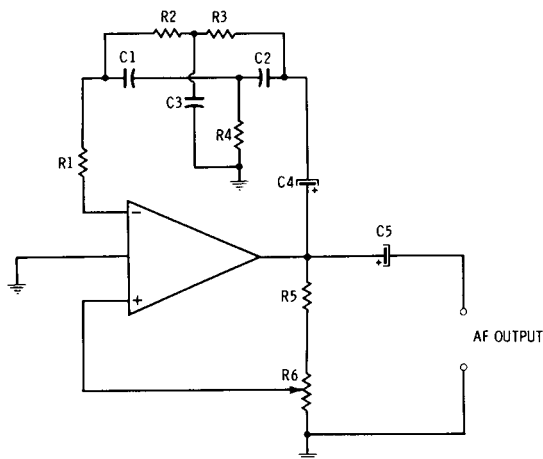


Fig. 3-1. Twin-T RC af oscillator.

This arrangement is essentially a sharply tuned af amplifier to which positive feedback has been added for oscillation. The twin-T network is inserted in the negative-feedback loop, and being a null network it removes one frequency ( $f_r$ ) from the negative feedback. The IC gain accordingly is cancelled at all other frequencies, while  $f_r$  is readily transmitted. In the network, the following formulas apply:

$$C1 = C2 = \frac{1}{2}C3$$

$$R2 = R3 = 2R4$$

$$f_r = 1 / (2\pi R2 C1)$$

where,

C's are in farads,

R's are in ohms,

$f_r$  is in hertz.

Coupling capacitor C4 serves as dc blocking, and its capacitance is very high with respect to C1, C2, and C3. It accordingly does not affect  $f_r$ . Resistance R1 is high with respect to

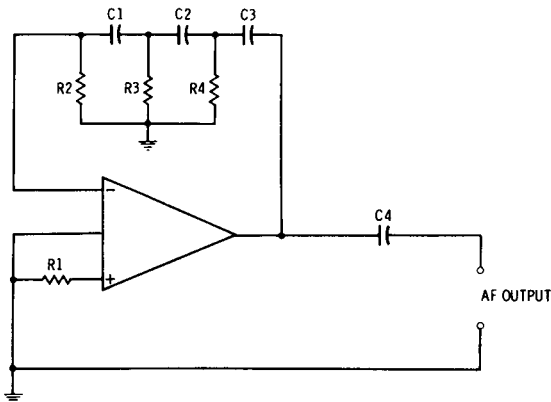
the input impedance of the IC, and serves to minimize loading of the twin-T network by the IC input circuit.

The addition of positive feedback, through the signal divider R5-R6, causes this sharply tuned amplifier to oscillate at frequency  $f_r$ . When potentiometer R6 is set to the point at which the circuit just begins to oscillate, the output-signal distortion is very low.

The oscillator may be made continuously tunable (e. g., 20 Hz to 20 kHz) by substituting a 3-gang potentiometer for resistors R2, R3, and R4, and switching capacitors C1, C2, and C3 in trios to change bands. Output control may be obtained with a potentiometer either added to the output or inserted between stages of the IC.

### 3.2 PHASE-SHIFT RC AF OSCILLATOR

The phase-shift type of resistance-capacitance-tuned af oscillator is well known for its very low harmonic distortion.



*Fig. 3-2. Phase-shift RC af oscillator.*

In this type of oscillator, RC tuning is accomplished with a 180-degree phase-shift network connected in the feedback loop of an inverting amplifier. The network accordingly produces the correct phase rotation of the signal for oscillation. Fig. 3-2 shows the connections for a phase-shift-type IC oscillator.

In this arrangement, the phase shift network consists of three identical RC legs in cascade: C1-R2, C2-R3, and C3-R4.

Here,  $C1 = C2 = C3$ , and  $R2 = R3 = R4$ . Each of these legs introduces 60 degrees of phase shift. The frequency at which the total shift is 180 degrees is found by the following formula:

$$f_r = 1/(10.88R2C1)$$

where,

$f_r$  is in hertz,  
R2 is in ohms,  
C1 is in farads.

In order to offset the inherent attenuation of the RC network, the gain of the IC should be 40 dB. The noninverting input of the IC is not used in this arrangement, it being returned to ground through resistor R1 (usually of the order of 1000 ohms).

This oscillator might be made continuously tunable (e. g., 20 Hz to 20 kHz) by substituting a 3-gang potentiometer for resistors R2, R3, and R4, and switching capacitors C1, C2, and C3 in trios to change bands. However, the attenuation of the network increases as the resistances decrease, and this would cause the output-signal amplitude to decrease rapidly with frequency, and oscillation might even cease when R2, R3, and R4 become very small at the high frequencies. Output control may be obtained with a potentiometer either added to the output or inserted between stages of the IC.

### **3.3 WIEN-BRIDGE RC AF OSCILLATOR**

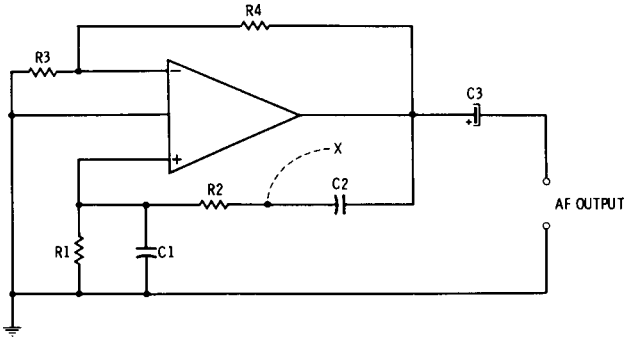
Whereas the resistance-capacitance-tuned af oscillators described in the preceding sections require three resistances and three capacitances for tuning, the IC circuit shown in Fig. 3-3 needs only two resistances (R1 and R2) and two capacitances (C1 and C2). The C1-C2-R1-R2 combination is half of a Wien bridge which, like the twin-T network in Fig. 3-1, is frequency sensitive.

The RC circuit is connected in the positive-feedback loop (to the noninverting input terminal). In the network,  $C1 = C2$ ,  $R1 = R2$ , and the response frequency is found by the following formula:

$$f_r = 1 / (2\pi R_1 C_1)$$

where,

$f_r$  is in hertz,  
 $R_1$  is in ohms,  
 $C_1$  is in farads.



**Fig. 3-3. Wien-bridge RC af oscillator.**

Negative feedback is applied through resistors  $R_3$  and  $R_4$  (which form a signal voltage divider) to the inverting input terminal. This negative feedback lowers output-signal distortion; however, it must be proportioned correctly (through adjustment of  $R_3$  and  $R_4$ ) so that it does not cancel the positive feedback and thus kill oscillation.

Oscillators of this type are readily made continuously tunable (e. g., 20 Hz to 1 MHz) by substituting a 2-gang potentiometer for resistors  $R_1$  and  $R_2$ , and switching capacitors  $C_1$  and  $C_2$  in pairs to change frequency bands. When the oscillator is tuned over a wide frequency range, however, its output-signal amplitude tends to vary with frequency. But this variation may be minimized by means of a suitable nonlinear resistor, such as a thermistor, varistor, or double-ended zener diode, connected between point "X" and ground. Output control may be obtained with a potentiometer either added to the output or inserted between stages of the IC.

### **3.4 TRANSFORMER-FEEDBACK AF OSCILLATOR**

Fig. 3-4 shows the connections for a simple af oscillator in which a miniature audio transformer (T1) supplies both the feedback and the tuning that convert the IC into an oscillator. A low-gain IC will operate successfully in this circuit.



In this arrangement, positive feedback is supplied to the noninverting input of the IC through transformer T1, which may be any convenient small unit. The frequency of oscillation is determined by capacitance C1 and the inductance (L) of the transformer winding across which this capacitor is connected. The following formulas apply to Fig. 3-4:

$$C1 = 1 / (4\pi^2 f_r^2 L)$$

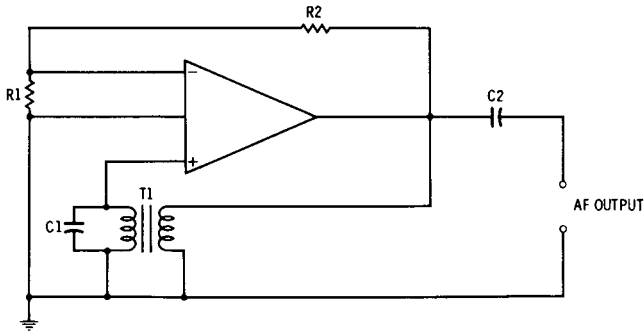
$$L = 1 / (4\pi^2 f_r^2 C1)$$

$$f_r = 1 / (2\pi \sqrt{LC1})$$

where,

- f<sub>r</sub> is in hertz,
- L is in henrys,
- C1 is in farads.

The transformer must be phased correctly for oscillation; but in the absence of oscillation due to incorrect wiring, the connections to only one winding need be reversed.



*Fig. 3-4. Transformer-feedback af oscillator.*

Negative feedback is applied through resistors R1 and R2, which form a signal-voltage divider, to the inverting input terminal. This negative feedback lowers output-signal distortion; however, it must be proportioned correctly (through adjustment of R1 and R2) so that it does not cancel the positive feedback and thus kill oscillation.

Output control may be obtained with a potentiometer either added to the output or inserted between stages of the IC.

### 3.5 TRANSFORMER-FEEDBACK RF OSCILLATOR

The radio-frequency oscillator circuit shown in Fig. 3-5 is similar to the transformer-feedback af oscillator described in Section 3.4, except that in this rf oscillator, positive feedback (for oscillation) and tuning are provided by an *air*-core transformer, L1-L2. A low-gain IC will operate successfully in this circuit.

In this arrangement, positive feedback is supplied to the noninverting input through the L1-L2 combination. (L1 is the high-turns winding of the transformer, whereas L2 consists of approximately one-quarter of the turns in L1 and is closely, but not tightly, coupled to L1.) The frequency of oscillation is determined by capacitance C1 and inductance L1. This frequency  $f_r$  is found by the following formulas:

$$C1 = 1 / (4\pi^2 f_r^2 L1)$$

$$L1 = 1 / (4\pi^2 f_r^2 C1)$$

$$f_r = 1 / (2\pi \sqrt{L1C1})$$

where,

C1 is in picofarads,

L1 is in microhenrys,

$f_r$  is in megahertz.

The transformer must be phased correctly for oscillation; but in the absence of oscillation, due to incorrect wiring, the connections to only one winding need be reversed.

Negative feedback is applied through resistors R1 and R2, which form a signal-voltage divider, to the inverting input

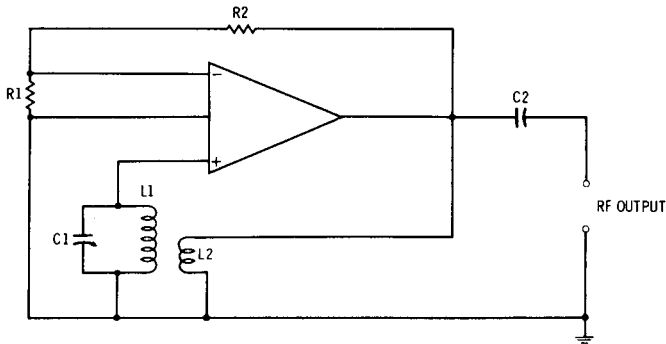


Fig. 3-5. Transformer-feedback rf oscillator.

terminal. This negative feedback stabilizes operation and reduces output-signal distortion; however, it must be proportioned correctly (through adjustment of R1 and R2) so that it does not cancel the positive feedback and thus kill oscillation.

Continuous tuning is provided by variable capacitor C1. For wide-range coverage, L1 and L2 may be changed in pairs to switch frequency bands.

### **3.6 COMBINATION AF/RF OSCILLATOR**

Fig. 3-6 shows the connections for an oscillator that, by means of plug-in inductors and plug-in capacitors, may be used to generate either audio-frequency or radio-frequency signals over a wide frequency range. In this arrangement, both positive and negative feedback are employed.

The tuned circuit (L1-C1) that determines the frequency of oscillation is connected in the negative-feedback loop. Acting as a wavetrap, therefore, this tuned circuit removes its resonant frequency,  $f_r$ , from the feedback. The IC, acting accordingly as a sharply tuned amplifier, thus transmits  $f_r$ , but has its gain cancelled at all other frequencies. The positive feedback, obtained through the signal voltage divider R1-R2, then causes the circuit to oscillate at frequency  $f_r$ . The formulas for this circuit are:

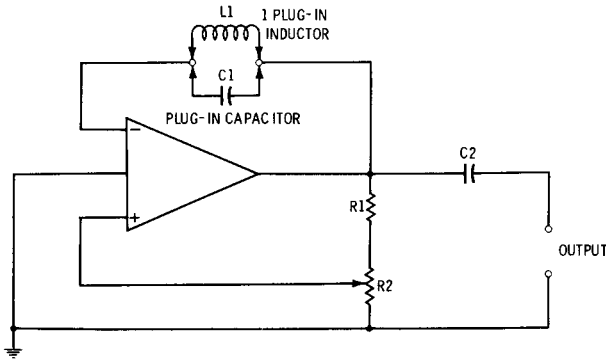
$$\begin{aligned}C1 &= 1/(4\pi^2f^2L1) \\L1 &= 1/(4\pi^2f^2C1) \\f_r &= 1/(2\pi\sqrt{L1C1})\end{aligned}$$

where,

$f_r$  is in hertz,  
L1 is in henrys,  
C1 is in farads.

High capacitance and inductance combinations will generate audio frequencies, and low capacitance and inductance will generate radio frequencies.

The intensity of oscillation depends upon the setting of positive-feedback potentiometer R2, so some degree of output-signal amplitude control is possible with this potentiometer. The circuit will operate with a variety of ICs.



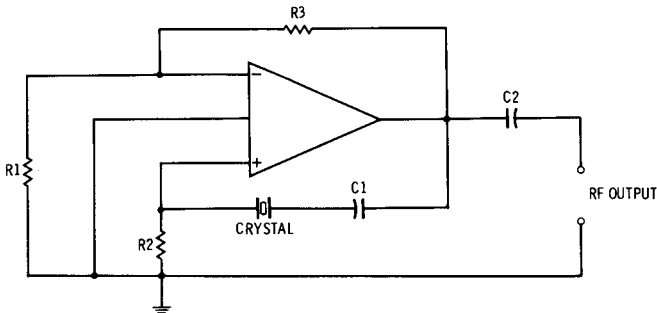
**Fig. 3-6. Combination a/rf oscillator.**

Since output-coupling capacitor C2 must transmit low and high frequencies, its capacitance must be a compromise value, such as 0.01  $\mu\text{F}$ , unless the user is willing to change this capacitor along with L1 and C1.

### 3.7 CRYSTAL-CONTROLLED RF OSCILLATOR

Fig. 3-7 shows the connections for a crystal-controlled rf oscillator requiring no tuning. This arrangement will work with multistage ICs of all sensitivities; however, medium- and high-gain units are recommended.

In this circuit, the crystal (XTAL) acts as an extremely high-Q bandpass filter in the positive-feedback loop of the IC. Positive-feedback current passed by the crystal develops a voltage drop across resistor R2, and this voltage is applied to the noninverting input terminal of the IC. Oscillation thus occurs at the crystal frequency. Capacitor C1 serves only for



**Fig. 3-7. Crystal-controlled rf oscillator.**

dc blocking, its capacitance being selected for low reactance at the crystal frequency. The input-ground (common) terminal of the IC is returned directly to the circuit ground, as shown.

A negative-feedback loop also is provided. This consists of resistors R1 and R3, which form a signal voltage divider. Negative-feedback current through this divider develops a voltage drop across resistor R1, and this voltage is applied to the inverting input terminal of the IC. The amplitude of this voltage must be correctly set (by adjustment of resistors R1 and R3) so that it does not cancel the positive feedback and thus kill oscillation. The negative feedback improves stability and lowers output-signal distortion. However, it may be dispensed with entirely when high harmonic output is desired, as in some transmitter service.

# Controls

Many electronic control systems may be implemented with ICs. These range from simple, sensitive dc relays, such as the one described here in Section 4.1, to highly sophisticated setups in which amplification, delays, clocking, gating, phasing, and holding all may play a part, and in which a number of ICs may be used. As an example of the utility of the IC, a dc relay (as in Fig. 4-1) can be sensitized 10,000 times by an IC that is only about 1/100 the size of the relay itself and which may easily be packaged with the relay. In fact, there are commercially available relay-IC combinations in a single TO-5 transistor can.

This chapter describes ten illustrative control circuits embodying ICs. Complex arrangements have been avoided, the setups shown here being the simple ones that most students and experimenters might prefer for test and observation. A variety of ICs are usable in these circuits, even when a specific IC is shown in the schematic.

In some cases, it might be desirable to have a higher input impedance than is afforded by a specified IC, in order to minimize loading of the control-signal source. Here, an IC having FET input may be employed, and the corresponding high input impedance will be comparable to that of a vacuum-tube circuit, or a FET stage may be operated ahead of a conventional IC.

## **4.1 SENSITIVE DC RELAY**

Fig. 4-1 shows a simple circuit in which the IC is employed as a stable dc amplifier to boost the sensitivity of a milliampere-type dc relay. The Type CA3036 IC consists of a dual Darlington pair. This is a pair of direct-coupled amplifiers in which the output (emitter) current of one transistor flows directly into the input (base) circuit of the next transistor. The two Darlington stages are coupled together by means of the external jumper shown, in Fig. 4-1, connected between terminals 2 and 8. The net result is the equivalent of a single transistor having a super beta.

A dc input signal of 0.5 V at  $0.5 \mu\text{A}$  is amplified sufficiently by the IC to close a 2-mA, 100-ohm dc relay. (This may be an inexpensive model-control relay, such as Lafayette No. 99 T 6199.)

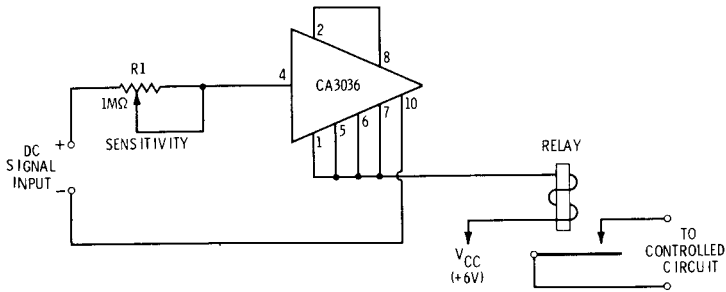
The equivalent dc input resistance of this circuit is 1 megohm when the sensitivity control R1 is set to zero resistance (maximum sensitivity). The control factor of this circuit (ratio of relay power to signal-input power) is 1600. Additional sensitivity may be obtained by operating a dc amplifier IC ahead of this control circuit.

Higher-current dc relays may be used in the output circuit of this setup, and the dc input-signal voltage will need to be boosted proportionately. The power gain of 1600 will hold, however.

## **4.2 SENSITIVE AF/RF RELAY**

The wideband characteristics of the Type CA3010 IC are utilized in the setup shown in Fig. 4-2 to obtain an ac relay capable of audio-frequency and radio-frequency operation. In this circuit, an input signal of 1 mV rms at  $0.1 \mu\text{A}$  is amplified sufficiently by the IC to actuate the rectifier-relay circuit connected to the IC output.

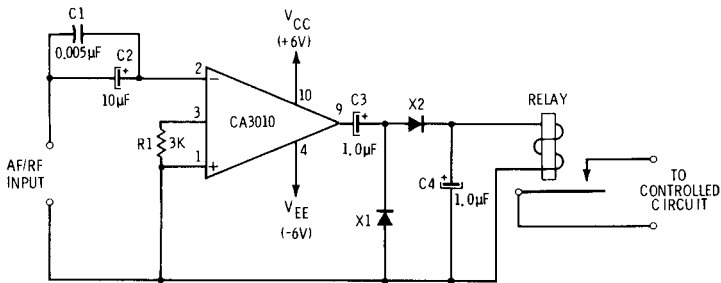
The relay rectifier converts the ac output of the IC to direct current to close the relay. This rectifier consists of two small-signal silicon diodes, X1 and X2, blocking capacitor C3, and relay bypass capacitor C4. The latter capacitor not only boosts the relay current, but also prevents relay chatter at low signal frequencies.



*Fig. 4-1. Sensitive dc relay.*

The equivalent input resistance of the circuit is greater than 10,000 ohms. At 1000 Hz, the useful power amplification ratio of required relay power to rms signal-input power is 10,000. The relay is a 1-mA, 1000-ohm unit (e. g., Sigma Series 5).

This amplifier-rectifier setup will be found adequate for many wideband control operations. The high-low capacitance coupling arrangement (C1-C2) should provide optimum input conditions. In some applications, in which operation is largely high radio-frequency, it might be advantageous to reduce the capacitance of C3 for better relay sensitivity.



*Fig. 4-2. Sensitive af/rf relay.*

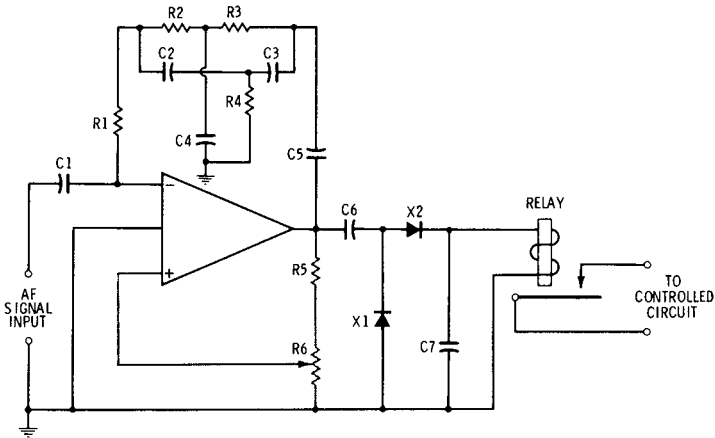
### 4.3 SELECTIVE AF RELAY

In some applications, especially those involving switching operations for a number of points, tuning of the control circuit is desirable. This then permits use of switching signals at various frequencies to close separate relays. Another use of tuning is to insure operation of the relay at only one



control frequency, and effective ignoring of signals at all other frequencies. Fig. 4-3 shows the connections for a tuned audio-frequency relay.

In this arrangement, the amplifier-rectifier setup is essentially the same as that described in preceding Section 4.2. The IC of amplifier itself secures its sharp tuning by means of a twin-T selective network (R2-R3-R4-C2-C3-C4) connected in the negative feedback loop (see Section 2.6, Chapter 2, for a complete explanation of the selective operation of this type of amplifier and for instructions regarding calculation of the resistance, capacitance, and pass frequency values). Where desired, the selectivity of the circuit may be sharpened by means of positive feedback through the R5-R6 signal divider.



*Fig. 4-3. Selective af relay.*

The sensitivity of the circuit depends upon the voltage gain of the IC and upon the maximum positive feedback that may be employed (through adjustment of potentiometer R6) before the setup oscillates. Response is limited in general to the audio-frequency spectrum, since beyond about 20 kHz, leakage through stray capacitances in the twin-T network degrades performance of this network.

This selective af relay will be attractive particularly to users who need several control channels, each operated at a different control frequency. The separate-channel circuits

are greatly simplified by the small-sized relay-IC combinations.

#### 4.4 SOUND-OPERATED RELAY

Fig. 4-4 shows the connections for a sensitive IC relay actuated by sound. This is not a selective circuit, but is an arrangement that is capable of operating from sounds between 100 Hz and 5 kHz in frequency.

The IC may be any operational amplifier having high voltage gain and wide frequency response. The microphone (MIC) is preferably a low-impedance unit. (If a high-impedance microphone is to be used, the IC should have FET input; otherwise, a FET amplifier stage must be operated ahead of the IC.)

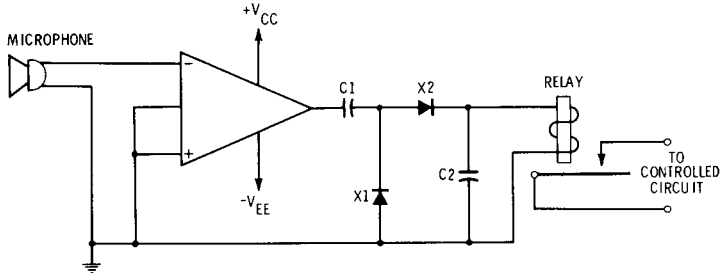


Fig. 4-4. Sound-operated relay.

The ac output of the amplifier is rectified by the dual-diode (X1-X2) combination (the diodes may be small-signal silicon or germanium units), and the resulting direct current deflects the relay. The latter may be a 1-mA, 1000-ohm unit, such as that employed in the af/rf relay, Fig. 4-2. Coupling capacitor C1 serves principally for dc blocking and should be high (e. g.,  $10\mu\text{F}$ ), and C2 serves as a relay bypass unit (typically  $10\mu\text{F}$ ).

For simplicity, the entire circuit given in Fig. 4-2 may be used in this application simply by connecting the microphone to the signal-input terminals. If gain control is desired, a suitable potentiometer may be connected between stages of the IC.

When selective operation is desired, as when the relay is to be actuated by a whistle of particular pitch, the IC ampli-

fier may be tuned to the required pitch by means of a twin-T negative-feedback network (see Fig. 4-3 and Section 4.3).

#### **4.5 PROXIMITY RELAY**

The applications of capacitance relays and touchplate relays are well known and need no repetition here. The actual construction of such a relay, however, is greatly simplified through use of an IC, which supplies the high sensitivity obtained from a large number of separate stages usually assembled for such relay operation. Fig. 4-5 shows a sensitive setup that may be used either as a capacitance relay or a touch-plate relay.

In this arrangement, the high-gain preamplifier described in Section 2.2, Chapter 2, is coupled ahead of the sensitive af/rf relay described in Section 4.2. The high input-signal terminal of the preamplifier is connected to a small touchplate (usually, a 2- or 3-inch-diameter metal or foil disc). When this plate is touched by the operator, his body couples into the circuit enough energy from the stray fields commonly found in all locations that the relay closes. When the entire system is operated at maximum sensitivity, touching the plate should not be necessary; merely placing the hand near the plate should couple-in enough energy through capacitance effects to operate the relay.

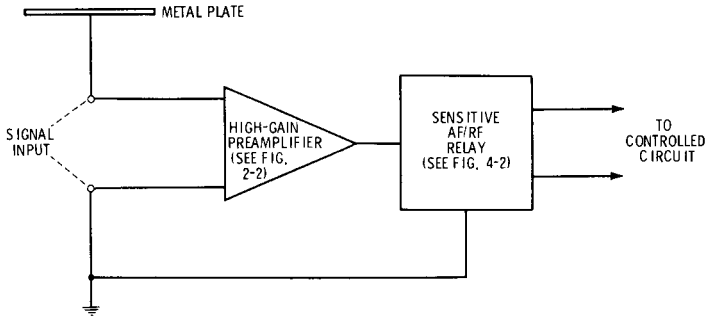
For adjustment of the sensitivity of the system, a suitable gain-control potentiometer may be installed either between the preamplifier output and the relay-amplifier input or between the stages of either one of those units. In most instances, however, the system will be operated "wide open," as shown in Fig. 4-5.

#### **4.6 PHOTOCELL AMPLIFIER**

Fig. 4-6 shows the connections for a simple IC dc amplifier for boosting the voltage output of a self-generating silicon photocell (solar cell). This amplifier employs only two out-board components: sensitivity-control rheostat R1 and negative-feedback resistor R2.

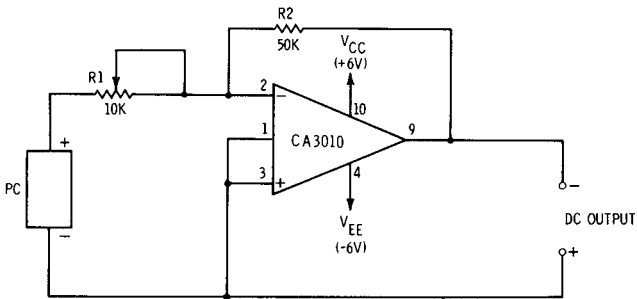
The Type CA3010 IC, operated in this configuration, gives a dc voltage gain of 4 when R1 is set to its lowest resistance

(maximum amplifier sensitivity). The photocell (PC) is poled for positive dc output to the inverting terminal of the IC. In a typical operating condition (the PC is a small, inexpensive silicon cell, such as an International Rectifier Type S1M; R1 is set for maximum sensitivity), bright sunlight on the cell (or equivalent artificial illumination) gives 2 volts (open circuit) at the DC OUTPUT terminals.



**Fig. 4-5. Proximity relay.**

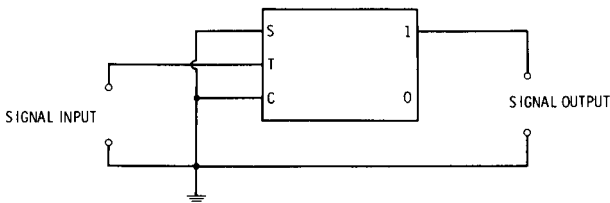
For increased amplification of the photocell voltage, two or more identical dc amplifier stages may be operated in cascade. ICs other than the CA3010 will give similar operation; however, the experimenter must keep in mind that the maximum output-voltage swing is determined by the IC output characteristics and the amount of negative feedback introduced by R2. Cascading will increase the overall sensitivity of the system, making it possible to obtain a given dc output voltage with a low level of illumination, but will not increase the maximum obtainable dc output for a given IC.



**Fig. 4-6. Photocell amplifier.**

## 4.7 SIMPLE LATCH

Fig. 4-7 shows the connections for a latch-switch circuit. Operation of this type of circuit is identical with that of the familiar electromechanical latching relay: A momentary signal switches the circuit ON, and it then remains ON (unless the dc power supply is momentarily interrupted). The next momentary signal that comes along switches the circuit OFF. Thus, if a chain of input-signal pulses is applied to the circuit, the latter is switched ON by every other pulse.



*Fig. 4-7. Simple latch.*

The basis of the setup is a flip-flop type of IC. This device has three inputs (*S*, set; *T*, clock; and *C*, clear) and two outputs (*1* and *0*). Only one of the outputs is used in the setup shown in Fig. 4-7. If the circuit, as shown, has zero output, a suitable pulse applied to the *T* input terminal will cause a voltage to appear at the SIGNAL OUTPUT terminals. This output voltage then remains present and unaltered even after the input pulse has disappeared. The next input pulse will switch the flip-flop OFF, i. e., will cause the output voltage to fall to zero. Thus, the output appears in response to alternate input pulses.

The output pulse may be used in various ways. For example, it may be used to fire an SCR circuit, or it may be applied to the input of a sensitive dc relay of the IC-amplifier type shown in Fig. 4-1. With some types of flip-flop, the relay itself may be connected to the output terminals.

Only one output terminal, *1*, is in use in Fig. 4-7. Actually, the *0* terminal might as well have been used: the *0* terminal is switched ON when the *1* terminal is switched OFF, and vice versa.

From the operation just described, it is seen that the latch circuit is a scale-of-two counter. It delivers one output pulse

for each two input pulses. If the OUTPUT terminals are connected to a counter, the counter will divide the number of input pulses by 2. If two such latches are operated in cascade, a divide-by-4 arrangement is secured, the signal output consisting of 1 pulse for each 4 successive input pulses. In a similar manner, the input-pulse total may be divided by 8, 16, 32, etc., by cascading the appropriate number of flip-flops.

#### 4.8 THRESHOLD CIRCUIT

In the setup shown in Fig. 4-8, the DC SIGNAL OUTPUT is zero until the input-signal voltage ( $V_i$ ) exceeds the value of a selected reference voltage ( $V_r$ ). This action is obtained by using both inputs of a differential operational amplifier. As long as the two voltages,  $V_i$  and  $V_r$ , are equal, the amplifier output is zero. When  $V_i$  is higher than  $V_r$ , however, the amplifier symmetry is destroyed and the dc output is  $V_i - V_r$ . The reference voltage thus serves as a threshold.

When  $V_i$  is lower than  $V_r$ , the output of the amplifier is positive. At this time, however, the back-connected, high-resistance, small-signal, silicon diode (X1) blocks the current through output resistor R1, and there is no output-voltage drop across this resistor. When  $V_i = V_r$ , the output is zero and there also is no drop across R1. When  $V_i > V_r$ , however, the amplifier output is positive, the diode then passes forward current, and the output-signal voltage results from the voltage drop produced across R1 by this current.

The threshold level may be set by choosing  $V_r$  equal to this level. In many instances, this reference voltage will be taken from the output of a voltage divider. The IC provides ampli-

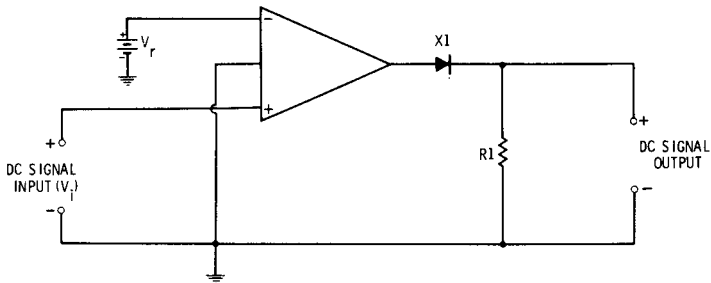


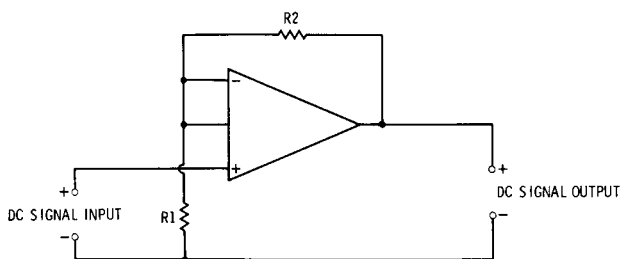
Fig. 4-8. Threshold circuit.

fication of both  $V_r$  and  $V_i$ , so that the DC SIGNAL OUTPUT will be higher than the input.

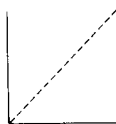
This threshold circuit may be used in various ways. Its output may be employed, for example, to drive a dc relay amplifier circuit of the type shown in Fig. 4-1. This will cause the relay to close whenever a monitored voltage exceeds a selected reference value. Or if the input voltage is a time-varying quantity, the output voltage will exhibit a delay, the extent of which may be varied by varying  $V_r$ , and the delay may be used in various control applications in which it is a desirable factor.

#### 4.9 CONTROL AMPLIFIER-LIMITER

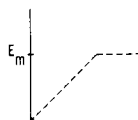
The simple dc amplifier setup shown in Fig. 4-9A may be used as a limiting amplifier, provided the input-signal voltage rises high enough to overdrive the amplifier. Thus, the input-signal voltage may increase uniformly, as shown in Fig. 4-9B; but, in response, the output-signal voltage will rise uniformly (and at an amplified level), but will level off at level  $E_m$ , as shown in Fig. 4-9C, when the amplifier reaches saturation. Any further increase in the input-signal voltage beyond this point results in no further increase in output voltage. The output signal thus is limited to the level  $E_m$ .



(A) Schematic.



(B) Input signal.



(C) Output signal.

Fig. 4-9. Control amplifier-limiter.

In control systems, this sort of limiting is advantageous when a control signal regularly makes large excursions, but the circuit to which it is applied demands a constant value. The IC-amplifier arrangement shown here has the advantage over passive devices, such as zener diodes, in this particular application, that it provides amplification and does not heavily load the signal source.

Any differential operational amplifier having the desired voltage output, gain, and impedance (resistance) characteristics might be used. The simple dc amplifier shown in Fig. 2-10, Chapter 2, is an example. It is necessary only that the selected unit, when operated with an available control signal, overload at output voltage level  $E_m$ .

#### 4.10 INTERVAL TIMER

Fig. 4-10 shows the circuit of a time-delay-relay type of interval timer. When push-button switch S1 is momentarily depressed, the relay closes and remains closed for an interval equal approximately to the time constant  $R_2C_1$ . Operation occurs in the following manner: When S1 is momentarily depressed, capacitor C1 is charged by a dc voltage derived from the voltage divider, R1-R3. This divider is proportioned so as to deliver approximately 1 volt from the supply  $V_{cc}$ .

The release of S1 disconnects C1 from the charging voltage, but the capacitor retains its charge for a while, dis-

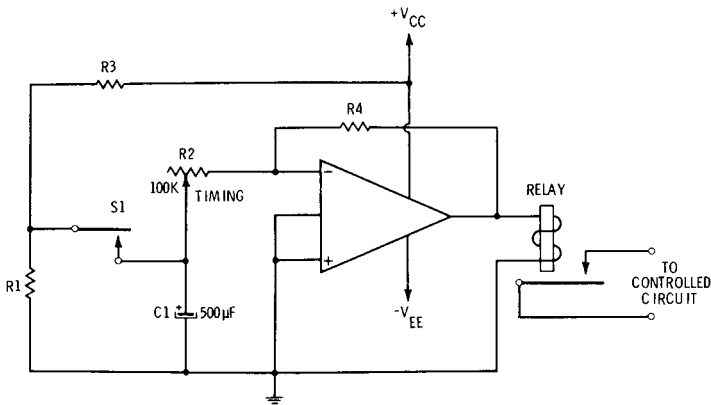


Fig. 4-10. Interval timer.



charging slowly through R2 and the input resistance of the IC. When the capacitor voltage has fallen sufficiently, the current delivered to the relay will be too low to keep the relay closed, and the latter consequently will open. The interval during which the relay remains closed is equal approximately to  $t = RC$ , where R is the resistance setting of the 100,000-ohm rheostat R2, and C is the capacitance of the 500- $\mu$ F electrolytic capacitor C1. At the maximum-resistance setting of R2, the closure interval thus is 50 seconds. Longer intervals may be obtained with higher values of R2.

This setup may be used with any dc amplifier IC and milli-ampere-type dc relay. (The circuit shown in Fig. 4-1 thus can be readily adapted by adding the timing subcircuit to the IC input in place of resistor R1 in Fig. 4-1.)

# Communications

Integrated circuits are finding increased application in commercial a-m, fm, and TV receivers and somewhat less lively adoption for small transmitters. At this writing, the IC is also attracting the attention of hobbyists and experimenters who build their own communications equipment. It seems reasonable, therefore, to expect that the IC eventually will bring about marked simplification of communications circuits—in the rf and video, as well as audio, sections.

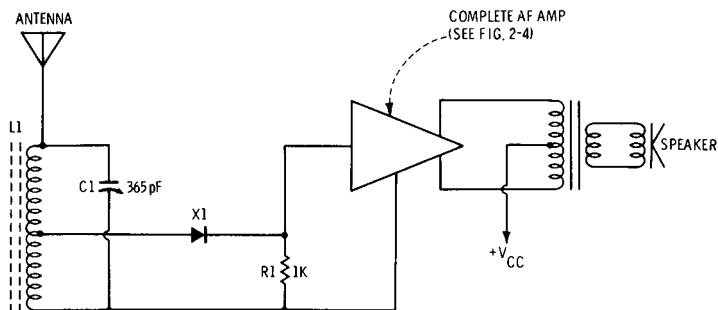
This chapter describes the application of ICs to several familiar receiver and transmitter functions. Other uses of a similar nature will suggest themselves to the reader.

For other setups (other than audio amplifiers) that also are suitable for use in communications equipment, see Sections 2.13, 2.14, 2.15, 2.16, 3.5, 3.6, 3.7, 4.2, 4.3, 4.4, and 4.5. The reader will note that many of the setups described elsewhere in this book may be combined in various ways to provide various receiver and transmitter functions, just as larger-sized modules similarly may be combined.

## ***5.1 SIMPLE RADIO RECEIVER***

Fig. 5-1 shows the connections for a simple tuned-diode type of a-m radio receiver. In this rudimentary arrangement, the signal is tuned in by the L1-C1 tank, in which L1 is

a tapped, ferrite loopstick antenna. The tap affords a good impedance match to the low-impedance diode X1, which may be any general-purpose germanium unit. The signal is demodulated by X1, and the resulting af output is amplified by the IC that drives the speaker. This setup is very effective for reception of local a-m stations in the standard broadcast band, and may be used at higher frequencies if a suitable inductor and outside antenna are substituted for L1.



*Fig. 5-1. Simple radio receiver.*

The modulation component of the signal is amplified by the IC, which combines both preamplifier and power output amplifier functions. A suitable IC is the Type CA3020 that is described in Section 2.5, Chapter 2. Operated from a single 9-volt dc source, this IC delivers  $\frac{1}{2}$  watt to the loudspeaker. A 35-mV detector output signal drives the amplifier to this full output. The entire amplifier should be used, as shown in Fig. 2-4, Chapter 2.

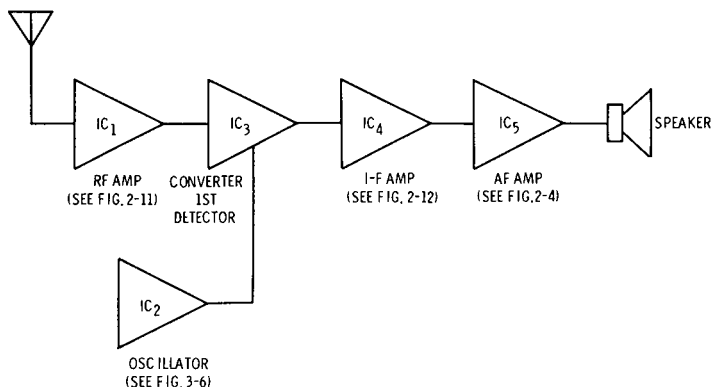
The sensitivity of a receiver circuit of this type is entirely a function of the gain of the audio amplifier, since the rf portion of the circuit is merely a diode detector and provides no amplification. With the CA3020 IC, the minimum rf signal amplitude for full speaker volume is somewhat in excess of 35 mV. If additional sensitivity is desired, a high-gain af preamplifier may be operated between the diode detector and the input of the audio amplifier, or an rf preamplifier may be operated ahead of the detector—or both may be used. Suitable amplifiers of both types are described in Chapter 2. It should be borne in mind when using only high-gain audio amplification, however, that the minimum rf signal ampli-

tude at which the diode will operate properly is approximately 0.5 mV.

A simple receiver of this type has a number of applications, including compact and small-sized provision for broadcast reception, special signal monitoring, and personal paging pickup. In control applications, an electronic relay circuit (e. g., Section 4.2, Chapter 4) may be operated in place of the speaker.

## 5.2 IC SUPERHET RECEIVER

ICs, together with any required outboard components, may be combined in a number of ways to provide complete receiver operation at a more sophisticated level than that of the simple receiver described in preceding Section 5.1. Fig. 5-2 shows the functional layout of an a-m superhet receiver.



*Fig. 5-2. Layout of superhet radio receiver.*

In this arrangement, IC<sub>1</sub> is an rf or wideband amplifier with external tuning, IC<sub>2</sub> is a wideband amplifier adapted for self-excited oscillation and for gang-tuning with IC<sub>1</sub>, and IC<sub>3</sub> (the converter stage) may be a suitable diode mixer or it may be a transistor circuit supplied by a transistor-array IC. IC<sub>4</sub> is an i-f amplifier with external transformer coupling, and IC<sub>5</sub> comprises the second detector and audio stages. Suitable selections and arrangements of ICs for these various stages are discussed in Chapters 2 and 3. In some arrangements, two rf and two i-f stages will be employed;

and in some, an IC containing a second detector and an af preamplifier will precede the audio output stage.

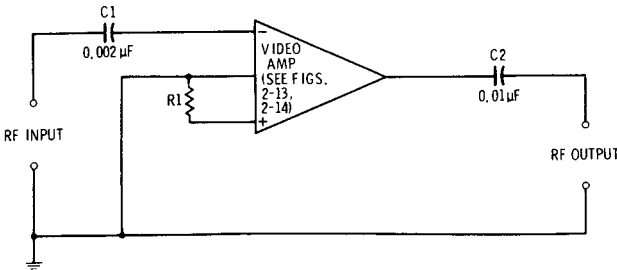
In general, the adapting of a superhet receiver to ICs presents little difficulty, but the process contributes a great deal to simplification and miniaturization of the receiver. Most external components intended for use with transistors (tuning inductors, i-f transformers, miniature audio transformers, etc.) are compatible with ICs.

### 5.3 UNTUNED RF AMPLIFIER FOR RECEIVERS

An untuned rf preamplifier is very effective in boosting weak signals before they reach the input of a receiver, and also for improving the signal-to-noise ratio of the receiver. A wideband IC amplifier, such as a video-amplifier type, will perform this function without tuned circuits, and the tiny IC (with its few outboard components) may be tucked into even the smallest receiver.

Fig. 5-3 shows the simple arrangement for such a preamplifier/booster. This arrangement requires only two external capacitors and one external resistor, in addition to the video-amplifier IC (e. g., Type CA3001). Similar video amplifier arrangements are shown in Figs. 2-13 and 2-14, Chapter 2, and described in Section 2.16.

The user should select the video amplifier IC that gives the highest gain at the frequency at which he will most often use the receiver. In approximately the lower half of the IC frequency response, however, the gain is fairly flat over a considerable frequency band. The Type CA3001 IC, for example, provides a voltage gain of 18 dB, flat within 1 dB from dc to 6 MHz, a span including the standard broadcast

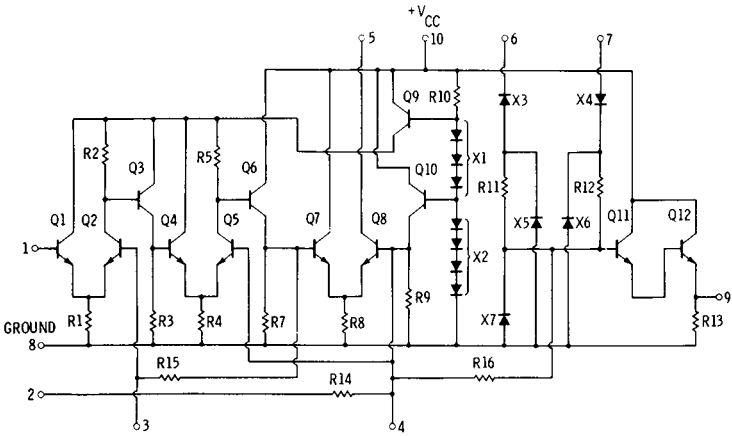


**Fig. 5-3. Untuned rf preamplifier for receivers.**

band and all of the assorted services from the top of that band to 6 MHz.

### 5.4 IC FM RECEIVER STAGES

Fig. 5-4 shows the internal circuit of the Type CA3013 IC, designed to supply the i-f amplifier, discriminator, and af amplifier stages of an fm superhet receiver. Considerable compactness and simplification are afforded by this small IC, which is housed in a 10-lead TO-5 can. This unit has a useful range extending from 100 kHz to higher than 20 MHz. Used in place of the i-f, second detector, and af sections shown in Fig. 5-2, this IC would convert the latter circuit from a-m to an fm receiver. Fig. 5-5 shows how the same IC supplies the sound i-f and the detector channel of a TV receiver.



*Fig. 5-4. IC for fm i-f amplifier/discriminator/af amplifier.*

The CA3013 (Fig. 5-4) contains three direct-coupled amplifier-limiter stages in cascade (Q1 to Q8), a dc supply voltage regulator (diode groups D1 and D2 and transistors Q9 and Q10), discriminator diodes (D3 and D4), signal-filter diodes (D5, D6, and D7), and a Darlington-pair af pre-amplifier (Q11 and Q12). An external discriminator transformer is connected to terminals 4, 5, 6, 7, and 10 (see also Fig. 5-5). The input i-f transformer is connected to terminals 1 and 2.

The small IC, the size of a small-signal transistor, reduces the external complication of this multistage fm circuit by several orders of magnitude.

### 5.5 IC TV SOUND I-F AMPLIFIER AND DETECTOR

The fm-channel IC described in Section 5.4 is shown functioning as the sound i-f amplifier and detector channel in an intercarrier TV receiver in Fig. 5-5. The description of the CA3013 given in Section 5.4 applies here also.

The TV sound channel, exclusive of the audio output amplifier, is reduced to a transistor-sized IC and nine outboard components: i-f transformer T1, discriminator transformer T2, capacitors C1 to C6, and resistor R1. The arrangement is adapted from the original RCA design.

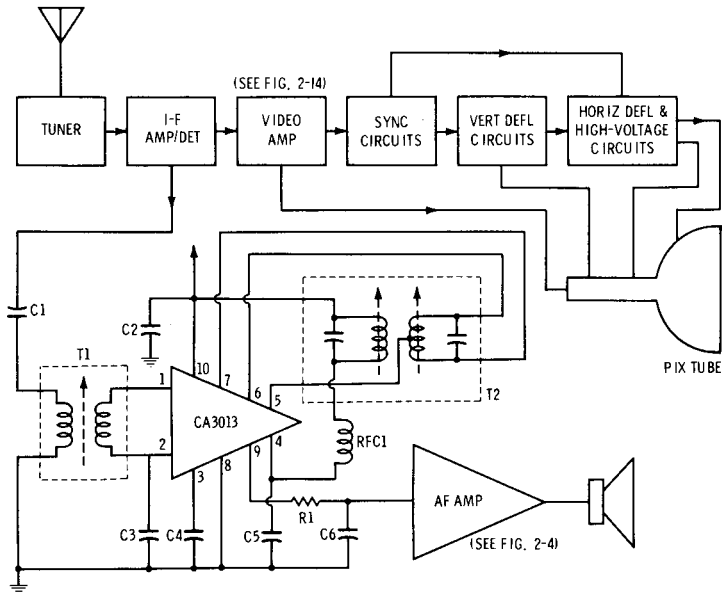


Fig. 5-5. IC TV sound i-f amplifier and detector. (After RCA.)

### 5.6 PRODUCT DETECTOR

In transmission systems involving carrier suppression and retention of one or more of the sidebands, the carrier must be reinserted at the receiver. This may be accomplished in a

product detector. The same method is used in some specialized test instruments.

Fig. 5-6 shows a product-detector circuit adapted from the original RCA design for the Type CA3005 IC. This IC is basically an rf-amplifier type consisting of two matched, common-emitter amplifiers whose emitter circuits are common to both. The useful frequency range extends from 0 to 100 MHz. In this detector circuit, the modulated signal is applied to IC terminals 1 and 7 (the bases of the two signal transistors) in push-pull, and the missing carrier is supplied by an external carrier oscillator (BFO) to terminal 3 (essentially to the emitters of both transistors in parallel). Variable capacitor C1 must be selected to tune the input transformer (T1) to the frequency of the modulated signal, and C2 is selected for critical adjustment of the supplied-carrier amplitude. The balanced nature of the differential pair of transistors contained in this IC makes it comparatively easy to obtain balanced-circuit operation, provided the secondary winding of transformer T1 is accurately center tapped. Symmetrical output is provided by terminals 10 and 11 (the collectors of the signal transistors).

As is seen from Fig. 5-6, very few outboard components are required. Aside from the input transformer (T1) and coupling capacitor (C2) and tuning capacitor (C1), already

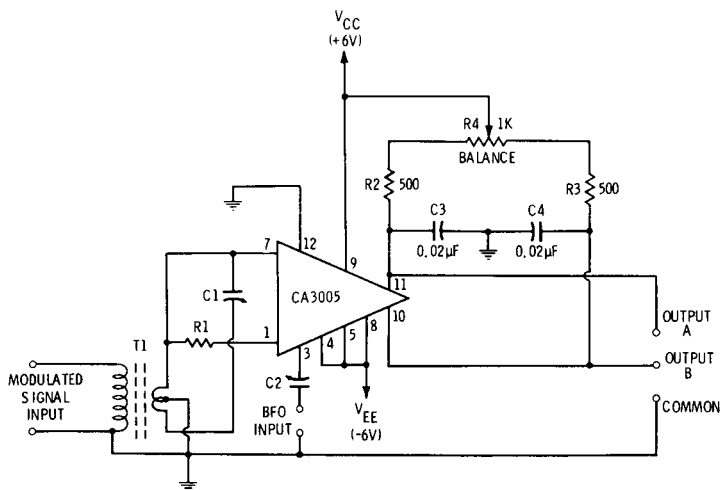


Fig. 5-6. Product detector.



mentioned, there are only the collector load resistors (R2, R3) and collector capacitors (C3, C4), all four being matched components.

### 5.7 BALANCED MODULATOR

Communications techniques involving carrier suppression and sideband selection (as well as certain test instruments, such as heterodyne wave analyzers) employ balanced modulators for suppression of the carrier and transmission of the sidebands. The differential IC amplifier offers marked virtues as a balanced modulator: close symmetry due to excellent matching of the integrated components, a compact modular unit requiring the minimum of external components, and easily balanced input and output.

Fig. 5-7 shows the connections for a balanced modulator employing a Type MC1596G IC. In this arrangement, potentiometer R3 is the offset adjustment, and potentiometer R9 is the output-balance adjustment. Adjustment of these two potentiometers causes the carrier to be rejected by better than 60 dB. As in all conventional triode-type balanced modulators, the carrier is applied to the two halves of the input circuit out of phase, while the modulation is applied to the inputs in parallel.

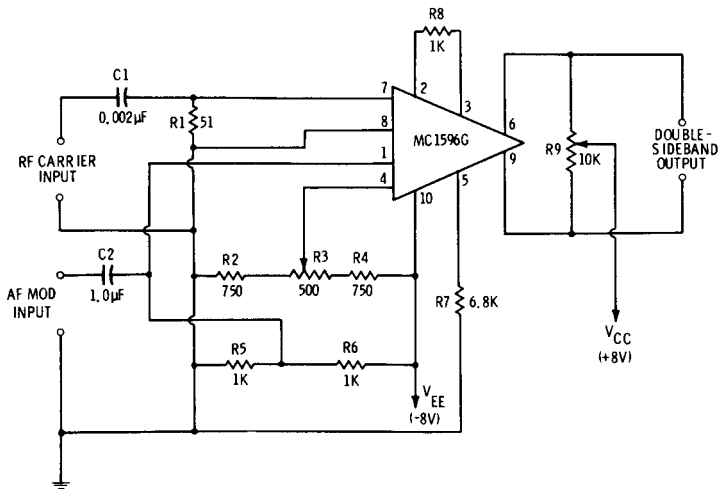


Fig. 5-7. Balanced modulator.

The modulator delivers double-sideband output, but a single sideband may be selected by means of a sharply tuned bandpass filter and amplifier. The balanced modulator is useful also in chopper applications and in phase detection.

### **5.8 MISCELLANEOUS RECEIVER AND TRANSMITTER APPLICATIONS**

Various IC setups described elsewhere in this book are useful in receivers and transmitters, in addition to the specific applications for which they were discussed. The audio amplifiers described in Sections 2.2, 2.3, 2.4, and 2.5, for example, may be employed in the audio/speech/modulator channel of a transmitter. Selective cw reception may be obtained by inserting a bandpass amplifier (Sections 2.6 and 2.7) into the af channel of a receiver to pass the desired signal, or a bandstop amplifier (Sections 2.8 and 2.9) into the af channel to remove an undesired signal. The rf, i-f, and video amplifiers described in Sections 2.13 to 2.16 may be used directly in receivers.

The af oscillators described in Sections 3.1 to 3.4 may be used for tone modulation of a transmitter. The combination oscillator (Section 3.6) can function as a variable-frequency oscillator in a transmitter when followed with a suitable buffer amplifier for boosting its low output power. The crystal oscillator (Section 3.7), when similarly followed by a suitable rf power amplifier/buffer, may be used as the oscillator section of a transmitter.

The sensitive af/rf relay described in Section 4.2 may be used to switch a receiver off when the transmitter goes on the air. And the threshold circuit (Section 4.8) may be used as an overmodulation alarm in a-m stations. (If the rectified carrier voltage is applied to one input, and the rectified modulation voltage is applied to the other input, and the ratio of the two applied voltages is correctly adjusted, the threshold circuit will deliver an output signal whenever the predetermined modulation percentage is exceeded.)

The self-excited rf oscillator (Sections 3.5 and 3.6) may be used as the high-frequency oscillator in a superhet receiver and may also be used as the cw oscillator (beat-frequency oscillator) in a receiver.

# Test Instruments

The integrated circuit simplifies, and sometimes improves, the design of any test instrument in which the amplifying waveshaping, or digital functions of the IC may be employed. This includes a considerable range of application, and the electronics specialist will have little trouble determining the effective use of ICs in signal generators, meters, converters, counters, and similar test instruments.

This chapter describes a number of adaptations of the IC to basic test equipment. From these illustrations, other—sometimes more complex and sophisticated—uses may be visualized. Aside from these examples, other setups discussed in earlier chapters may also be used in, or as, test instruments. See, for example, Sections 2.3, 2.5–2.9, 2.12–2.16, 3.1–3.7, 4.6, 4.8–4.10, 5.6, and 5.7.

Where specific operating constants are given, unless shown otherwise on the schematic or in the text, capacitances are in microfarads, resistances are in ohms, and electrolytic-capacitor working voltage is 25 Vdc.

## ***6.1 IC AS INSTRUMENT AMPLIFIER***

Test instruments such as electronic voltmeters, oscilloscopes, and signal tracers occasionally are insensitive for a particular measurement, and a suitable external preamplifier

is required. The IC, because of its high gain and wide pass-band, often may be used as an instrument amplifier, with the minimum of outboard components. Usually, a single IC will suffice, but two or more units may be cascaded for increased gain.

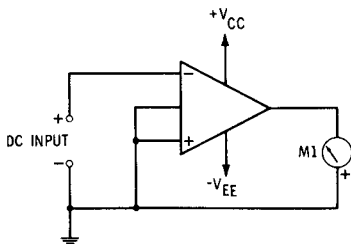
The IC is selected for appropriate overall gain, frequency response, input impedance, and output impedance. Sometimes, phase relations also are important. The designer will often find several ICs that are equally well suited to his requirements for an instrument amplifier. When minimum loading of the signal source is imperative, the IC must have FET input; otherwise, a field-effect transistor must be connected ahead of the IC as an input-impedance converter.

The ICs listed as *wideband amplifiers* or *video amplifiers* are suitable for this application. (See, for example, Section 2.16, Chapter 2.) Overall response of the unit may be modified as desired by use of appropriate outboard components. The user should bear in mind, however, that feedback, external loading, and signal-source impedance sometimes cause marked changes in the characteristics specified by the IC manufacturer.

## 6.2 BASIC ELECTRONIC VOLTMETER

The electronic voltmeter, with its well-known advantages, has occupied an important place in electronic testing ever since the first appearance of the vacuum-tube voltmeter. The transistorized voltmeter is one of the line of such instruments.

The differential-input operational-amplifier IC offers the symmetrical circuit that is valued in the electronic voltmeter. Fig. 6-1 shows the basic arrangement. The dc input signal is



*Fig. 6-1. Basic electronic voltmeter.*

applied to the inverting input terminal; the noninverting input terminal is grounded. The single output terminal is connected to the dc milliammeter or microammeter, M1. The degree of balance between the two amplifier sections of the IC usually is so close that if dc supply voltages  $V_{cc}$  and  $V_{ee}$  are equal there is initially no current through the meter and no need for a zero-set adjustment.

A dc signal (test voltage) applied to the +DC INPUT terminal unbalances the circuit and causes a negative dc output voltage to appear. This, in turn, drives the meter. The signal voltage required for full-scale deflection depends upon the gain of the IC. One advantage of the electronic voltmeter is its high input impedance, but this is obtained in the simple arrangement in Fig. 6-1 only if the IC has high input resistance. For immediate results, an IC having FET input should be employed; otherwise, an outboard FET stage must be operated ahead of the IC.

To adapt the simple circuit to multirange voltage measurement, the designer need only provide a suitable input range-switching circuit in the usual way at the input of the basic circuit (this is done in Figs. 6-2 and 6-3). The basic arrangement is for dc voltage measurement. For ac operation, a suitable rectifier may be operated ahead of the basic circuit or ahead of the indicating meter.

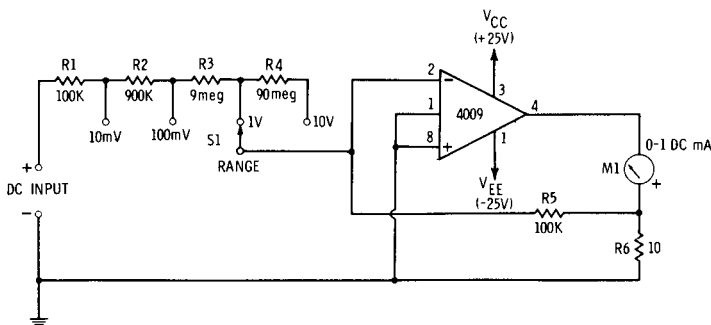
### **6.3 DC VOLTMETER/MILLIVOLTMETER**

Fig. 6-2 shows the circuit of an IC-type electronic dc voltmeter/millivoltmeter. This instrument offers four ranges: 0-10 mV, 0-100 mV, 0-1 V, and 0-10 V. This arrangement, employing a Type 4009 IC, is seen to be similar to the basic circuit (Fig. 6-1), except for the addition of the range-switching circuit (R1-R2-R3-R4-S1) and the negative-feedback loop (R5-R6).

The range selector circuit is a series multiplier, consisting of resistors R1 to R4 in a series string. This arrangement causes the input resistance of the instrument to vary with the voltage range, extending from 100,000 ohms at 10 millivolts to 100 megohms at 10 volts. In applications in which this varying input resistance might be undesirable, the conventional parallel voltage-divider circuit may be used (as in

Fig. 6-3), provided a FET input stage is operated ahead of this IC. The input resistance then will be constant at a single high value, say, 100 megohms.

The resistors in the input circuit (R1-R4) should be accurate within at least 1 percent. For close calibration, a 1000-ohm wirewound CALIBRATION rheostat may be connected in series with meter M1.



*Fig. 6-2. Dc voltmeter/millivoltmeter.*

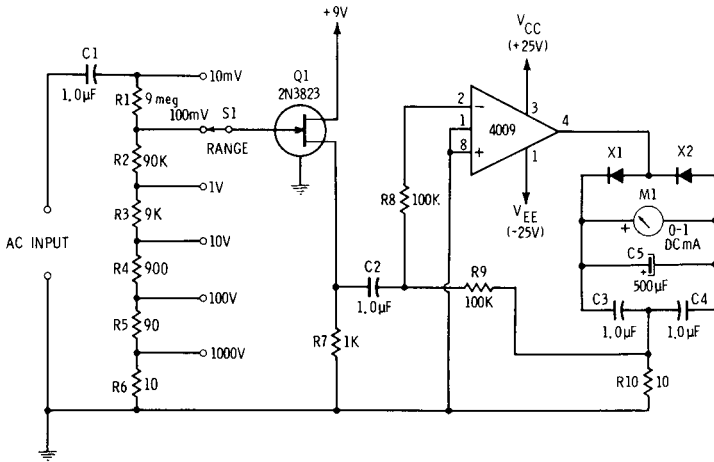
The negative feedback provided by M1, R5, and R6 stabilizes operation of the circuit and increases the input resistance of the IC beyond its normal level.

### **6.4 AC VOLTMETER/MILLIVOLTMETER**

Fig. 6-3 shows the circuit of an IC-type ac voltmeter/millivoltmeter of the amplifier-rectifier type. This instrument offers six ranges: 0-10 mV, 0-100 mV, 0-1 V, 0-10 V, 0-100 V, and 0-1000 V. The input resistance is constant at 10 megohms. All resistors in the input range-switching circuit (R1-R2-R3-R4-R5-R6-S1) must be accurate within at least 1 percent.

For high input resistance, to permit operation of the conventional, parallel input-voltage divider (R1-R6), a FET (Q1) is operated ahead of the Type 4009 IC as a source follower. This FET-IC combination has a frequency response of 50 Hz to 100 kHz.

The ac output signal of the IC is applied to a bridge rectifier circuit (X1-X2-C3-C4), and the resulting dc drives the 0-1 dc milliammeter, M1. In this circuit, X1 and X2 may



*Fig. 6-3. Ac voltmeter/millivoltmeter.*

be any general-purpose germanium diodes, such as Type 1N34A.

A portion of the output signal develops a voltage drop across the 10-ohm resistor, R10, and this in turn is applied (through resistor R9) as negative-feedback voltage to the inverting input terminal. The feedback stabilizes operation of the IC and linearizes the meter response.

For close calibration, a 1000-ohm wirewound rheostat may be connected in series with meter M1, or the 100,000-ohm input resistor R8 (or a portion of this resistance) may be made variable.

## **6.5 SQUARE-WAVE MULTIVIBRATOR**

The utility of square waves in electronic testing, and the usefulness of the multivibrator as a frequency divider are well known to the reader. Fig. 6-4 shows the connections for a simple IC multivibrator that delivers a reasonably good square-wave output signal. Virtually any convenient differential-input operational-amplifier IC may be used. This arrangement may be used as a square-wave generator or as a frequency-dividing multivibrator for use with frequency standards and control equipment.

In this arrangement, negative-feedback voltage is applied to the inverting input terminal through the RC voltage di-

vider, R2C2. Simultaneously, positive feedback derived from the voltage divider R3R4 is applied to the noninverting terminal through resistor R1.

The oscillation frequency is determined by the values of R2 and C2:

$$f = 1/6.28R2C2$$

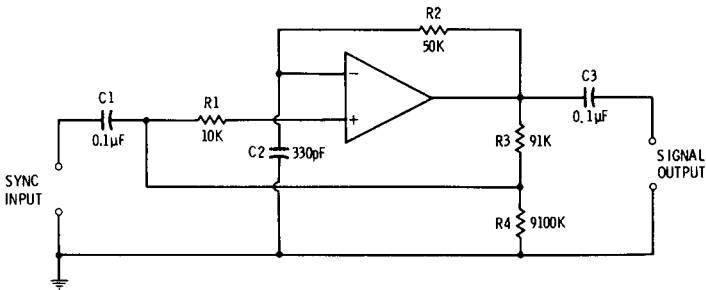
where,

- f is the approximate frequency in hertz,
- R2 is in ohms,
- C2 is in farads.

The values shown in Fig. 6-4 are those required for 10-kHz operation.

A sync signal, applied at the SYNC INPUT terminals, is injected into the noninverting channel of the IC when the multivibrator is used for frequency division and for closely controlled oscillation.

The square-wave amplitude is a function of the dc operating voltage of the particular IC used.



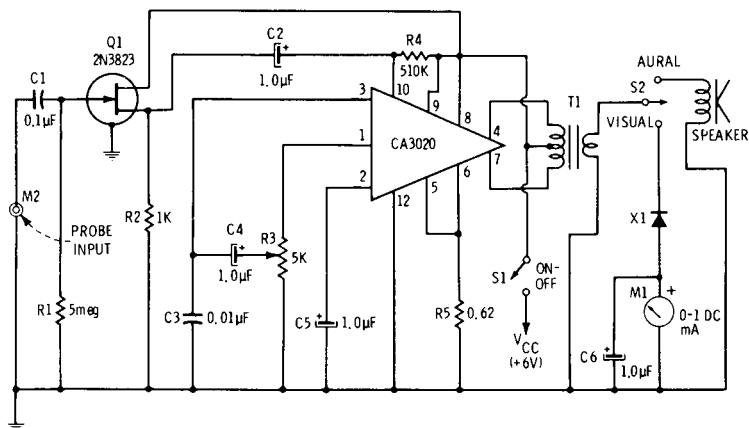
*Fig. 6-4. Square-wave multivibrator.*

## 6.6 AF/RF SIGNAL TRACER

In many types of electronic servicing, a signal tracer is a handy instrument for localizing trouble. In its conventional form, this instrument gives both visual and aural indications of signal strength and can be used to follow af and rf signals through a circuit. It is usually untuned.

Fig. 6-5 shows the circuit of such a signal tracer, employing an outboard FET amplifier for high input impedance and an IC type of complete af amplifier to drive the loud-





**Fig. 6-5. Af/rf signal tracer.**

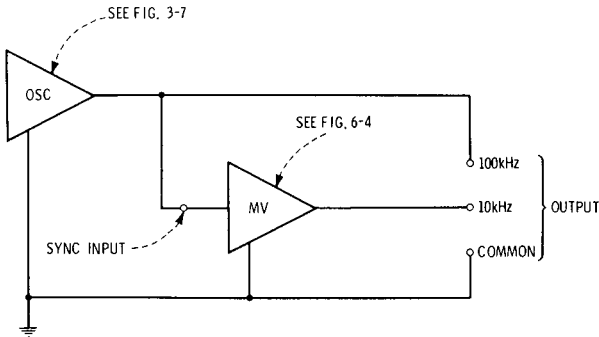
speaker and output meter. The IC is a Type CA3020, which contains complete preamplifier, driver, and Class-B output stages. Operated from a 6-volt dc source, as shown here, the audio output is in excess of  $\frac{1}{2}$  watt, which is ample for this service. The input impedance of the instrument is approximately 5 megohms, the resistance of the gate resistor, R1.

Either an af probe or rf (demodulator type) probe is plugged into input jack M2 to follow an amplitude-modulated test signal through a circuit under test. Tracer sensitivity is adjustable by means of the 5000-ohm gain-control potentiometer, R3. The output transformer, T1, is a miniature, transistor-type unit for matching 125 ohms center tapped to 3.2 ohms. The single-pole, double-throw selector switch, S2, permits the selection of either aural indications (via the loudspeaker) or visual indications (via the rectifier-type meter, X1-C6-M1).

### 6.7 SECONDARY FREQUENCY STANDARD

Any one of the rf oscillators described in Chapter 3 may be used as a frequency standard, provided it is operated from a steady dc supply and tuned to 100 kHz or 1 MHz. The self-excited oscillators may be synchronized with WWV standard frequency broadcasts by tuning their tank circuits for zero beat with the station carrier (this applies to the units de-

scribed in Sections 3.5 and 3.6). The crystal oscillator (Section 3.7) may be synchronized by tuning the crystal a small amount with a small variable capacitor (10 to 30 pF maximum) connected in parallel with the 100-kHz or 1-MHz crystal.



**Fig. 6-6. IC-type frequency standard.**

Fig. 6-6 shows the connections for a frequency standard employing IC-type oscillator and multivibrator. A unit of this type will supply 100-kHz and 10-kHz check points. The oscillator may be the crystal oscillator described in Section 3.7, Chapter 3, and the multivibrator may be the arrangement described in Section 6.5. The oscillator output terminal is connected to the SYNC INPUT terminal of the multivibrator, as well as to the 100-kHz output terminal.

## 6.8 TEST OSCILLATORS

The oscillator circuits described in Chapter 3 may be used for signal generators, provided they are operated from steady dc supplies and are equipped with output controls as explained in Chapter 3.

The Wien-bridge af oscillator (Fig. 3-3) lends itself very well to wideband operation and is the basis of most RC-tuned audio oscillators used in laboratory and service work: R1 and R2 are made the two sections of a 2-gang potentiometer in which  $R1 = R2$  at all settings. Capacitors C1 and C2 are switched in identical pairs to change ranges. An output-control potentiometer may be connected between amplifier stages of the IC.

The transformer-tuned audio oscillator (Fig. 3-4) is useful especially for single-frequency applications and may be adjusted for good sine-wave output. The RC-tuned audio oscillators (Figs. 3-1 and 3-2) have excellent sine-wave output.

The transformer-tuned rf oscillator (Fig. 3-5) is easily adapted for multiband operation by arranging L1 and L2 to be plugged in. The crystal oscillator (Fig. 3-7) is, of course, basically a spot-frequency device. But this circuit may be adapted to multifrequency operation by means of a number of selected crystals arranged for switching into and out of the circuit.

The combination oscillator (Fig. 3-6) may be used at either audio or radio frequencies, depending upon the characteristics of the plug-in coil-capacitor combinations, L1-C1. An output-control potentiometer may conveniently be connected between stages of the IC amplifier, or may be added to the output.

## **6.9 NULL DETECTORS**

The electronic voltmeters described earlier in this chapter may be used as sensitive, bridge null detectors. The dc instrument (Section 6.3) is satisfactory for use with dc (Wheatstone) bridges and with some millivolt potentiometers. The ac instrument (Section 6.4) is satisfactory for use with ac bridges (impedance bridges, capacitance bridges, inductance bridges, and T-networks).

Although these voltmeters do not employ center-zero indicating meters, such as are found especially in many dc null detectors, their operation occasions little difficulty in reading response both above and below null. Each instrument possesses sufficient sensitivity to suit it efficiently to use in standard bridge circuits, with negligible loading of the measurement circuit.

## **6.10 DISTORTION METER**

The bandstop amplifiers described in Chapter 2 may be used with some success for the measurement of total harmonic distortion. Either the RC-tuned unit (Fig. 2-7) or the

LC-tuned one (Fig. 2-8) may be used. The response of each amplifier may be sharpened by connecting a 50,000-ohm negative-feedback resistor from input to output, i. e., from terminal 1 to terminal 5 in either circuit. The amplifier must be tuned to reject the fundamental frequency of the high-purity sinusoidal test signal. An electronic ac voltmeter is connected to the amplifier output.

The test technique is well known to electronics specialists and will be reviewed here only briefly: Since the fundamental frequency is removed by the bandstop amplifier, the output voltage of the amplifier contains harmonics only. If the test voltage (fundamental plus harmonics) is measured at the point at which it is applied to the equipment under test, and then the output of the bandstop amplifier (which is connected to the output of the equipment under test) is measured, the distortion percentage may be calculated from these two voltages. Thus,  $D\% = 100 (V_o/V_i)$ , where  $V_i$  is the applied test voltage, and  $V_o$  is the output voltage of the bandstop amplifier.

The LC-type circuit (Fig. 2-8) is suitable for spot-frequency testing only, since the inductor and capacitor required at audio frequencies are too large electrically to be made variable. The RC-type circuit (Fig. 2-7), however, may be made continuously tunable if R1, R2, and R3 are made the sections of a 3-gang potentiometer, and capacitors C3, C4, and C5 are switched in trios to change ranges (see Section 2.8, Chapter 2).

Unless extraordinary care is exercised in the layout and wiring of the bandstop amplifier and ac voltmeter, the fundamental-suppression method of distortion measurement will be limited to frequencies below about 5 kHz. Above this frequency, stray reactances in the circuit cause attenuation of harmonic-frequency components, as well as obscure the null.

# Supplementary Applications

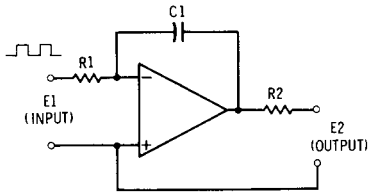
This chapter presents several miscellaneous applications of the IC that are supplementary to those in the preceding chapters. These additional illustrations serve to round out the picture of IC service.

As in previous instances, the layouts shown in this chapter may sometimes be combined with those appearing elsewhere in the book to obtain more complex arrangements for specific purposes. The versatility of the IC is such that layout is often useful for purposes other than the specific one described here.

The setups shown here are primarily illustrative, and therefore are limited to functional block diagram presentation. Where specific values are shown for components, however, resistances are in ohms, and capacitances are in microfarads. A number of ICs, easily available commercially, may be employed in these typical layouts with equal success.

## **7.1 INTEGRATOR**

Fig. 7-1 shows the connections for a simple integrator employing an IC operational amplifier. A unit of this type finds application in computing, as well as in instrumentation and control.



*Fig. 7-1. Integrator.*

This arrangement consists essentially of an amplifier in which feedback is applied between the output and inverting input terminals. The negative-feedback loop consists of capacitor C1. This capacitance, together with input resistance R1, shapes response of the amplifier correctly for integration of the input signal.

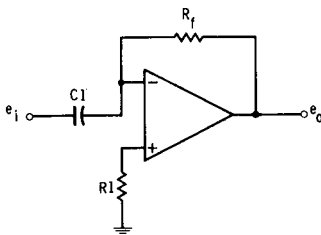
The output voltage (E2) is proportional to the integral of the input voltage with respect to time: that is, the output voltage  $E2 = -(1/R1C1) \int E1dt$ . Various ranges of operation and response are obtainable by suitable variation of the R1 and C1 values.

For a listing of mathematical applications of the integrator, see any one of the practical handbooks of analog computers.

## **7.2 DIFFERENTIATOR**

Fig. 7-2 shows the connections for a simple differentiator employing an IC operational amplifier. A unit of this type, like the integrator (Section 7.1), finds application in computing, as well as in instrumentation.

This arrangement consists essentially of an amplifier in which negative feedback is applied between the output and inverting input terminals through resistor  $R_f$ . This feedback resistance, together with input capacitance C1, correctly



*Fig. 7-2. Differentiator.*

shapes response of the amplifier for differentiation of the input signal.

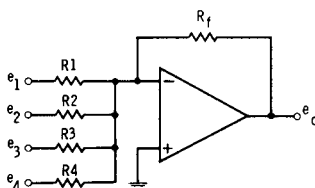
The output voltage ( $e_o$ ) is proportional to the differential of the input voltage with respect to time: that is, the output voltage  $e_o = -R_f C1 (de_i/dt)$ . Various ranges of operation and response are obtainable by suitable variation of the  $R_f$  and  $C1$  values.

For a listing and explanation of mathematical applications of the differentiator, see any one of the practical handbooks of analog computers.

### 7.3 INVERTING ADDER

The IC operational amplifier provides a simple unit for the assembly of an adder. A unit of this type (like the integrator in Section 7.1 and the differentiator in Section 7.2) finds application in computing, as well as in instrumentation and electronic control. Fig. 7-3 shows the connections for a simple adder.

*Fig. 7-3. Inverting adder.*



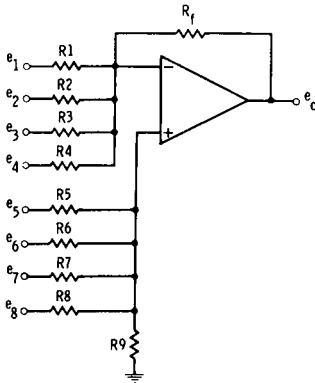
This arrangement consists essentially of an amplifier in which negative feedback is applied between the output and the inverting input terminals through resistor  $R_f$ . Several input-signal voltages ( $e_1$  through  $e_4$ ) may be applied to the amplifier in any desired combination.

All resistances are equal:  $R1 = R2 = R3 = R4 = R_f$ . Under these conditions, if all positive input voltages are employed, the output voltage ( $e_o$ ) is the sum of the input voltages: that is,  $e_o = -(e_1 + e_2 + e_3 + e_4)$ . Any desired number of inputs may be added in this manner, provided the output sum never exceeds the maximum voltage swing of the amplifier.

For a listing and explanation of mathematical applications of the adder, see any one of the practical handbooks of analog computers.

## 7.4 COMBINATION ADDER AND SUBTRACTER

Fig. 7-4 shows the connections for a simple combination adder and subtracter employing an IC operational amplifier. A unit of this type (like the others described in Sections 7.1, 7.2, and 7.3) finds application in computing and also in instrumentation and electronic control.



*Fig. 7-4. Combination adder and subtracter.*

This arrangement consists essentially of an amplifier in which negative feedback is applied between the output and inverting input terminals through resistor  $R_f$ . The input-signal voltages to be added ( $e_1$  through  $e_4$ ) are applied through resistors  $R_1$  through  $R_4$  to the inverting input; the input-signal voltages to be subtracted ( $e_5$  through  $e_8$ ) are applied through resistors  $R_5$  through  $R_8$  to the noninverting input.

All resistances are equal:  $R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = R_7 = R_8 = R_f$ . All input-signal voltages are positive. Under these conditions, the output voltage ( $e_o$ ) remainder results from the application of minuend ( $e_1$  through  $e_4$ ) and subtrahend ( $e_5$  through  $e_8$ ) to the input terminals. That is: 
$$e_o = -(e_1 + e_2 + e_3 + e_4) - (e_5 + e_6 + e_7 + e_8).$$

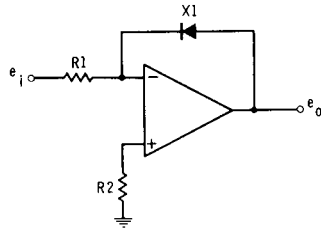
Any desired number of inputs may be added and subtracted in this manner, in any combination, provided the output  $e_o$  never exceeds the maximum output-voltage swing of the amplifier.



## 7.5 LOGARITHMIC CONVERTER

Fig. 7-5 shows the connections for a simple logarithmic converter employing an IC operational amplifier. A unit of this type, like the ones described in the four preceding sections, finds application in computing and also in instrumentation and electronic control.

This arrangement, like the others, consists essentially of an amplifier in which negative feedback is applied between the output and inverting input terminals. In this case, however, the feedback loop includes a logarithmic diode, X1. (Some conventional small-signal diodes may be operated in the logarithmic, or quasi-logarithmic, portion of their volt/ampere response characteristic, if the special diode is not available.)



*Fig. 7-5. Logarithmic converter.*

In this setup,  $R1 = R2$ . Under these circumstances, the output voltage is proportional to the common logarithm of the input voltage. That is,  $e_o = \log_{10} e_i$ .

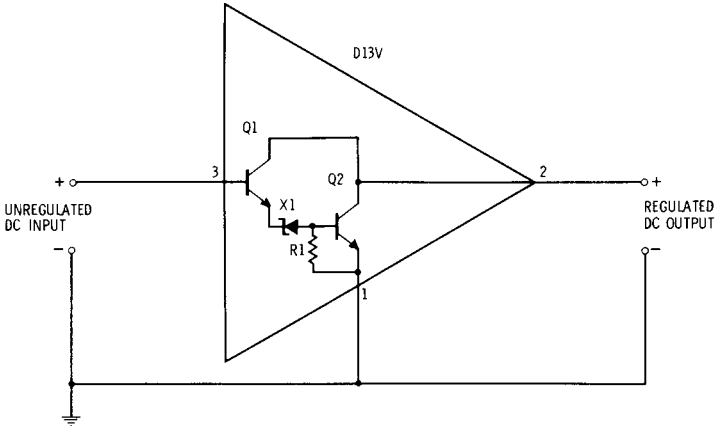
For a listing and explanation of mathematical applications of the converter, see any one of the practical handbooks of analog computers.

## 7.6 VOLTAGE REGULATOR

The integrated circuit has greatly simplified the design and construction of voltage-regulated dc power supplies by providing the dc amplifier needed for control. Still further simplification has been provided by special ICs that include the entire voltage regulator circuit and thus require no outboard components.

Fig. 7-6 shows the connections for a dc voltage regulator employing a Type D13V IC. This IC is supplied in a TO-98

package and, as shown in Fig. 7-6, contains the transistors (Q1 and Q2), zener diode (X1), and bias resistor (R1) needed for a shunt-type voltage regulator. This simple arrangement permits close regulation of dc voltages between 10 and 40 V at power levels up to 400 mW.



**Fig. 7-6. Voltage regulator.**

# IC Manufacturers

The manufacturers of integrated circuits whose products are shown in the circuits in this book and their addresses are as follows:

Radio Corporation of America, Electronics Components and Devices, Harrison, N.J. 07029.

CA3000	CA3013
CA3001	CA3020
CA3005	CA3030
CA3007	CA3034
CA3010	CA3035
CA3012	CA3036

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General Electric Company, Semiconductor Products Department, Syracuse, N.Y. 13201.

D13V

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Fairchild Semiconductor, Mountain View, California 94040  
9040

$\mu$ A739C

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Opamp Labs, 172 S. Alta Vista Blvd., Los Angeles, Calif.  
90036

4009

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Sylvania Electric Products, Inc., 730 Third Ave., New York,  
N. Y. 10017

MS-100A

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Motorola Semiconductor Products, Inc., Phoenix, Arizona  
85036

MC1596G

# Index

## A

Ac voltmeter/millivoltmeter,  
78-79

Adder, 88  
inverting, 87

Af/rf relay, 55-56

Amplifier

audio, 30-31, 32-33  
bandpass, LC type, 35-36  
RC type, 33-35  
bandstop, LC type, 37-38  
RC type, 36-37

bandpass, 74

bandstop, 74, 84

dc voltage, 40-41

IC, 30-43

i-f, 42

instrument, 75-76

limiting, 63-64

photocell, 59-60

rf, 41

untuned, 41, 69

TV, i-f, 71

video, 43

wideband, 69

Antenna

impedance match, 67

loopstick 66-67

Audio

amplifier, 30-31, 32-33  
driver, 31-32

## B

Balanced modulator, 73-74

Bandpass amplifier, 74

audio

LC type, 35-36

RC type, 30-35

Bandstop amplifier, 74, 84

audio

LC type, 37-38

RC type, 36-37

Bandwidth, 21

open-loop, 22

Bias current, 21

## C

Capacitor, integrated, 11-12

Cascaded

amplifiers, 39

operation, 25-26

Common-mode

gain, 21

impedance, 21

Converter, logarithmic, 89

Counter, scale-of-two, 61-62  
Crystal-controlled oscillator,  
52-53, 83  
Cw reception, 74

## D

Darlington pair, 55, 70  
Dc  
  relay, 55  
  voltage amplifier, 40-41  
  voltmeter/millivoltmeter, 77-78  
Detector  
  null, 83  
  product, 71-73  
  TV, 71  
Differential input  
  impedance, 21  
  voltage range, 21  
Differential operational amplifier;  
  *See* Opamp  
Differentiator circuit, 86-87  
Digital IC, 16-17  
Diodes, integrated, 9-10  
Diode, zener, 48  
Distortion  
  harmonic, 22  
  meter, 83-84  
Drift, input-voltage, 21

## E

Electronic voltmeter, 76-77

## F

Feedback, 25  
FET, 54, 76, 77, 78, 80  
Fm receiver, 70  
Frequency  
  range, 21  
  standard, secondary, 81-82

## G

Gain, 21-22  
  common-mode, 21  
Gyrator, 12

## H

Harmonic distortion, 22  
High-gain preamplifier, 31  
Hybrid IC, 16

## I

IC  
  amplifiers, 30-43  
  characteristics, 21-23  
  classification of, 15-18  
  construction of, 8-9  
  defined by Electronic Industries  
    Association, 14  
  digital, 16-17  
  hybrid, 16  
  installation, 23-24  
  invention of, 7  
  linear, 16  
  monolithic, 15-16  
  packaging, 17-18  
  receiver applications, 74  
  symbols, 18-20  
  thin-film, 16  
  transmitter applications, 74  
  typical examples, 13-14  
  video amplifier, 69  
I-f amplifier, 42  
Impedance  
  common-mode, 21  
  input, 22, 77  
  match, antenna, 67  
  output, 22  
Input impedance, 22, 77  
  differential, 21  
Input/output relationships, 26  
Input-voltage offset, 22  
Instrument amplifier, 75-76  
Integrated  
  capacitor, 11-12  
  diodes, 9-10  
  passive components, 11-12  
  resistor, 11  
  transistors, 10-11  
Integrator circuit, 85-86  
Interval timer, 64-65  
Inversion of signal, 24, 26  
Inverting adder, 87

- K**
- Kilby, Jack S., 7
- L**
- Large-scale integration; *See* LSI  
 Latching relay, 61–62  
 Limiting amplifier, 63–64  
 Linear IC, 16  
 Logarithmic converter, 89  
 Loopstick antenna, 66–67  
 LSI, 27–28
- M**
- Meter, distortion, 83–84  
 Modulator, balanced, 73–74  
 Module, 7–8  
 Monolithic IC, 15–16  
 Multivibrator, square-wave, 79–80
- N**
- Network, twin-T, 33, 36, 57, 59  
 Null  
   circuit, 35, 38  
   detector, 83
- O**
- Offset, input-voltage, 22  
 Opamp, 25, 27, 76–77  
 Open-loop  
   bandwidth, 22  
   voltage gain, 22  
 Oscillator  
   af, transformer feedback, 48–49  
   combination af/rf, 51–52  
   crystal-controlled, 52–53, 83  
   phase-shift, 46–47  
   rf, transformer feedback, 50–51  
   test, 82–83  
   transformer-tuned, 83  
   twin-T, 45–46  
   Wien-bridge, 47–48, 82  
 Oscillators, 44–53
- Output**
- impedance, 22  
 power, 23  
 swing, 22–23
- P**
- Passive components, integrated, 11–12  
 Phase-shift oscillator, 46–47  
 Photocell amplifier, 59–60  
 Power  
   dissipation, 23  
   output, 23  
   supply, for ICs, 24  
 Preamplifier  
   high-gain, 31  
   stereo, 39–40  
 Product detector, 71–73  
 Proximity relay, 59
- R**
- Radio receiver, 66–68  
 Range, frequency, 21  
 Receiver  
   applications, 74  
   fm, 70  
   radio, 66–68  
   sensitivity, 67  
   superhet, 68–69  
 Relay, 54–61, 65  
   af/rf, 55–56  
   dc, 55  
   latching, 61–62  
   proximity, 59  
   selective, 56–57  
   sound-operated, 58  
 Resistor, integrated, 11  
 Rf amplifier, 41  
   untuned, 41, 69
- S**
- Scale-of-two counter, 61–62  
 Secondary frequency standard, 81–82  
 Selective relay, 56–57  
 Sensitivity, receiver, 67

Signal  
  inversion, 24, 26  
  tracer, 80-81

Slew rate, 23

Sound-operated relay, 58

Square-wave multivibrator, 79-80

Stereo preamplifier, 39-40

Subtractor, 88

Superhet receiver, 68-69

Supply

  current, 23

  voltage, 23

## T

Temperature, 23

Test oscillator, 82-83

Thermistor, 48

Thin-film IC, 16

Threshold circuit, 62

Timer, interval, 64-65

Transformer-feedback oscillator

  af, 48-49

  rf, 50-51

Transformer-tuned oscillator, 83

Transistors, integrated, 10-11

Transmitter applications, 74

TV i-f amplifier and detector, 71

Twin-T

  network, 33-36

  oscillator, 45-46

## V

Varistor, 48

Video amplifier, 43, 69

Voltage

  gain, open-loop, 22

  range, differential-input, 21

Voltage regulator, 89-90

  supply, 23

Voltmeter

  electronic, 76-77

  input impedance, 77

Voltmeter/millivoltmeter

  ac, 78-79

  dc, 77-78

## W

Wideband amplifier, 69

Wien-bridge oscillator, 47-48, 82

## Z

Zener diode, 48