Electronic Circuits and Applications

BERNARD GROB

Technical Career Institutes, Inc.

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Preface

This book is designed for courses covering basic electronic circuits and their applications. A background in algebra and a working knowledge of solid-state diodes and transistors are prerequisites for studying this text. However, where necessary to the development of new material, semiconductor theory is reviewed briefly. While not essential to the use of this text, the student's knowledge of basic vacuum tube theory will be useful in the few vacuum tube applications discussed. Although modern electronics is dominated by solid-state devices, it is unrealistic to think that technicians will not encounter vacuum tubes sometime in their work experiences. Vacuum tube applications are likely to remain for many years.

SEMICONDUCTOR DEVICES The discrete circuits discussed in this book include PNP and NPN bipolar junction transistors, field-effect transistors (FETs), two-terminal diodes including varactor, zener, and Schottky, and thyristors such as silicon controlled rectifiers, diacs, triacs, and unijunction transistors (UJTs). Integrated circuits are discussed both as building blocks for digital circuits and as single packages containing complete stages of radio and audio systems. Logic gate ICs, op amps, and other basic units are developed both in block diagram form and as a combination of discrete devices. Many circuit applications are given in terms of both the IC package and the combination of discrete devices.

COMMUNICATIONS APPLICATIONS Communications receivers and transmitters constitute the major subject area developed in this textbook. Formerly this would have meant a rather lengthy and detailed discussion of AM radio. But modern communications covers much more than that and this textbook reflects that growth. There are chapters on such traditional but essential topics as the superheterodyne AM and FM receivers, automatic volume control, and audio systems. There are also discussions of microwave systems (including applications to satellite communications), transmitters, modulation, and antennas. Modulation includes such areas as amplitude modulation, frequency modulation, pulse modulation, single side-band transmission, and multiplexing.

As noted previously, the emphasis in this book is on solid-state electronics—both discrete devices and integrated circuits. Although the preponderance of communications systems rely on analog electronics, the rapid growth of digital electronics in these systems requires that the subject be covered in some depth.

PRACTICAL APPLICATIONS There is no question that theory is an important part of any electronics program. But theory without practical applications does not serve the needs of the electronics technician or servicer. For that reason, all of the circuits discussed in this book are related to actual equipment and practical functions. Mathematically derived theory in most cases is best left to the engineer and designer. The only mathematics required to use this book is algebra though the language and techniques of trigonometry are developed in those few instances where trigonometry is required. The numerical examples presented are those technicians and servicers will likely have to solve in the course of their practical experience. These usually involve finding values of current, voltage, resistance, power, decibels, and the like.

TROUBLESHOOTING While the primary aim of this textbook is to explain how and why circuits work and how and why they function in combination to form such practical devices as radio and television receivers—there is another purpose. That second purpose is to show why the circuit or the combination of circuits are not working. What went wrong? How can we tell exactly where the trouble originated? These questions are answered by techniques that generally fall under the category of troubleshooting. We might say that all the theory and practical information gathered about circuits form the data base from which we derive our troubleshooting information. Rather than discuss circuit problems in the abstract, troubleshooting techniques and information are included together with the circuit descriptions themselves. Thus the student will learn why the circuit works as it does and what might be wrong when the circuit does not work as it should. Troubleshooting techniques are so closely related to testing and measuring that special attention is given to methods of testing diodes, transistors, and thyristors. Alignment procedures, although not strictly troubleshooting, are nevertheless so allied to problems in AM and FM receivers that they are covered in some depth. Signal injection is included since it is an important technique for localizing a defective stage in a receiver or amplifier. If one were to name the single most versatile troubleshooting instrument, the oscilloscope would probably be named first. For that reason an entire chapter has been devoted to the instrument, covering its circuits, capabilities, and precise procedures for its use. While this chapter is placed at the end of the book, it can be, and should be used throughout the course whenever oscilloscope techniques are discussed.

LEARNING AIDS The strength of a textbook lies not only on the amount of information it contains but on how it gets the information to the student and how it helps the student retain the information he or she has learned. The student aids included in this textbook are designed to do a number of things, as described below.

Introduction: Each chapter begins with a brief paragraph describing the material covered in the chapter, why the material is important, and how it relates to the overall objectives of the book. The paragraph concludes with a list of the main topics to be covered in the chapter.

Test Point Questions: After each section of text, and before a new concept is introduced, the student is given a few specific questions directly related to the section just covered. These questions are designed to produce a complete correct response from the student. All answers are given at the end of the chapter. This serves as an immediate reinforcement of the text and a confidence-builder for the material that is to follow. The questions are not framed in such a way as to trap the student or to test his or her cumulative knowledge to that point. If students find the questions easy and the answers obvious it means they are doing their work and can move on to the next section. This method of short progressive units, broken by brief test point questions, has proven to be an effective learning tool in my text, *Basic Electronics*.

Summary: At the end of each chapter the key points of the chapter are summarized in concise statements. The purpose of the summary is two-fold. First, it serves as a quick review of the material covered in the chapter, free of the details and mathematics (if any). One might say it is the framework, or skeleton of the chapter. The second purpose of the summary is to serve as a detailed outline, or preview, of the material in the chapter. Some students find it effective to read the summary to get an overview of the chapter before delving into the heart of the material. Of course, the summary section in no way can substitute for the detailed discussions in the chapter itself.

Self-Examination Questions: Following the Summary section is a set of short answer questions, the answers for which are given in the back of the book. These questions are intended for the student's self-appraisal of his or her understanding of the material in the entire chapter as well as its relationship to material in the preceding chapters.

Essay Questions: These are questions that require fuller, more detailed answers such as comparisons, descriptions, definitions, circuit diagrams, and the like. Answers or suggestions for answers can be found within the text itself. Thus, the student must research or reread the material in the text to find the responses called for in the essay questions.

Problems: The problems in this section refer to questions requiring numerical calculations based on circuits discussed in the chapter. Answers to the odd-numbered problems are given at the back of the book.

Special Questions: The purpose of these questions is to draw the student's thinking outside the immediate material in the text and to relate their studies with experiences outside the immediate course they are taking. Thus students may be required to research certain materials in the library, to write manufacturers for data, or to describe experiences with electronic or electrical equipment they own or use. The questions are given at different levels of difficulty so that the teacher may assign the materials according to the students' needs, background, and interest.

ACKNOWLEDGMENTS The photographs of components and equipment have been provided by many manufacturers. Grateful acknowledgment is given to each source in the legend that accompanies the material. I also want to thank Charles A. Schuler for his assistance with the materials on RF circuits and Roger L. Tokheim for his assistance with the materials on digital electronics. Finally, thanks to my wife, Ruth, for her assistance in the preparation of the manuscript.

Bernard Grob

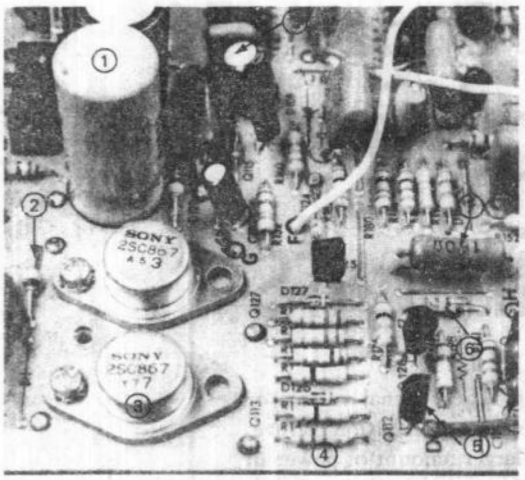
Contents

Chapter 1 Amplifier Circuits

Amplification means increasing the amplitude of a desired ac signal voltage or current such as an audio signal for sound or a video signal for a television picture. The amplifier allows a small input signal to control a larger amount of power in the output circuit. The output signal is a copy of the input signal, but it has more amplitude.

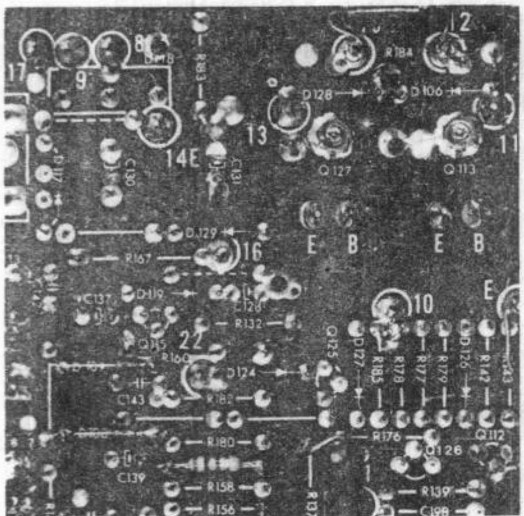
Amplifiers are necessary in most applications because the desired signal is usually too weak to be directly useful. As an example, audio output from a microphone may be as little as one millivolt, whereas the loudspeaker needs at least a few volts of audio signal. With an amplifier, however, a faint whisper can be made to fill a large room with sound.

Transistors are used as the amplifiers in most circuits. In addition, resistors, inductors, and capacitors are required to form complete amplifier circuits. They provide paths for the input and output signals. As an example, Fig. 1-1 illustrates a complete audio amplifier on a printed-circuit (PC) board. A similar amplifier may also be contained in a single integrated circuit "chip." More details of the different types of amplifier circuits are explained in the following topics:



1. FILTER CAPACITOR
2. DIODE
3. POWER TRANSISTOR
4. CARBON RESISTOR
5. SMALL-SIGNAL TRANSISTOR
6. DIODE
7. WIRE-WOUND RESISTOR
8. COUPLING CAPACITOR

(a)



(b)

Fig. 1-1. Audio amplifier transistors and associated components on printed-circuit (PC) board. Size is 3 by 5 in [7.6 by 12.7 cm]. (*a*) Component side. (*b*) Printed wiring side.

1-1 BASIC AMPLIFIER REQUIREMENTS

A transistor or vacuum tube used as an amplifier needs dc voltages applied to its electrodes in order to conduct any current. The amplification comes from having a small ac input signal control much larger dc values in the output circuit. Furthermore, a load impedance is required in the output circuit to develop the output signal. The reason is that the current inside the transistor or tube must be made to flow in an external component. Otherwise, there is no way to take out the amplified signal. Those two basic requirements for amplifiers are illustrated in Fig. 1-2.

Types of Amplifier Load Impedance In Fig. 1-2, Z_L can be either a resistor or a coil. A capacitor cannot be used because it would block the dc supply voltage needed for the amplifier.

A coil as the Z_L may be either a single inductor or the primary of a transformer. At audio frequencies, iron-core coils are used. At radio frequencies, the inductors can be air-core or have a ferrite core. In a tuned RF amplifier, Z_L is the high impedance of a parallel-resonant *LC* circuit. In general, a higher Z_L allows more amplified signal voltage in the output.

Typical DC Supply Voltages For vacuum tubes, 90 to 280 volts (V) is generally needed for the plate and screen-grid electrodes. For transistors, the supply voltage is usually 4.5, 9, or 28 V

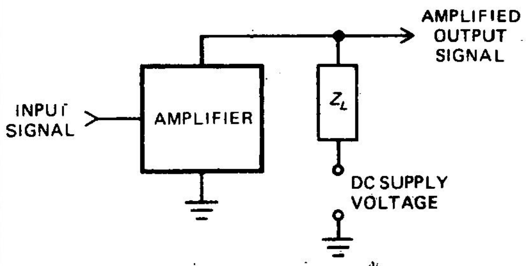


Fig. 1-2. The two basic requirements for an amplifier circuit are a dc supply voltage to make the amplifier conduct and a load impedance Z_L across which the output signal is developed.

for the collector. Higher values up to 100 V can be used with power transistors. The higher the dc supply voltage the greater the power output possible for the transistor amplifier. Integrated-circuit packages generally use 5, 12, or 20 V.

Test Point Questions 1-1
(Answers on Page 24)

Answer True or False.

a. A resistor can be used for the load in the collector circuit of a transistor amplifier.
b. The required dc supply voltage for a transistor amplifier can be provided by a 9-V battery.

1-2 TRANSISTOR CIRCUIT CONFIGURATIONS

In NPN and PNP junction transistors, the three electrodes are emitter, base, and collector. The emitter supplies charges, either electrons or holes, for current to the collector. The base controls the amount of collector current.

In the field-effect transistor (FET), the corresponding electrodes are source, gate, and drain. The source supplies charges for current to the drain, which is controlled by the gate. The current is electron flow with an N-channel.

Either type of transistor has just three terminals. One is for input signal, and the other is for amplified output signal. The third terminal does not have any signal; it is the return connection common to the input and output circuits. Six different combinations for using the transistor in an amplifier circuit are shown in Fig. 1-3.

Common-Emitter (CE) Circuit In the circuit of Fig. 1-3*a*, the input signal is applied to the base and the amplified output is taken from the collector. The emitter is the common electrode. This circuit is the one generally used for transistors because the CE amplifier has the best combination of current gain and voltage gain.

The corresponding FET circuit is the common-source (CS) amplifier. The input signal is applied to the gate, and the amplified output is taken from the drain electrode (Fig. 1-3*d*).

Gain specifies how much the signal is amplified. As an example, when a base signal current of 2 milliamperes (mA) is increased to 60 mA of signal in the collector circuit, the gain is 60 mA/2 mA, or 30. In addition, an amplifier with voltage gain of 100 can provide a 500-millivolt (mV) output signal with 5-mV input signal.

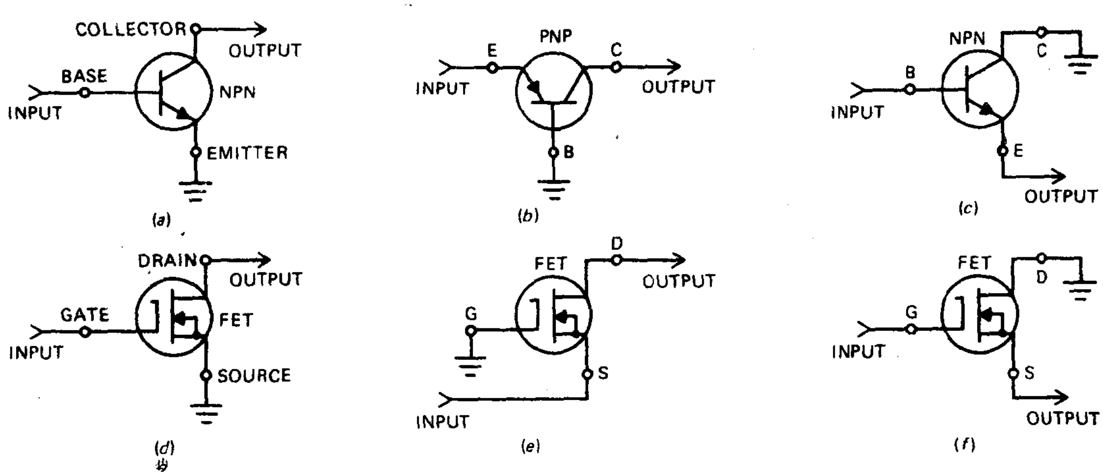


Fig. 1-3. Circuit configurations for junction transistors and field-effect transistors (FETs). (*a*) Common-emitter. (*b*) Common-base. (c) Common-collector or emitter-follower. (*d*) Common-source. (*e*) Common gate. (*f*) Source-follower.

Common-Base (CB) Circuit In the circuit of Fig. 1-3*b*, the input signal is applied to the emitter instead of to the base. The amplified output signal is still taken from the collector. The base is the common electrode.

The relatively high emitter current, compared with base current, results in a very low value of input impedance. Its input circuit, therefore, loads down the collector output circuit of the previous stage. For that reason, the CB circuit is seldom used for amplifiers.

The corresponding FET circuit is the common-gate (CG) amplifier. Input signal is applied to the source, and the amplified output is taken from the drain. The gate electrode is grounded (Fig. 1-3*e*).

Emitter-Follower Circuit The common-collector (CC) circuit of Fig. 1-3c has an input signal to the base, as in the CE amplifier, but the output is taken from the emitter. The collector cannot supply a signal because it is grounded. This circuit is generally called an *emitter follower*. The name means that the output signal voltage at the emitter follows the input signal at the base with the same phase but a little less amplitude. Although the voltage gain is less than 1, the emitter follower is often used for impedance matching. The stage has high input impedance at the base as the load for a preceding circuit and low output impedance at the emitter as a signal source for the next circuit.

The corresponding FET circuit is the *source follower*. An input signal is applied to the gate, and an output is taken from the source. The drain electrode is grounded (Fig. 1-3*f*).

Comparison of CE, CB, and CC Circuits See Table 1-1. Note that the circuit is named for the electrode that is common. That terminal may or may not be connected to chassis ground. Furthermore, the common electrode is the one that does not have the signal input or output.

Although no load impedance is shown for the amplifier circuits in Fig. 1-3, it should be noted that Z_L is in the circuit of the electrode that has the amplified output signal. In the CE and CB amplifiers, Z_L is in the collector output circuit; in the emitter follower, it is in the emitter circuit.

Test Point Questions 1-2
(Answers on Page 24)

a. Which of the amplifier circuits using junction transistors has the best gain?
b. Which FET circuit corresponds to the CE amplifier?
c. Which circuit has its output signal from the emitter?

Table 1-1
Circuits for Junction Transistors

Name	Signal Input	Signal Output	Applications
Common-emitter (CE)	Base	Collector	This is the amplifier circuit generally used because of its high current and voltage gain.
Common-base (CB)	Emitter	Collector	Little used because of low input impedance
Common-collector (CC)	Base	Emitter	Emitter-follower circuit. Often used for its high input and low output impedances.

1-3 RESISTANCE-LOADED AMPLIFIER

The circuit shown in Fig. 1-4 is often used for audio frequency (AF) amplifiers because R_L allows the same amount of gain for a wide range of audio frequencies. Also, it is economical compared with an audio transformer. The circuit of Fig. 1-4*a* is generally called an RC-coupled amplifier, but the capacitive coupling can be used with other types of output load impedance.

In Fig. 1-4*a*, R_L is the load in series with V^+ for the amplifier. Since R_L has the same resistance at all audio frequencies, the amplifier has uniform gain. The flat frequency response is shown by the response curve in Fig. 1-4*b*.

A disadvantage of using R_L is the relatively high dc voltage drop. As an example, with collector output current in a transistor amplifier the voltage drop is $I_C \times R_L$. As a result, the voltage at the collector is much less than the dc supply voltage. In Fig. 1-4*a*, note that V^+ is 24 V but the collector voltage would be only 10 V. The other 14 V is across R_L.

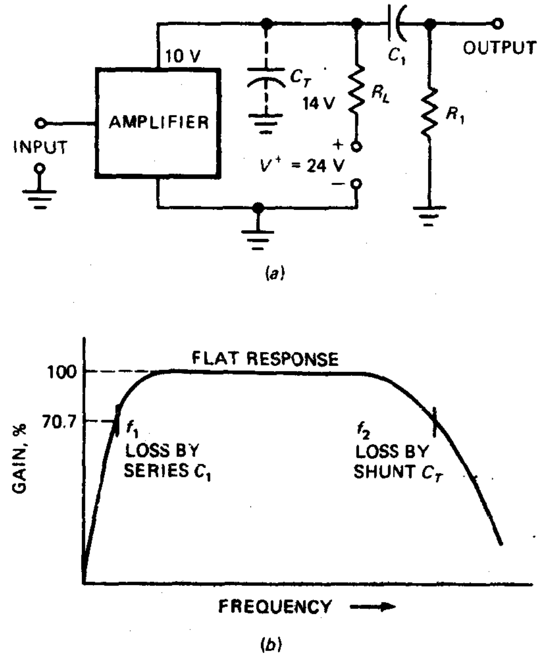


Fig. 1-4. RC coupling for amplifier output. (*a*) Audio amplifier circuit. R_L is the load with R_1C_1 coupling. (*b*) Response curve showing amplifier gain at different frequencies.

Chassis-Ground Returns The input and output circuits have a common ground return but they are shown separately in Fig. 1-4*a*, in order to emphasize these connections. Keep in mind the following important points:

1. V^+ is for the collector but V^- must return to the emitter. Therefore, both V^- and the emitter are connected to the common chassis return line. Without V_{CE} the transistor cannot conduct any current.
2. The amplified signal coupled by C_1 is an ac voltage from collector to chassis ground.
3. The output signal for the next stage is across R_1 from the high side to chassis ground.
4. The input circuit of the next stage must have one side connected to chassis ground in order to receive the input signal.

Low-Frequency Response At low frequencies, the output is reduced because of the reactance of C_1. Remember that X_C increases as the frequency decreases. More of the amplifier output voltage is across C_1, therefore, and less is across R_1 in the next circuit. As a series circuit, C_1 and R_1 divide the ac signal voltage.

In Fig. 1-4*b*, note that the gain is down to 70.7 percent response for the frequency f_1, at the left side of the curve. At that frequency, the reactance of C_1 is exactly equal to the series resistance of R_1. Larger values for both C_1 and R_1 improve the low-frequency response.

High-Frequency Response At high frequencies, the amplifier gain decreases because of the shunting effect of the stray, distributed capacitances. The total, parallel capacitance indicated as C_T is typically 10 to 40 picofarads (pF). Even that small C can bypass high frequencies around a high value of R_L.

Actually, the amplifier load is an impedance Z_L consisting of R_L in parallel with C_T. As the frequency increases, the X_{C_T} decreases. The parallel combination then has less Z_L, and the result is less gain for the amplifier.

In Fig. 1-4*b* note that the gain is down to 70.7 percent response at the frequency f_2, at the right side of the curve. At that frequency, $C_T = R_L$.

Smaller C_T values improve the high-frequency response. Furthermore, smaller R_L values also extend the high-frequency gain for flat response, although the overall gain is reduced.

Test Point Questions 1-3
(Answers on Page 24)

a. In a resistance-loaded amplifier, is low-frequency response down because of C_C or C_T?

b. In a resistance-loaded amplifier, is high-frequency response down because of C_C or C_T?

1-4
RC COUPLING

The R_1C_1 coupling circuit of Fig. 1-4 is shown by itself in Fig. 1-5 so we can analyze how it blocks the dc component but passes the ac signal variations. Here the V_{in} is the output of the amplifier but is also the input to the coupling circuit. In this example, the values for V_{in} are:

10 V	Average dc level
±4 V	AC variations around 10-V axis
14 V	Maximum instantaneous value
6 V	Minimum instantaneous value

Remember that, in a coupling circuit, X_{C_1} must be very small compared with R_1. That requirement is the same as a long time constant for R_1C_1.

Since the path for both charge and discharge in the *RC* coupling circuit is the same, C_1 charges to the average dc level of 10 V. That 10-V axis for V_{in} becomes the zero axis for the ac output across R_1.

When V_{in} rises above 10 V, C_1 can take on more charge. The charging current produces positive voltage across R_1. All the changes of V_{in} between 10 and 14 V provide the positive half-cycle for V_{R_1} between 0 and 4 V.

When V_{in} drops below 10 V, C_1 discharges. The discharge current produces negative voltage across R_1. All the changes of V_{in} between 10 and 6 V provide the negative half-cycle for V_{R_1} between 0 and −4 V.

The final result is that the 10-V level is blocked as the dc voltage across C_1. It is considered blocked because the voltage across C_1 is connected to only one terminal of the next circuit. However, V_{R_1} is connected between that terminal and chassis ground. Therefore, the ac voltage across R_1 has the two connections needed to provide an input signal to the next circuit.

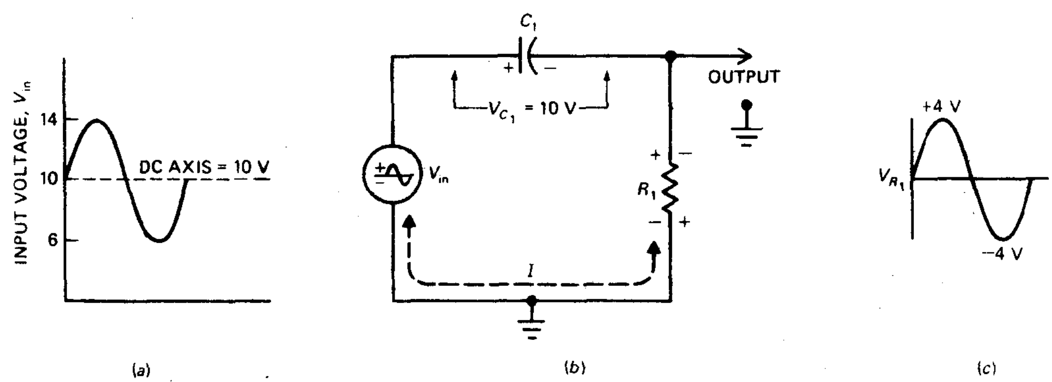


Fig. 1-5. How the *RC* coupling circuit blocks dc but passes ac signal. (*a*) Fluctuating dc input voltage. (*b*) Circuit with an average dc level of 10 V blocked as voltage across C_1. (*c*) AC component of ±4 V passed as voltage across R_1.