CONSUMER ELECTRONICS SERIES

Lenk's Audio Handbook

Operation and Troubleshooting

John D. Lenk

LENK'S AUDIO HANDBOOK

John D. Lenk

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Greetings from the Villa Buttercup!
To my wonderful wife Irene,
Happy Anniversary. Thank you for being by my side all these years!
To my lovely family, Karen, Tom, Brandon, and Justin.
And to our Lambie and Suzzie, be happy wherever you are!
To my special readers, may good fortune find your doorways! Thank you for buying my books and making me a best seller!
This is book number 71.
Abundance!

PREFACE

This is a "something for everyone" audio book. No matter where you are in electronics, this book provides basics, experimentation, simplified design, testing, and troubleshooting information that can be put to immediate use. *If you are an experimenter, student, or serious hobbyist,* the book provides sufficient information for you to design and build audio circuits "from scratch." The design approach here is the same as used in all of the author's best-selling books on simplified and practical design.

Design problems start with approximations or guidelines for the selection of all parts on a trial-value basis, assuming a specific design goal and a given set of conditions. Then, using these approximate values in experimental test circuits, the desired results (power output, rolloff, etc.) are produced by varying the test values.

Although operation of all circuits is described thoroughly where needed, mathematical theory is kept to a minimum. No previous design experience is required to use the design data and techniques described here. The reader need not memorize elaborate theories, or understand abstract math, to use the design data, which makes the book ideal for the *practical experimenter.*

With any audio circuit, it is possible to apply certain guidelines for the selection of component values. These rules are stated in basic equations, requiring only simple arithmetic for their solution. Specific design examples are given as required.

If you are a beginning technician or student, there is an entire chapter devoted to basic testing and troubleshooting audio equipment. A simple audio amplifier is used as an example. Not only does the chapter cover operation of the audio circuits, but it describes testing and troubleshooting approaches for the audio amplifier in step-by-step detail.

If you are an advanced technician or field-service engineer, there are seven chapters devoted to advanced testing and troubleshooting for a cross section of audio circuits and equipment. Each chapter includes a general description of the circuits or equipment, user controls, operating procedures and installation, circuit descriptions, typical testing and adjustment procedures, and step-by-step troubleshooting.

Chapter 1 is devoted to a review and summary of audio basics, from a practical standpoint.

Chapter 2 covers practical considerations for audio. The main concern is with audio power amplifiers (IC or discrete) where temperature-related problems can arise in design and service.

Chapter 3 describes theory and simplified, step-by-step design for audio circuits. The information in this chapter permits the reader to design audio circuits not readily available in IC form.

Chapter 4 describes basic testing and troubleshooting for audio equipment. The chapter starts with a review of typical audio test equipment and then goes on to describe test procedures that can be applied to audio circuits and devices. The chapter concludes with a summary of the basic troubleshooting approach for audio equipment, followed by a specific step-by-step troubleshooting example.

Chapter 5 describes the overall functions, user controls, operating procedures, installation, circuit theory, typical testing and adjustment procedures, and step-by-step troubleshooting for state-of-the-art solid-state and IC amplifiers and loudspeakers.

Chapters 6 through 10 provide coverage, similar to that of Chapter 5, for the audio sections of AM/FM tuners, tape cassettes, CD players, graphic equalizers and turntables, stereo TVs, and surround-sound systems.

Chapter 11 describes formats and circuits found in hifi audio-tape equipment such as VCRs and camcorders, including VHS hifi, S-VHS, Beta hifi, Super Beta and 8 mm. Also discussed are the formats and circuits used in digital audio tape (DAT) players. The chapter concludes with universal hifi audio-tape troubleshooting approaches.

John D. Lenk

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CONTENTS

Preface xi

Chapter 1. Audio Basics 1.1

1.1. Audio-Amplifier Classifications / *1.1*
1.2. Audio-Amplification Principle / *1.1*
1.3. Transistors in Audio Amplifiers / *1.2*
1.4. Common-Emitter Audio Amplifiers / *1.3*
1.5. Common-Base Audio Amplifiers / *1.5*
1.6. Common-Collector Audio Amplifiers / *1.5*
1.7. Audio Bias Networks / *1.5*
1.8. Operating Point of Audio Circuits / *1.10*
1.9. Audio Distortion / *1.14*
1.10. Decibel Basics / *1.15*
1.11. Field-Effect Transistors in Audio / *1.17*

Chapter 2. Practical Considerations for Audio 2.1

2.1. Temperature-Related Problems / *2.1*
2.2. Heat-Sink and Component Mounting Techniques / *2.4*
2.3. Power Dissipation Problems in IC Components / *2.8*

Chapter 3. Simplified Audio Design 3.1

3.1. Frequency Limitations in Audio Circuits / *3.1*
3.2. Audio Coupling Methods / *3.3*
3.3. How Transistor Ratings Affect Audio Performance / *3.6*
3.4. Basic Audio Amplifier Design / *3.10*
3.5. Emitter Bypass / *3.14*
3.6. Multistage Audio Circuits / *3.15*
3.7. Transformer Coupling / *3.24*
3.8. Audio Phase Inverters / *3.25*
3.9. IC Audio / *3.26*

Chapter 4. Basic Testing and Troubleshooting for Audio Equipment and Circuits 4.1

4.1. Typical Audio Test Equipmdent / *4.1*
4.2. Tools and Fixtures for Audio Troubleshooting / *4.9*
4.3. Safety Precautions / *4.9*

4.4. Cleaning, Lubrication, and General Maintenance / *4.9*
4.5. Basic Audio Troubleshooting Approaches / *4.10*
4.6. Basic Audio Tests / *4.11*
4.7. Feedback Problems in Audio Circuits / *4.20*
4.8. Troubleshooting Audio Circuits with Feedback / *4.23*
4.9. Effects of Transistor Leakage on Audio Performance / *4.25*
4.10. Example of Audio Amplifier Troubleshooting / *4.27*

Chapter 5. Audio Amplifiers and Loudspeakers **5.1**

5.1. Overall Description / *5.1*
5.2. Keyboard and Display Circuits / *5.6*
5.3. Power-Protection Circuits / *5.8*
5.4. Device-Select Operation / *5.10*
5.5. Amplifier Operating and Adjustment Controls / *5.12*
5.6. Amplifier Output Circuits / *5.18*
5.7. Output Protection Circuits / *5.24*
5.8. Typical Testing and Adjustments / *5.27*
5.9. Preliminary Troubleshooting / *5.29*

Chapter 6. AM/FM Tuner Audio **6.1**

6.1. Overall Descriptions / *6.1*
6.2. Relationship of Tuner Circuits / *6.2*
6.3. Keyboard and Display Circuits / *6.6*
6.4. Frequency Synthesis Tuning / *6.8*
6.5. Audio Output-Select Circuits / *6.12*
6.6. Audio Control Circuits / *6.13*
6.7. Audio-Output and Muting Circuits / *6.15*
6.8. Front-Panel Display Circuits / *6.18*
6.9. Typical Testing and Adjustments / *6.19*
6.10. Preliminary Troubleshooting / *6.27*

Chapter 7. Tape Cassete Audio **7.1**

7.1. Overall Descriptions / *7.1*
7.2. Relationship of Deck Circuits / *7.6*
7.3. Record/Playback Functions / *7.7*
7.4. Music-Detect Functions / *7.13*
7.5. Dolby Processing / *7.15*
7.6. Tape-Transport Functions / *7.17*
7.7. Tape Stop and Reversal Circuits / *7.20*
7.8. Front-Panel Display / *7.22*
7.9. Command Circuits / *7.24*
7.10. Typical Testing and Adjustments / *7.26*
7.11. Routine Maintenance / *7.32*
7.12. Preliminary Troubleshooting / *7.33*

Chapter 8. CD Audio **8.1**

8.1. Overall Description / *8.1*
8.2. Relationship of CD Player Circuits / *8.6*
8.3. Mechanical Functions / *8.7*

8.4. Laser Optics and Circuits / *8.12*
8.5. Laser Signal Processing / *8.15*
8.6. Audio Circuits / *8.18*
8.7. Autofocus / *8.20*
8.8. Laser Tracking / *8.23*
8.9. Turntable Motor Circuits / *8.26*
8.10. Typical Testing and Adjustments / *8.28*
8.11. Preliminary Troubleshooting / *8.34*

Chapter 9. Graphic Equalizer and LP Turntable Audio **9.1**

9.1. Graphic Equalizers / *9.1*
9.2. LP Turntables / *9.7*

Chapter 10. Stereo TV and Surround-Sound Audio **10.1**

10.1. Stereo TV Basics / *10.1*
10.2. Stereo TV Circuits / *10.6*
10.3. Stereo TV Tests and Adjustments / *10.16*
10.4. Stereo TV Troubleshooting Approach / *10.20*
10.5. Surround Sound / *10.23*

Chapter 11. HIFI Audio-Tape (VHS, Beta, 8 MM, DAT) Equipment **11.1**

11.1. VHS Hifi / *11.1*
11.2. Basic Hifi VCR Audio Circuits / *11.5*
11.3. Beta Hifi and Super Beta Audio / *11.7*
11.4. 8-mm Audio / *11.11*
11.5. Digital Audio Tape (DAT) / *11.15*
11.6. Hifi Audio-Tape Troubleshooting / *11.19*

Index Follows Chapter 11

CHAPTER 1
AUDIO BASICS

This chapter provides a review and summary of audio basics from a practical standpoint. The information presented here provides the background necessary to understand the design, test, and troubleshooting data found in the remaining chapters. It is essential that you understand the basics to properly test and troubleshoot any audio equipment.

1.1 AUDIO-AMPLIFIER CLASSIFICATIONS

Audio amplifiers are classified in many ways. The two most common methods are by *operating-* or *bias-point* and *circuit connections*. Audio amplifiers are also classified by *function* or *purpose* (voltage amplifier, power amplifier, etc.). Before we get into classifications, let us review the basic audio-amplification principle.

1.2 AUDIO-AMPLIFICATION PRINCIPLE

Figure 1.1*a* shows a typical common-emitter (CE) audio circuit. Under *no-signal* (or *quiescent*) conditions, current flows in the input circuit (across R_1), causing a steady value of current to flow in the output circuit (across R_3).

A voltage is developed across R_1 during the first half (or alternation) of the audio signal applied to the input. This voltage, positive at the base end of R_1, adds to the bias voltage at the junction of R_1 *and* R_2, causing the base-to-emitter voltage (sometimes called V_{BE}) to increase.

Under these conditions, the voltage from collector to emitter (V_{CE}) increases but with the *phase inverted* (the collector goes negative when the base goes positive). Amplification occurs because the collector current (I_C) is *many times greater* than the base-emitter current (I_{BE}). When the second half of the audio signal is applied across R_1, the voltage across R_3 also alternates but in the opposite direction (a negative swing at the input produce a positive swing at the output and vice versa).

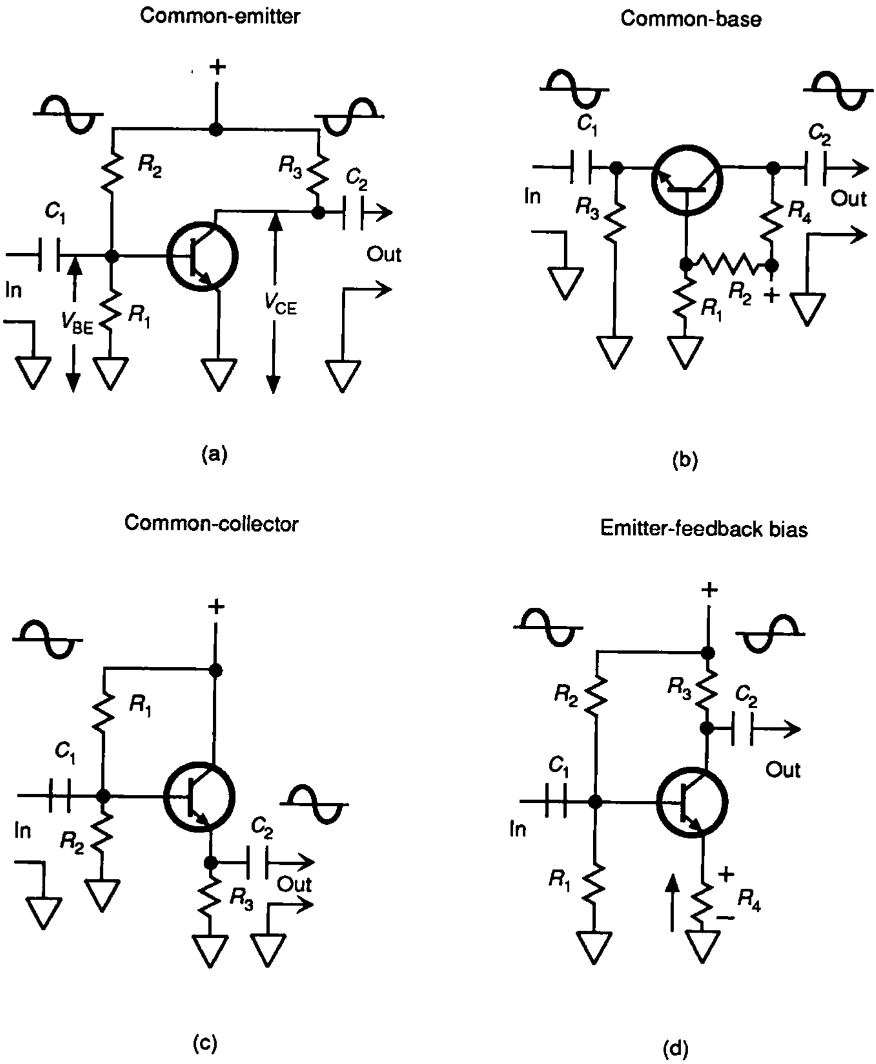

FIGURE 1.1 Audio-amplification and emitter-feedback basics. (*a*) Common emitter; (*b*) common base; (*c*) common collector; (*d*) emitter-feedback bias.

1.3 TRANSISTORS IN AUDIO AMPLIFIERS

The following general rules can be helpful in a practical analysis of how transistors operate in audio amplifiers. The rules apply primarily to a class A amplifier (Sec. 1.8.1) but also remain true for many other audio circuits. The rules are included here primarily for those totally unfamiliar with bipolar or two-junction transistors (and for those who have forgotten). FET audio circuits are discussed in Sec. 1.11.

In the NPN transistor, electrons flow from the emitter to the collector, so the *collector must be positive* in relation to the emitter. In PNP transistors, holes flow from emitter to collector, so the *collector must be negative* in relation to the emitter.

The *middle letter* in PNP or NPN applies to the base. The *first two letters* in PNP or NPN refer to the *relative bias polarities of the emitter* with respect to either the base or collector. For example, the letters PN (in PNP) show that the emitter is positive with respect to either the base or collector. The letters NP (in NPN) show that the emitter is negative with respect to both the base and collector.

The *dc electron-current flow* is always against the direction of the arrow in the emitter. If electron flow is into the emitter, electron flow is out from the collector. If electron flow is out from the emitter, electron flow is into the collector.

The collector-base junction is always reverse biased. The emitter-base junction is generally forward biased.

A *base-input voltage that opposes* or decreases the forward bias also decreases the emitter and collector currents. For example, a negative input to the base of an NPN, or a positive input to a PNP base, decreases *both* currents.

A *base-input voltage that aids* or increases the forward bias also increases the emitter and collector currents (positive to NPN, negative to PNP).

1.4 COMMON-EMITTER AUDIO AMPLIFIERS

The common-emitter (CE) circuit shown in Fig. 1.1*a* is the most widely used audio-amplifier configuration. The emitter is common to both the input and output circuits and is frequently called the grounded element (although the emitter is not always connected to ground).

To summarize the CE amplifier, the input signal is applied between base and emitter, and the output signal appears between emitter and collector. This provides a moderately low input impedance and a very high output impedance, with a 180° phase reversal between input and output. The CE amplifier produces the highest power gain of all three transistor amplifier circuits. The voltage and current gains are fairly high. CE amplifiers are most often used in audio work since there are current, voltage, resistance, and power gains (which we just happen to discuss next).

1.4.1 Audio Gain

Many terms are used to express gain of CE amplifiers, as well as other amplifier configurations. The terms are interrelated and are often interchanged (properly and improperly). To minimize confusion, the following is a summary of audio gain terms used in this book.

Alpha and Beta. The terms alpha and beta are applied to transistors connected in common-base (CB) and CE configurations, respectively. Both terms are a measure of current gain for the transistor (but not necessarily for the circuit). Alpha is always less than 1 (typically 0.9 to 0.99). Beta is more than 1 and can be as high as several hundred (or more). The relationships between alpha and beta are: alpha = beta/(beta + 1); beta = alpha/(alpha − 1).

The terms alpha and beta do not necessarily represent the current gain of the audio circuit in which the transistors are used. Instead, the current gain of the circuit *cannot be greater* than the alpha or beta of the transistor.

Current Gain. The term current gain can be applied to either the transistor or to the audio circuit and is a measure of *change* in current at the output for a given change in current at the input.

For example, when a 1-mA change in input current produces a 10-mA change in output current, the current gain is 10. Since alpha (CB) is always less than 1, there is no current gain in CB audio circuits (Sec. 1.5). Instead, there is a slight loss.

Resistance Gain. The ratio of output resistance (or impedance) divided by input resistance (or impedance) is the resistance gain. For example, if the input resistance is 1000 and the output resistance is 15,000, the resistance gain is 15. The input and output resistances (or impedances) depend on circuit values, as well as transistor characteristics.

Resistance gain, by itself, produces no usable gain for the audio circuit. However, resistance gain has a direct effect on the voltage and power gains, such as with the previous values (current gain of 10 and resistance gain of 15).

Assume that the input resistance is 1000 and a 1-mV signal is applied at the input. This results in an input current change of 1 μA. With a current gain of 10, the output current is 10 μA. This 10-μA current passes through a 15,000 output resistance to produce a voltage change of 150 mV. As a result, the 1-mV input signal produces a 150-mV output signal (a voltage gain of 150).

Voltage and Power Gain. Voltage gain is equal to the difference in output voltage divided by the difference in input voltage. Power gain is equal to the difference in output power divided by the difference in input power. Except in CB circuits, power gain is always higher than voltage gain, since power is based on the square of the voltage (power = E^2/R), as well as the square of current (I^2/R). Using the same values, the input power of the stage is 1×10^{-9}, the output power is 1.5×10^{-6}, and the power gain is 1500.

Voltage and Power Amplifiers. The function of a *voltage amplifier* is to receive an input signal consisting of a small voltage of definite waveform and to produce an output signal consisting of a voltage with the same waveform but much larger in amplitude. For example, the output produced by the pickup of an audio turntable is usually in the order of a few millivolts. The voltage amplifier of an audio system amplifies this voltage to produce a similar voltage that is large enough to operate a *power amplifier* which, in turn, operates the power-consuming loudspeakers.

Transistors designed for voltage amplification usually have high betas, with small current-carrying capability. Power transistors have large current-carrying capacity but relatively low betas. If the power involved exceeds about 1 W, the transistor (or IC) must be operated with *heat sinks* (as discussed in Chap. 2).

1.5 COMMON-BASE AUDIO AMPLIFIERS

The common-base circuit shown in Fig. 1.1*b* is not used extensively in audio work. One exception is where the audio source is at a low impedance.

To summarize the CB audio circuit, the input signal is applied between base and emitter (across R_3), and the output appears between base and collector (across R_4). This provides an *extremely low* input impedance and a very high output impedance. The output signal is *in phase* with the input. The CB amplifier produces high voltage gains and modest power gains even though there is no current gain. This is possible because of the resistance gain, as discussed in Sec. 1.4.1.

1.6 COMMON-COLLECTOR AUDIO AMPLIFIERS

The common-collector (CC) circuit shown in Fig. 1.1*c* is also known as an *emitter follower* since the output is taken from the emitter resistance, and the output follows the input (in phase relationship).

To summarize the emitter follower, the input signal is applied to the base (across R_2), and the output signal appears at the emitter (across R_3). This provides extremely high input impedance and a very low output impedance (usually set by the value of R_3). The output signal is *in phase* with the input. The emitter follower produces modest current gain (as well as power gain) even though there is no voltage gain. In general, the emitter-follower current gain (and power gain) is limited by the current gain (beta) of the transistor. The most common use of an emitter follower in audio work is to match the high impedance of a solid-state circuit to a low-impedance device (such as when an audio amplifier must be matched to a loudspeaker).

1.7 AUDIO BIAS NETWORKS

All audio circuits require some form of bias. As a minimum, the collector-base junction of any circuit must be reverse biased. That is, current should not flow between collector and base. Any collector-base current that does flow is a result of leakage or breakdown.

Under no-signal conditions, the emitter-base circuit of a solid-state amplifier can be forward, reverse, or zero biased (no bias). However, emitter-base current must flow under some condition of operation. The desired bias is produced by applying voltages to the corresponding transistor elements through bias networks, usually composed of resistors. The bias networks (or the resistors used to form the networks) serve more than one purpose. Typically, the bias network resistors (1) set the operating point, (2) stabilize the circuit at the operating points, and (3) set the approximate input-output impedances of the circuit as follows:

Operating point: Bias networks establish collector-base-emitter voltage and current relationships at the operating point of the audio circuit. (The operating point is also known as the quiescent point, Q-point, no-signal point, idle point, or static point.) Since transistors rarely operate at the Q-point, the basic bias networks are generally used as a reference or starting point for design. The actual circuit values are generally selected on the basis of dynamic circuit conditions (desired output voltage swing, expected input signal level, and so on).

Audio bias stabilization: In addition to establishing the operating point of an audio circuit, the bias networks must maintain the operating point in the presence of temperature and power-supply changes and possible transistor replacement. As discussed in the following paragraphs, a shift in operating point can produce distortion and a change of frequence response (two very undesirable effects in any audio circuit). The process of maintaining an audio circuit at a given operating point is generally referred to as *bias stabilization*. Improper bias stabilization can also produce another undesired effect known as *thermal runaway*.

Thermal runaway: Heat is generated when current passes through a transistor junction. If all heat is not dissipated by the case or heat sink (often an impossibility), the junction temperature rises. This, in turn, causes more current to flow through the junction even though the voltage, circuit values, and so on remain the same. With more current, the junction temperature increases even further, with a corresponding increase in current flow. The transistor burns out if the heat is not dissipated by some means.

In addition to the heat sinks described in Chap. 2, many audio circuits are provided with bias stabilization to prevent any drastic change in junction current, despite changes in temperature, voltage, and so on. This bias stabilization maintains the circuit at the desired operating point (within practical limits) and prevents thermal runaway.

Input-output impedances: The resistors used in bias networks also have the function of setting the input and output impedances of the circuit. In theory, the input-output impedances are set by many factors (transistor beta, transistor input-output capacitance, and so on). In practical audio circuits, the input-output impedances are set by the bias network resistors. For example, the output impedance of a CB or CE audio circuit is about equal to the collector resistor (or total resistance between the collector and power source).

1.7.1 Basic Bias-Stabilization Techniques

All bias-stabilization circuits use a form of *negative* or *inverse feedback*. That is, any change in transistor current produces a corresponding voltage or current change that tends to *offset* the initial change. This feedback not only offsets the undesired change but also tends to reduce and stabilize gain (when the feedback principle is used in an audio amplifier).

Typical Emitter-Feedback Bias Network. Figure 1.1*d* shows a typical emitter-feedback bias network (this is the most common audio bias circuit). Note that this circuit is essentially the same as the basic CE amplifier shown in Fig. 1.1*a* but with an emitter resistor to provide bias stabilization. The use of an emitter-feedback resistance in any audio circuit can be summed up as follows.

Base current (and, consequently, collector current) depends on the *differential* in voltage between base and emitter. If the differential voltage is lowered, less base current (and, consequently, less collector current) flows. The opposite is true when the differential is increased. All current flowing through the collector (ignoring collector-base leakage, I_{CBO}) also flows through the emitter resistor.

The voltage across the emitter resistor therefore depends (in part) on the collector current.

Should the collector current increase (for any reason), emitter current and the voltage drop across the emitter resistor also increase. This negative feedback tends to decrease the differential between base and emitter, thus lowering the base current. In turn, the lower base current tends to decrease the collector current and offset the initial collector-current increase.

1.7.2 Typical Audio Bias Networks

Figures 1.2 and 1.3 show typical bias networks found in a variety of audio circuits. Note that the equations in Figs. 1.2 and 1.3 hold true throughout the audio range (and typically up to about 100 kHz). Also note that emitter feedback is used in all of the bias circuits. Examples of simplified, practical design for audio circuits using these basic networks are given in Chap. 3.

As shown by the equations in Figs. 1.2 and 1.3, the approximate input and output impedance of the circuit are set by resistance ratios, as are voltage and current gain. This fact can be helpful in testing and troubleshooting audio equipment.

For example, in the circuit in Fig. 1.2*a*, if the value of R_2 is 10 times that of R_3, the output signal (at the collector) should be about 10 times the input signal (at the base). Of course, if the transistor does not have enough gain (beta) or the power supply does not allow sufficient collector-voltage swing, the output can be limited. *However, the resistance ratio does provide a guideline for troubleshooting* (if you find no gain or gain far less than the collector-emitter resistance ratio, the circuit is suspect).

Maximum Gain with Minimum Stability. The circuit in Fig. 1.2*a* provides the greatest possible gain but the least stability of all the bias circuits described here.

Maximum Gain with Improved Stability. The basic characteristics for the bias circuit in Fig. 1.2*b* are the same as for the circuit in Fig. 1.2*a* except that stability is increased. The increase in bias stabilization is brought about by connecting base resistance R_1 to the collector rather than to the supply.

In the circuit in Fig. 1.2*b*, if the collector current increases for any reason, the drop across R_2 increases, lowering the voltage at the collector. This lowers the base voltage and current, thus reducing the collector current. The feedback effect is combined with that produced by emitter resistor R_3 to offset any variation in collector current. However, gain for the circuit in Fig. 1.2*b* is only slightly less than for the circuit in Fig. 1.2*a*.

Maximum Stability. The bias circuit in Fig. 1.2*c* offers more stability than the circuits in Fig. 1.2*a* and *b* but with a trade-off of lower audio gain and lower input impedance.

As shown by the characteristics in Fig. 1.2*c*, the input impedance is about equal to R_2 (at frequencies up to about 100 kHz). Technically, the input impedance is equal to R_2 in parallel with $R_4 \times$ (beta + 1). In practice, unless the beta is very low, the $R_4 \times$ (beta + 1) factor is much greater than R_2. As a result, the value of R_2 (or slightly less) can be considered as the stage or circuit input impedance.