transistor circuits

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contents

introduction

APPLICATION of the transistor to electronic circuitry is a striking example of technological progress. Eight years prior to this writing, very few knew how the transistor worked and some were openly skeptical of its future. Today, many people need transistor circuit information. They range all the way from the scientist and engineer to the casual experimenter.

This book is a collection of practical transistor circuits, each of which has been tested by the author in his own laboratory. These circuits are presented with the expectation that they will save many hours of design time. As building blocks with values already worked out, they may be employed singly or (in systems) in combination with each other or with other circuitry. Slight modifications of component values will allow the reader to obtain results different from those originally intended. A study of the chapter headings will show that an effort has been made to cover a wide range of interests.

The circuits in this book have been designed by many persons or are based upon their inventions. No claim is made or implied that they are of the author's invention. Transistorized circuits have become so numerous that already their use is becoming "customary." That is, a certain circuit becomes so useful and commonplace (even as with vacuum-tube circuits) that eventually the originator's name is dropped, although no less respected.

No space is devoted to theory, except in occasional instances where it appears necessary for a clear understanding of the circuit under discussion. For a general treatment of the subject of transistors, the reader is referred to the author's book *Transistors, Theory and Practice* from the same publisher.

Several of the circuits have been taken from articles which have appeared previously under the author's name in various magazines. These are listed as references at the end of each chapter so that the reader might explore the subject more extensively. For permission to use this material, the author is grateful to the editors of *Audiocraft, Electronics, Popular Electronics,* RADIO-ELECTRONICS Magazine, *Radio & Television News* and *Tele-Tech & Electronic Industries.*

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PRELIMINARY NOTES

1. All resistances are specified in ohms, all capacitances in microfarads, unless labeled otherwise.
2. All resistors are ½-watt rating, unless labeled otherwise.
3. P-n-p transistors are shown in most of the circuits. N-p-n transistors having the same characteristics may be substituted, provided the battery connections are reversed as well as the connections of dc meters, electrolytic capacitors and photocells.
4. Where a ground (chassis) connection is shown with dotted lines, a ground might improve the circuit stability but cannot always be guaranteed to do so. The reader therefore should test the circuit with and without the dotted-line grounds. Results vary with different layouts and workmanship.
5. Use the exact component values specified. When the circuit is to be modified to suit individual requirements, wire it first according to the book and verify its operation against the author's representations. Then, undertake the changes.

chapter 1

audio amplifiers

THE first widespread practical application of transistors was in audio amplifiers. The reason for this is easy to understand when it is remembered that the early transistor essentially was a low-frequency device. Its small size, low dc voltage and current requirements and high efficiency suit the transistor naturally to use in hearing aids, which are small-sized audio amplifiers.

Since the early developmental period, great progress has been made in the design and manufacture of transistors and allied circuit components and in amplifier circuit design. Numerous circuits have been offered to the engineer, technician and hobbyist.

Representative audio-amplifier circuits are described in this chapter.

Single-stage, R-C-coupled, common-base amplifier

Fig. 101 shows the circuit of a single-stage resistance–capacitance-coupled amplifier employing the common-base configuration. This circuit sometimes is called "grounded base."

This amplifier provides a voltage gain of 30 when operated into a high-impedance load. Power output is 1.8 milliwatts. Its input impedance is 130 ohms and output impedance 5,000 ohms. The maximum input signal voltage which may be applied before output-voltage peak clipping appears is 0.1 volt rms. The corresponding maximum output signal voltage is 3 volts rms. Fig. 102 shows the frequency response.

Two batteries are required in the common-base amplifier, B1 (1.5 volts) for the emitter bias and B2 (6 volts) for collector bias.

Battery B2 supplies approximately 0.8 milliampere dc and battery B1, 0.85 ma. The dpst switch (S1–S2) makes and breaks connections to both batteries simultaneously.

An alternative, single-battery circuit is shown in Fig. 103. Here, a voltage divider R3–R4 is operated with a single 7.5-volt battery. Current flowing through the divider develops the emitter voltage as a drop across R3 and collector voltage across R4. The bleeder current is 9.62 ma.

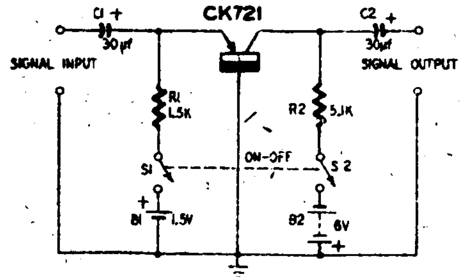

Fig. 101. *Single-stage, R-C-coupled, common-base amplifier.*

All resistors in Figs. 101 and 103 are ½ watt. Capacitors C1 and C2 may be miniature, low-voltage tantalum electrolytics if subminiaturization is desired.

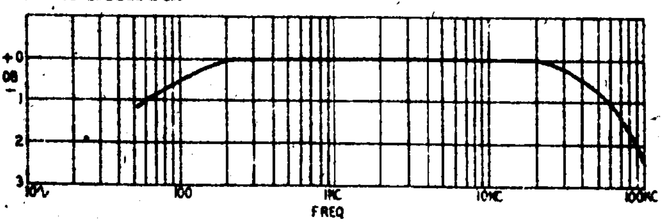

Fig. 102. *Frequency response of single stage, R-C-coupled, common-base amplifier.*

Single-stage, transformer-coupled, common-base amplifier

In any transistorized amplifier, the highest per-stage power gain is obtained only with transformer coupling between stages or between input and output.

Fig. 104 shows the circuit of a typical common-base, transformer-coupled, single-stage amplifier employing a General Electric 2N45 transistor. This amplifier has been designed for 50,000 ohms input impedance and 500 ohms output impedance. Power output is 2 milliwatts and power gain is 500 times, or 27 db. This means that an input-signal driving power of 4 microwatts will give full output.

Miniature transformers are employed for input (T1) and output

(T2) coupling. If these transformers are mounted close together, they must be oriented in such a way that their cores are at right angles to prevent feedback.

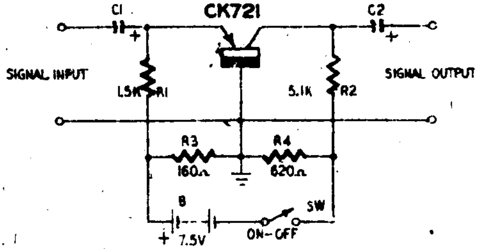

Fig. 103. *Alternative arrangement using single battery and voltage divider.*

Bypass capacitors C1 and C2 may be standard 25-volt electrolytics or miniature tantalum electrolytics. Variable resistor R is a 2,000-ohm miniature wirewound rheostat. Initially, this control is set for a dc collector current of 1 milliampere.

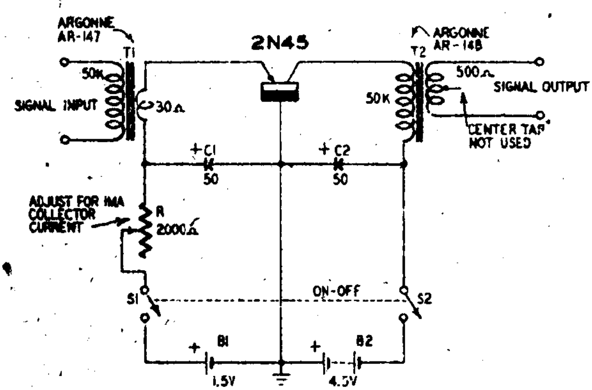

Fig. 104. *Single-stage, transformer-coupled, common-base amplifier.*

Single-stage, R-C-coupled, common-emitter amplifier

The common-emitter circuit, also called grounded-emitter, provides high voltage and high power gain and is adapted readily to single-battery operation.

Fig. 105 gives the circuit of a single-stage, R-C-coupled, common-emitter amplifier employing a Sylvania 2N34 transistor. Fig. 106 shows its frequency response. The input impedance, measured at 1,000 cycles, is 780 ohms; the output impedance 10,000 ohms. The voltage gain is 80 when the amplifier is operated into a high-impedance load. (Higher values of gain may be obtained with individual transistors.) Maximum input-signal voltage before output-voltage peak clipping is 20 millivolts rms.* Corresponding maximum output-signal voltage is 1.7 volts rms. Total current drain is 500 microamperes dc.

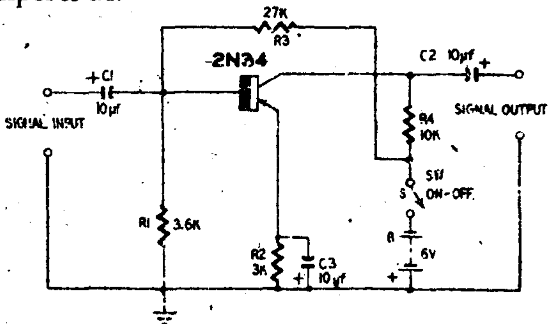

Fig. 105. *Single-stage, R-C-coupled, common-emitter amplifier.*

The transistor operating point is stabilized by the steady value of base bias voltage supplied by voltage divider R1–R3 and emitter resistor R2. The latter is bypassed by capacitor C3 to prevent degeneration.

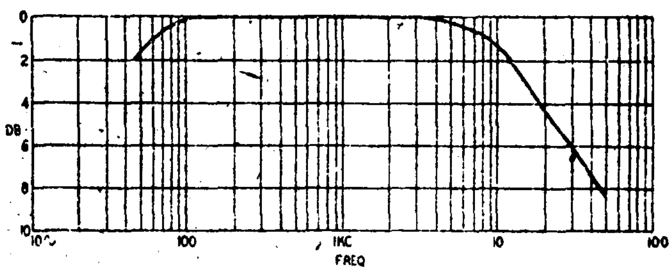

Fig. 106. ***Frequency response of circuit shown in Fig. 105.***

The electrolytic coupling capacitors C1 and C2 and bypass capacitor C3 may be standard-size 25-volt components or miniature, tantalum electrolytics.

Single-stage, transformer-coupled, common-emitter amplifier

Transformers are employed for input and output coupling in the common-emitter circuit shown in Fig. 107. This allows very nearly the full 39-db power gain of the transistor (Raytheon CK722) to be obtained.

Miniature transformers are used. While the 200-ohm secondary of T1 and the 15,000-ohm primary of T2 do not match the transistor input and output impedances exactly, the match is close enough for good power transfer. The secondary of T2 may be connected directly to the base-input circuit of a similar amplifier stage.

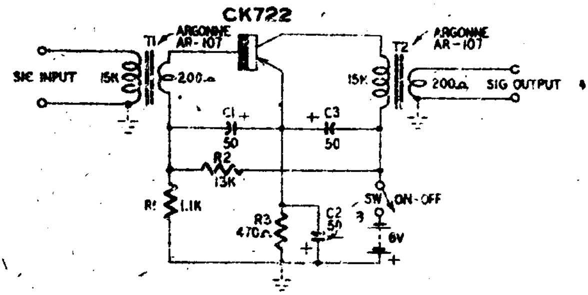

Fig. 107. *Single-stage, transformer-coupled, common-emitter amplifier.*

Dc base bias is supplied by the R1–R2 voltage divider. Further stabilization of the operating point is provided by emitter resistor R3 which is bypassed by C2 to prevent degeneration.

Single-stage, R-C-coupled, common-collector amplifier

The common-collector circuit (also known as the grounded collector) has the highest input impedance of the three transistor amplifier configurations. Its operation and characteristics resemble somewhat those of the vacuum-tube cathode follower and, for this reason, the common collector often is referred to as an "emitter follower."

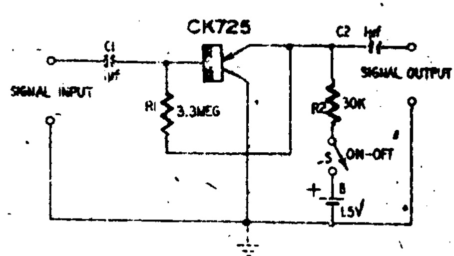

Fig. 108. *Single-stage, R-C-coupled, common-collector amplifier.*

Fig. 108 shows a single-stage, resistance–capacitance-coupled, common-collector amplifier employing a Raytheon CK725 transistor. At 1,000 cycles, the input impedance of this amplifier is 1 megohm. Output impedance is 30,000 ohms. The input impedance varies with the signal frequency, being 1.2 megohms at 20 cycles (Fig. 109-a) and 160,000 ohms at 50 kc.

The voltage gain of the amplifier is constant at 0.96 from 20 cycles to 10 kc (Fig. 109-b) and falls slowly to 0.88 at 50 kc. The maximum input-signal voltage before positive-peak clipping ap-

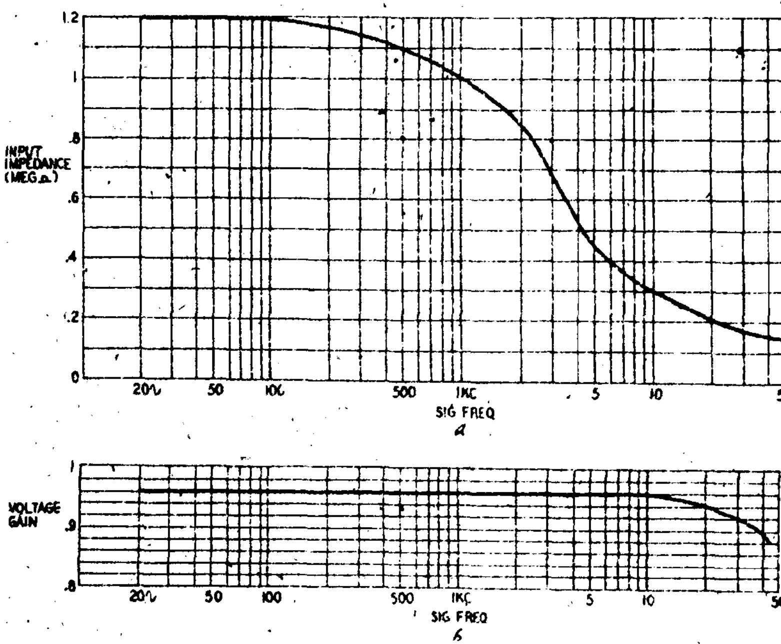

Fig. 109-a, -b. *Characteristics of common-collector amplifier: (a) input impedance variation; (b) frequency response.*

pears in the output signal is 0.52 volt rms. The corresponding maximum output-signal voltage is 0.499 volt rms when the external load is 300,000 ohms or higher. Power gain is 30.74, corresponding to 14.87 db.

Single-stage, transformer-coupled, common-collector amplifier

The common-collector amplifier is convenient for coupling into a low-impedance line. However, Z_i varies with the output impedance (Z_o), with the result that Z_i drops to approximately 20,000 ohms when $Z_o = 500$ ohms.

The most satisfactory operating conditions therefore are obtained when the common-collector output is transformer-coupled to the lower-impedance line. Fig. 110 shows a common-collector amplifier with transformer output. Here, the input impedance follows the curve given in Fig. 109-a and the output impedance is constant at 100 ohms.

The common-collector amplifier may be transformer-coupled to the base-input circuit of a common-emitter amplifier by employing a transformer having a 1,000-ohm secondary.

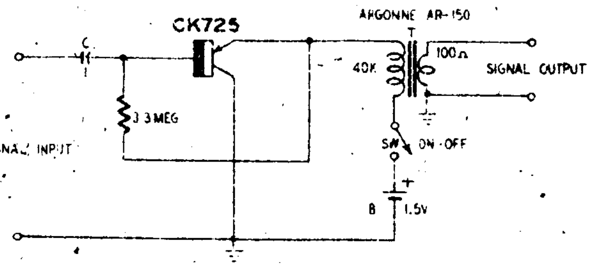

Fig. 110. *Single-stage, transformer-coupled, common-collector amplifier.*

Multistage R-C-coupled amplifier

Fig. 111 shows the circuit of a four-stage, resistance–capacitance-coupled amplifier employing Sylvania 2N34 transistors. Each stage utilizes the common-emitter circuit.

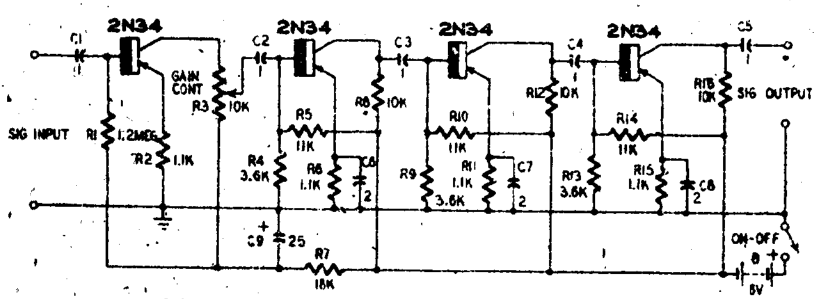

Fig. 111. *Multistage R-C-coupled amplifier.*

With the GAIN CONTROL set at maximum, this amplifier provides a voltage gain of 4,000. The maximum input-signal voltage before output-voltage peak clipping is 0.2 millivolt rms. The corresponding maximum output-signal voltage is 1.2 volts rms. At 1,000 cycles, the input impedance is approximately 1,000 ohms. The noise level was measured as 5 millivolts, with the input terminals of the amplifier short-circuited (72 db below maximum output voltage). Fig. 112 shows the frequency response.

Stabilizing bias is applied to the bases of the transistors by voltage-divider networks R4–R5, R9–R10 and R13–R14. To prevent degeneration, emitter resistors R6, R11 and R15 are bypassed by capacitors C6, C7 and C8. Emitter resistor R2 in the input stage is left unbypassed for a small amount of degeneration in this stage.

Capacitor C9 and resistor R7 form a decoupling network to suppress motorboating.

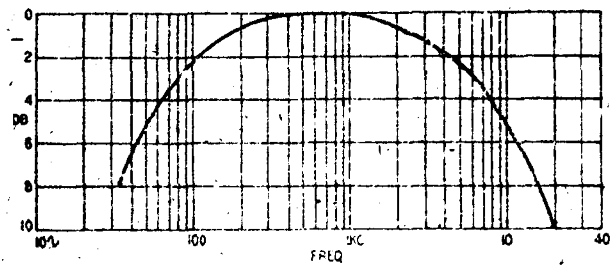

Fig. 112. *Frequency response of the circuit shown in Fig. 111.*

Total current drain is approximately 8 milliamperes dc from the 6-volt battery.

Multistage transformer-coupled amplifier

A three-stage transformer-coupled amplifier employing Raytheon CK722 transistors is shown in Fig. 113. This circuit provides an overall power gain of 80 db (with GAIN CONTROL R5 set to maximum) and a power output of 6 milliwatts. The input impedance is approximately 1,000 ohms and the output impedance 1,200 ohms.

The dc base bias is stabilized in each stage by means of voltage dividers R1–R2, R6–R7 and R9–R10. Emitter current-limiting resistors R3, R8 and R11 are bypassed adequately by C2, C5 and C7 to prevent degeneration. Capacitor C3 and resistor R4 form a decoupling network to suppress motorboating. The total current drain from the 3-volt battery is 7.3 milliamperes dc.

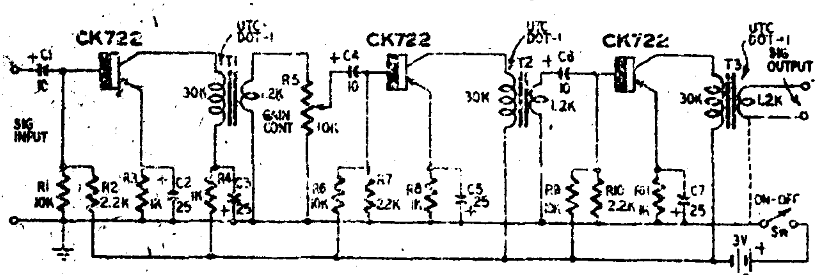

Fig. 113. *Three-stage transformer-coupled amplifier.*

In the construction of this amplifier, the miniature transformers T1, T2 and T3 must be mounted far enough apart that their magnetic fields do not interact. When a compact layout necessitates close spacing, the transformers must be oriented in such a way that their cores are at right angles.

Push-pull output circuits

As in vacuum-tube practice, push-pull output amplifier stages and drivers are employed when more signal power is desired than can be supplied by a single-ended transistor stage. Fig. 114 shows typical class-A and class-B push-pull output stages.

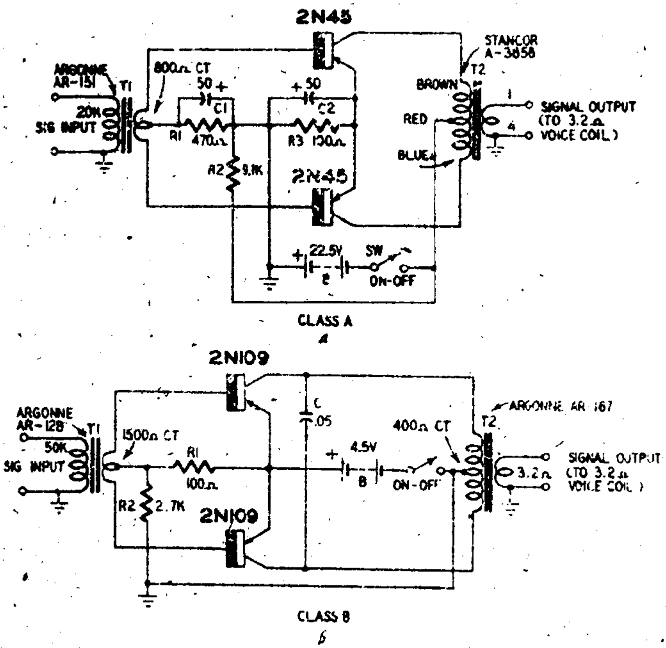

Fig. 114-a, -b. *Push-pull amplifiers: (a) class A; (b) class B.*

Class A

(Fig. 114-a). Here, two General Electric 2N45 transistors are employed. The input impedance is 20,000 ohms. (The 20,000-ohm primary of the input transformer T1 can act as the collector load of a single-ended transistor input stage.) The output impedance matches the 3.2-ohm voice coil of a loudspeaker. At 5% total harmonic distortion (measured at 1,000 cycles), the power output is 75 milliwatts and the overall power gain 30 db, or 1,000 times.

The total continuous current drain is 12 milliamperes dc from the 22.5-volt battery. The collector-circuit efficiency is 42%. Stabilizing dc bias is supplied to the bases of the transistors by the voltage divider R1–R2. The emitter current-limiting resistor R3 is bypassed by C2 to prevent degeneration.

Class B

As in tube practice, class-B transistor output amplifiers are preferred to class-A units because of their higher collector-circuit efficiency. In the class-A circuit (Fig. 114-a), a rather large collector current flows continuously, while in class-B circuits large values flow only on audio peaks and at other times the "resting" collector current is negligible.

Fig. 114-b shows a typical class-B circuit employing two RCA 2N109 transistors. The input impedance of this amplifier is 50,000 ohms and the output impedance 3.2 ohms to match the voice coil of a loudspeaker. At approximately 8% total harmonic distortion (measured at 1,000 cycles), the power output is 75 milliwatts and overall power gain is 30 db, or 1,000 times. The collector-circuit efficiency is 64%.

The zero-signal total collector current is approximately 4 ma dc, and the maximum-signal total collector current approximately 26 milliamperes. The base-bias voltage divider R1–R2 draws approximately 1.6 milliamperes.

Phase inverters

The interesting properties of transistors permit the design of ingenious phase inverter circuits. Fig. 115 shows two types.

Single-transistor type

(Fig. 115-a). This is a simple circuit employing one Raytheon CK721 transistor and is similar to the so-called "hot-cathode" phase inverter sometimes used with triode vacuum tubes. A portion of the output-signal voltage (OUTPUT 1) is developed across the collector load resistor R4 and a second portion (OUTPUT 2) across the emitter resistor R3. Due to phase shift, which is inherent in the common-emitter circuit, OUTPUT 1 is out of phase with the input-signal voltage while OUTPUT 2 is in phase with the input. The two output-signal voltages accordingly are out of phase with each other.

A 20-millivolt rms input-signal voltage will give output voltages of approximately 0.8 volt when the phase inverter feeds into high-impedance loads. Actually, these two output voltages are not exactly equal because the circuit is not perfectly balanced. However, they may be made very nearly equal by adjustment of R3 either above or below the specified 4,700-ohm value, as required.

Complementary-symmetry type

The circuit shown in Fig. 115-b makes use of the principle of com-