The AEROVOX Research Worker

The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 26, NO. 7 and 8 JULY - AUGUST, 1956 Subscription By Application Only

TUBELESS AMPLIFIERS

By the Engineering Department, Aerovox Corporation

THE mention of the term *tubeless amplifiers* brings the immediate question "Why is there interest in amplifiers which do not employ tubes?" When vacuum tubes were both costly and fragile 35 years ago, there was a constant but fruitless search for other amplifying devices. But the quest was abandoned when tube prices became more reasonable and the product more dependable. Interest in this direction has been revived in recent years because the tube often has proven to be the important unreliable link in complex electronic systems.

The non-tube amplifiers give promise of greatly increased reliability, especially since some of these devices have unlimited life. Neither type uses a filament or heater, and thus makes more efficient use of the local power and has simpler power supply demands.

A number of tubeless amplifiers have come forward during the past ten years. Principal among these are the transistor, magnetic, and dielectric amplifiers. When contrasting these devices, it is impossible to find a more suitable basis of comparison than the type of power supply employed. The transistor, for example, like the tube, employs a d-c power supply. The magnetic amplifier and dielectric amplifier, on the other hand, employ a-c (often high-frequency) power supplies. Comparisons which use the tube circuit as a standard often tend to discredit from the start all devices requiring a-c power supplies, even before other characteristics are considered.

It is interesting to examine the operating principles and characteristics of tubeless amplifiers. This article surveys these characteristics and is intended to provide the reader with an over-all view of the present art. This basic information will permit a more discerning examination of the improvements constantly being made in this class of device.

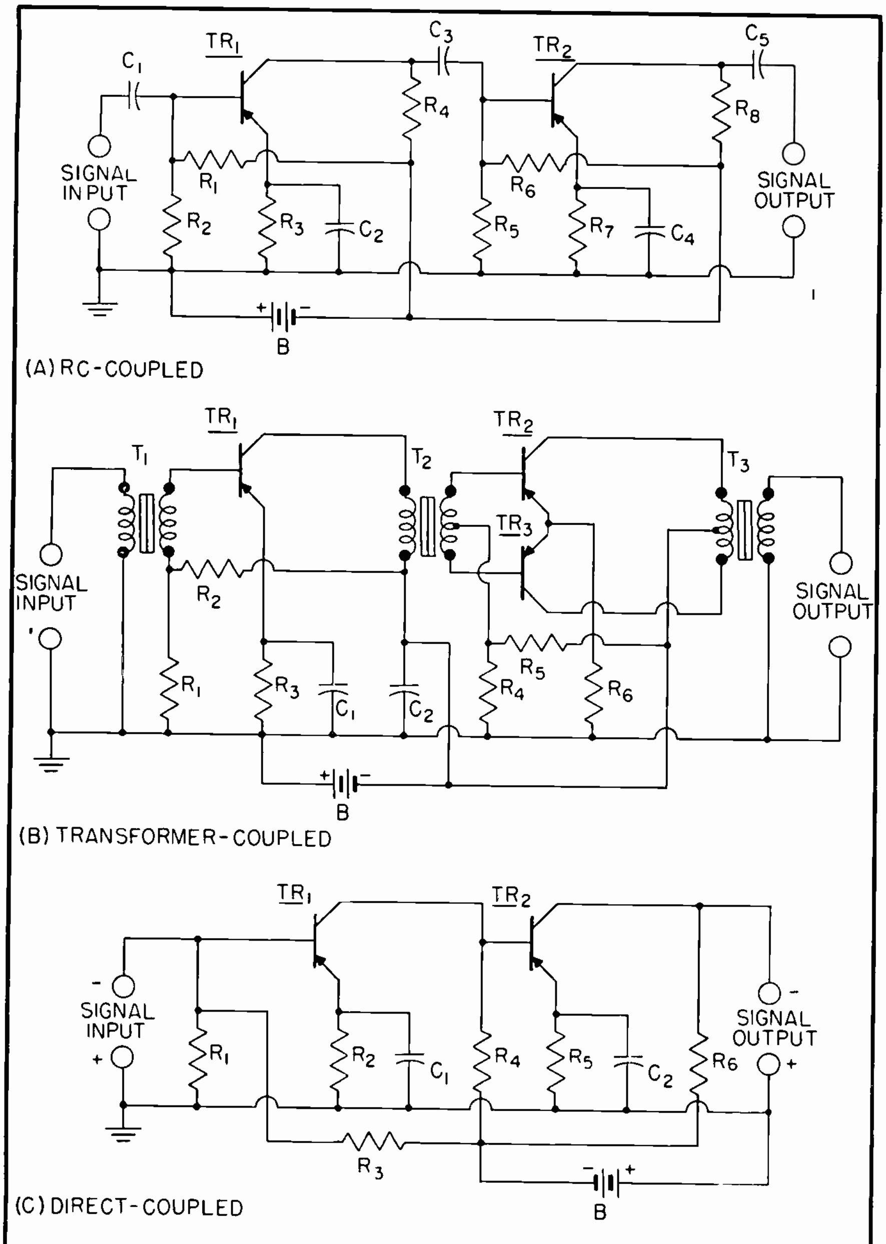
TRANSISTOR AMPLIFIER

The transistor depends for its operation upon the control of electron flow in a solid material (semiconductor) instead of in a vacuum. Transistors in widest present use are triodes, although some tetrodes have been developed and a few are available commercially.

In a triode transistor, the *emitter* electrode functionally resembles the cathode of a tube, the *base* the grid, and the *collector* the plate. A d-c supply places the proper bias on the electrodes. The transistor is a current-operated device.

Depending upon the manner in which the transistor is connected into the circuit, the signal output current may be higher or lower than the signal-input current. However, since the output resistance normally is higher than the input resistance,

Printed monthly by Aerovox Corporation, New Bedford, Mass., U. S. A.



TRANSISTOR AMPLIFIERS

FIGURE 1

both voltage and power gain are provided even when the current gain is 1 or less.

Figure 1 shows representative transistor amplifier circuits of the *common-emitter* type (also called "ground emitter"). Figure 1 (A) is the conventional resistance-capacitance-coupled type. The collector load resistors (R$_4$ and R$_8$) correspond to the plate load resistors in a tube amplifier. Emitter resistors R$_3$ and R$_7$ are similar to the cathode resistors in a tube circuit and are by-passed (C$_2$ and C$_4$) for the same reason — to prevent degeneration. The single d-c supply, B, provides negative voltage for the collectors and negative voltage, through divider networks R$_1$-R$_2$ and R$_5$-R$_6$, for the bases of transistors TR$_1$ and TR$_2$.

Figure 1 (B) shows a transformer-coupled amplifier. Higher gain is obtained when transformers are used between transistor stages, since they provide a close match between the high-impedance collectors and low-impedance bases. This permits maximum power transfer, impossible in the cascaded RC-coupled circuit of Figure 1 (A).

As in vacuum-tube practice, transistors may be direct-coupled. (See Figure 1C). This allows the amplification of direct-current signals, as well as extending the frequency range of a-c signal amplification down to a cycle or less per second. The direct-coupled amplifier provides somewhat less over-all gain than the RC-coupled—and transformer-coupled circuits.

At this writing, the following characteristics are representative of transistor amplifiers:

Frequency Range. Zero to 600 Mc. (including special high-frequency types).

Efficiency. 30 to 40 percent Class-A, 50 to 70 percent Class-B.

Power Output. Up to 40 watts. (60 watts and higher have been reported in experimental, laboratory models).

Power Gain. 40 db per single-ended stage.

Size. Subminiature in conventional types. Small in high-power types.

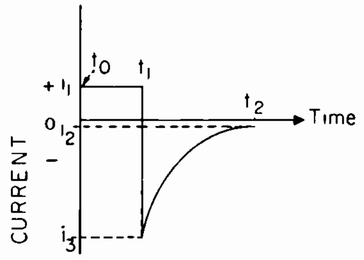
The reader's attention is directed to References 2, 4, 5, and 6 for additional detailed treatment of special phases of transistor application.

MAGNETIC AMPLIFIER

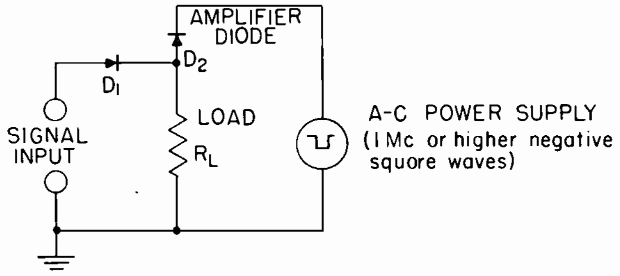
The magnetic amplifier offers the advantages of simplicity, ruggedness, compactness, foolproof circuitry, unlimited life, and components not easily burned out in normal use. The magnetic amplifier requires an a-c power supply.

Figure 2(A) shows a basic magnetic circuit. In this arrangement, coils L$_1$, L$_2$, and L$_3$ are wound on a three-legged core made of a special alloy having a rectangular hysteresis loop. Coils L$_1$ and L$_3$ are connected in series with each other and with the a-c power supply and load. The impedance of this combined winding therefore is in series with the power supply and load and determines the load current and voltage drop.

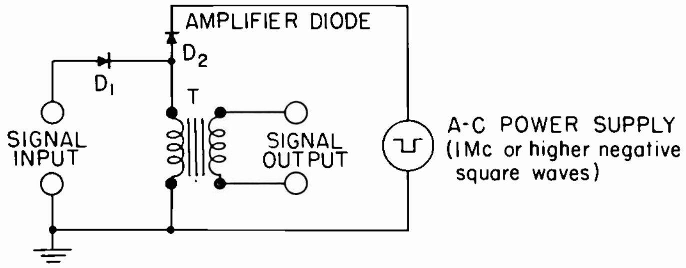
Direct current flowing through the control winding, L$_2$, produces vary-



(A) DIODE REVERSE TRANSIENT CHARACTERISTIC



(B) RESISTANCE-COUPLED AMPLIFIER



(C) TRANSFORMER-COUPLED

DIODE AMPLIFIER

FIGURE 4

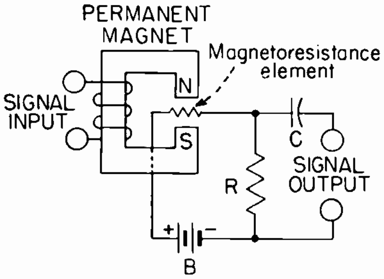
load resistor. By providing a step-down turns ratio in this transformer, a current gain is realized from operation of the amplifier.

Like the magnetic and dielectric amplifiers, the diode amplifier requires an a-c power supply. Power gains up to 10 per stage have been reported for diode amplifiers.

GALVANOMAGNETIC TYPE. This amplifier exploits the phenomenon of *magnetoresistance*, the ability of certain metallic combinations to change their resistance in response to a varying magnetic field.

Figure 5 shows the circuit of a simple amplifier employing this principle. A magnetoresistive element, made of a material such as indium antimonide, is supported between the pole pieces of a permanent magnet around which is wound a field coil, L, carrying an alternating input-signal current. The signal causes fluctuations in the magnetic flux which, in turn, cause corresponding fluctuations in the resistance of the magnetoresistive element. A fluctuating current accordingly flows from battery B and through resistor R. The resulting fluctuating voltage drop is coupled to the output terminals through capacitor C.

Since only a small input signal is required to vary a high current through R, considerable amplification is afforded by this circuit. 30 to 40 db gain has been reported at room temperature and 60 db at the temperature of liquid nitrogen. (See References 7, 8, and 9).

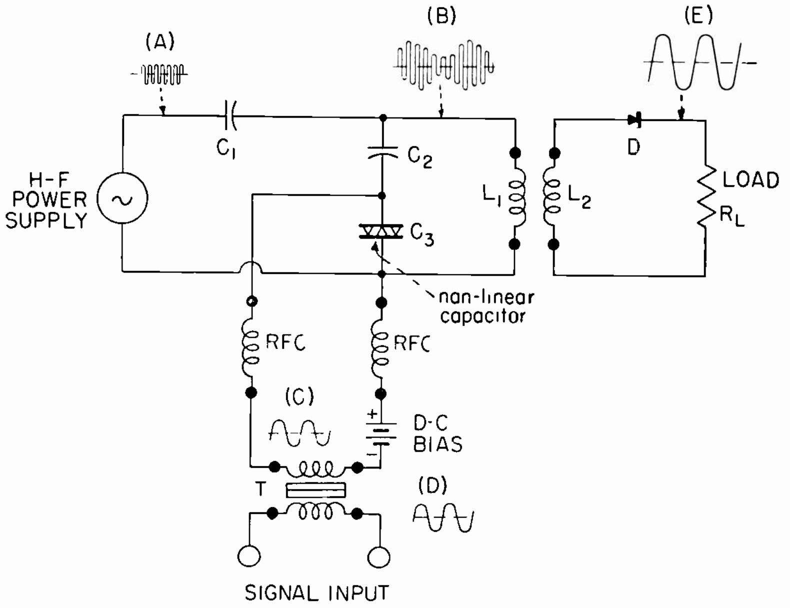


GALVANOMAGNETIC AMPLIFIER

FIGURE 5

REFERENCES

1. *The Dielectric Amplifier* AEROVOX RESEARCH WORKER, August 1952.
2. *Recent Developments in Transistors.* AEROVOX RESEARCH WORKER, October-November 1952.
3. *The Magnetic Amplifier.* AEROVOX RESEARCH WORKER, February 1952.
4. *Junction Transistor Circuits.* AEROVOX RESEARCH WORKER, April-May 1953.
5. *Class-B Transistor Amplifier Data.* AEROVOX RESEARCH WORKER, January 1955.
6. *Sensitive Transistorized Field Strength Meter.* AEROVOX RESEARCH WORKER, July 1955 (Part 1), August 1955 (Part 2).
7. *Magnetoresistance — New Tool for Electrical Control.* R. K. Willardson and A. C. Beer. ELECTRICAL MANUFACTURING, January 1956. p. 79.
8. *Der galvanomagnetische Verstarker.* ARCHIV DER ELEKTRISCHEN UBERS TRAGUNG. 8, 269. (1954).
9. *Applications of Indium Antimonide.* I. M. Ross and E. W. Saker. JOURNAL OF ELECTRONICS (London), September 1955. p. 223.



DIELECTRIC AMPLIFIER

FIGURE 3

The input signal (waveforms C and D) varies the capacitance of C_3, detuning the L_1-C_2-C_3 circuit in sympathy with the input frequency. If C_2 is adjusted to place the response of the tuned circuit along its steep slope, the resulting voltage changes will be large and the amplitude-modulated signal waveform will have high peaks. (See waveform B). This accounts for the amplification afforded by the circuit. The waveform shown at B, however, contains a high-frequency carrier component (A), as well as the modulation envelope which is an amplified replica of the input signal. The latter is recovered by passing the modulated signal through diode D, the result being the amplified wave, E.

Dielectric amplifiers have been employed at signal frequencies up to 2 to 3 megacycles. They provide high voltage gain and high power gain per stage. Power gains up to 10,000 per stage have been reported. Small units have been used to obtain audio-frequency power outputs of 300 milliwatts.

Unlike the magnetic amplifier, the dielectric amplifier has high input impedance. Like the magnetic amplifier, it requires a power supply frequency at least 10 times higher than the highest signal frequency which is to be amplified. Its principal shortcoming is the pronounced temperature-sensitivity of the nonlinear dielectric material it employs.

MISCELLANEOUS TUBELESS AMPLIFIERS

Additional tubeless amplifiers which are not as well known nor as well-developed as the three types described in the foregoing Sections include the *diode type* and *galvanomagnetic type*. These are described separately in the following paragraphs.

DIODE TYPE. This amplifier utilizes the reverse transient ("recovery time") effect found in germanium and silicon *junction* diodes. Figure 4(A) illustrates this transient characteristic which is explained in the following manner: If the diode is conducting forward current resulting from the application of a positive voltage from time t_0 to t_1, and is switched suddenly to a high negative anode voltage by the application of a negative square wave, the reverse current quickly reaches a high peak value (i_3) and then recovers somewhat slowly to the value (i_2) which is normal for the particular value of applied negative voltage.

The reason for this sudden high conduction is that the carriers (holes or electrons) injected into the semiconductor by the positive-current flow are still present during the switching and they enhance the current flow. High current accordingly flows until the negative voltage has had time to sweep these carriers away. Unless the switching interval is of short duration (1 microsecond or less), the carriers will recombine (holes with electrons, and vice versa, within the semiconductor) and the high-current pulse will not be obtained. If there has been no recent flow of positive current through the diode, no transient current pulse will occur, normal, low current flowing upon application of the negative switching voltage. In a diode operating in this manner, the anode acts first as an emitter and then as a collector, simulating the action of a transistor.

The transient current is proportional to the positive current and is many times larger. The transient diode exhibits amplification, since a small positive input signal applied to the diode in series with a negative, square-wave, switching voltage (power supply) will give a higher output signal.

Figure 4(B) shows the circuit of a simple diode amplifier. The power supply delivers 1-Mc negative square waves to the amplifier diode (D_2) with anode negative. The positive half-cycles of the signal-input voltage are supplied by D_1 which is a high-back-resistance diode having virtually no reverse transient (such as a point-contact diode). As long as there is no input signal, no voltage appears across load resistor R_L, except perhaps a small spike due to the flow of power-supply current through the capacitance of D_2, because no carriers are injected into the amplifier diode. Application of the signal, however, injects carriers into D_2, and each succeeding power supply pulse forces a large current momentarily through R_L and produces a high voltage drop across this resistor.

In Figure 4(C), an output transformer has been substituted for the ing degrees of saturation in the core, depending upon the direct current level. This saturation lowers the impedance of the L_1-L_2 combination and allows more ac to flow through the load. The voltage drop across R_L thus is proportional to the applied d-c voltage. When d-c output is desired, a semiconductor rectifier may be connected in series with R_L, as shown by the dotted-line symbol. Because a small d-c input produces a large change in output, amplification takes place.

Frequently, in place of d-c, an a-c input signal is employed. However, the power supply frequency must be several times higher than that of any a-c signal which is to be amplified (usually not less than 10 times the signal frequency). This requirement has limited most large, practical magnetic amplifiers to the handling of dc and low frequencies. However, audio-frequency magnetic amplifiers have been constructed to operate from 100-kc power supplies, and special experimental amplifiers with small, thin cores of high-efficiency alloys have been operated at power supply frequencies up to 10 megacycles.

Figure 2(B) shows how a fourth core leg and winding may be added for feedback. Both positive and negative feedback have been employed in magnetic amplifiers. The feedback polarity depends upon the sense of winding L_3. The regeneration provided by positive feedback increases the sensitivity, while the degeneration provided by negative feedback improves the signal waveform. The circuit of Figure 2(B) is shown arranged for d-c input and output. However, it may be adapted for a-c signal amplification by omitting the output rectifier and feeding back a portion of the a-c output to L_3 in the proper phase for regeneration or degeneration, as desired.

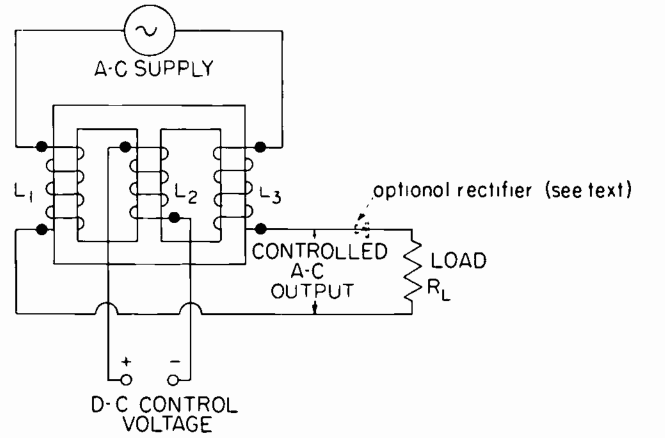
Like transistors, magnetic amplifiers have low input impedance. They have excellent power-handling ability, having been employed at levels up to many hundred kilowatts. They have replaced tubes in some voltage-regulated d-c power supplies. Their response speed is somewhat slow when compared with that of amplifiers of other types, chiefly because of the magnetization characteristics of the core material and the limitations imposed by the low power-supply frequencies. (See Reference 3).

DIELECTRIC AMPLIFIER

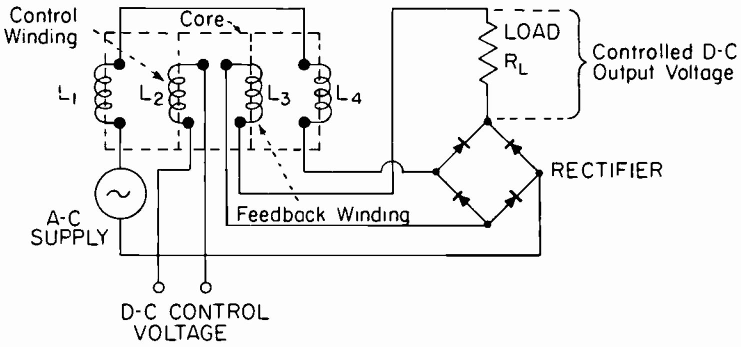
The dielectric amplifier may be thought of as the capacitive counterpart of the magnetic amplifier. Employing an a-c power supply and operating in a similar fashion, the dielectric amplifier utilizes a change in capacitive reactance, in contrast to the magnetic amplifier which uses a change in inductive reactance to obtain control of output current and voltage.

The heart of the dielectric amplifier is a capacitor containing a voltage-sensitive dielectric. The latter is a material, such as barium titanate, the dielectric "constant" of which decreases with applied voltage. When such a capacitor is connected in series with an a-c power supply and load, it may be used to control the current flow through the load as its reactance is changed by a biasing control-signal voltage.

Figure 3 shows one type of dielectric amplifier circuit. Here, the a-c power supply is a high-frequency type. (In practical circuits, the frequency is a 1 megacycle or higher). The non-linear capacitor, C_3 (i. e., the capacitor with voltage-sensitive dielectric) is connected in series with a conventional capacitor, C_2, across inductor L_1. This series-capacitance combination forms a tuned circuit with L_1 resonant at the power supply frequency. The d-c source biases the voltage-sensitive dielectric to the steep portion of its capacitance-vs-voltage curve. The input signal is applied in series with this d-c voltage. C_1 is a dc-blocking capacitor.



(A) BASIC AMPLIFIER



(B) FEEDBACK TYPE

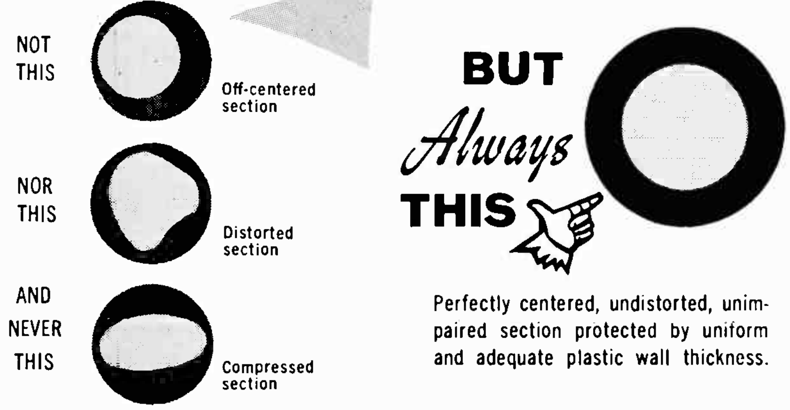
MAGNETIC AMPLIFIERS

FIGURE 2

Here's why

tubular capacitors give you better performance and longer life!

All Aerovox P88N molded tubular capacitors are manufactured by a unique low-pressure, low-temperature molding process that insures perfectly centered sections with uniform wall thickness on every single unit. Only Aerovox gives you round, uniform, undistorted, coaxially-centered sections solidly imbedded in the *right* plastic for superb mechanical, electrical and climatic characteristics.



Perfectly centered, undistorted, unimpaired section protected by uniform and adequate plastic wall thickness.

That's the inside story why Aerovox Duranite capactiors are recognized for their **top performance** and **utmost reliability** and **extra-generous** service life. Your local Aerovox Distributor carries a complete stock of Aerovox capacitors to meet **ALL** your service needs. Drop in soon and ask for a copy of the latest Aerovox catalog or write

AEROVOX CORPORATION

DISTRIBUTOR SALES DIVISION
NEW BEDFORD, MASS.

In Canada: AEROVOX CANADA, LTD., Hamilton, Ont.
Export: Ad. Auriema., 89 Broad St., New York, N. Y. • Cable: Auriema, N. Y.