The Aerovox Research Worker

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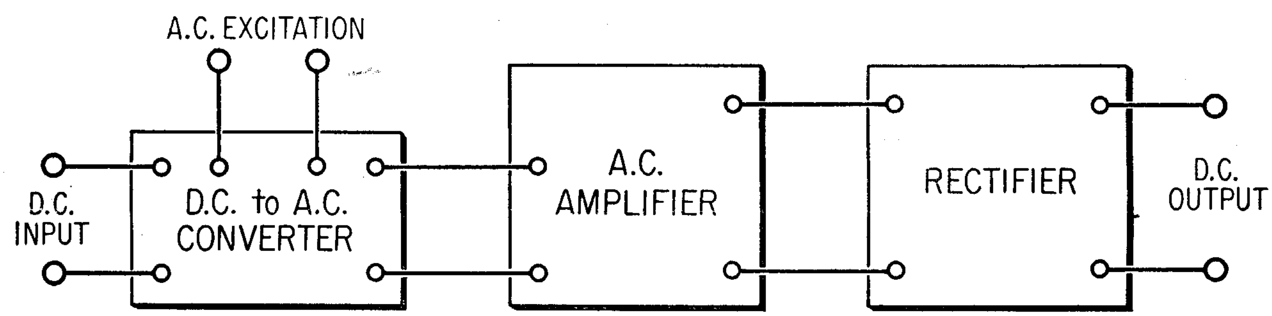
Conversion-Type D.C. Amplifiers

By the Engineering Department, Aerovox Corporation

IN an effort to escape the instability and drift of conventional, direct-coupled d. c. amplifiers, various conversion-type amplifier circuits have been developed.

In these arrangements, illustrated by the block diagram of Figure 1, the d. c. to be amplified is applied first to a d. c. — a. c. converter. An a. c. excitation voltage also is applied to the converter. The converter output is an a. c. having the same frequency as that of the excitation voltage but with an amplitude which is proportional to that of the applied d. c.

This output signal from the converter then is applied to a conventional a. c. amplifier which can be made quite stable by conventional techniques. Both voltage gain and power gain may be provided by this amplifier. The voltage gain is chosen to give the desired signal set-up ratio, and the output power is selected for efficient driving of the output device. Rectification of the amplifier output recovers the d. c. Thus, the d. c. input signal effectively is amplified by a system which partakes



BASIC ARRANGEMENT OF CONVERTER-TYPE D.C. AMPLIFIER
FIG. 1

CORRECTION: Despite careful fact-findings, writing and editing, two errors crept into the December 1954 *issue, entitled "Elementary Binary Arithmetc". In the table on page two, column three,* $+ 0 \times 2^{-1} = 0$ *making the correct total* 100101.01 = 37.25. *In the table on page three, column two,* $+ 1 \times 2^{-2} = 0.25$ *making the correct total* 10.01 = 2.25.

Additional references on Binary Arithmetic are as follows: High Speed Computing Devices — by the Engineering Staff of Engineering Research Associates, (McGraw-Hill, N. Y.); Calculating Instruments and Machines — by D. R. Hartree (University of Illinois Press); Number, the Language of Science — by Tobias Dantzig (McMillan, N. Y.); Introduction to the Foundations of Mathematics — by Raymond L. Wilder (Wiley, N. Y.); and New Numbers — by F. Emerson Andrews (Essential Books, N. Y.).

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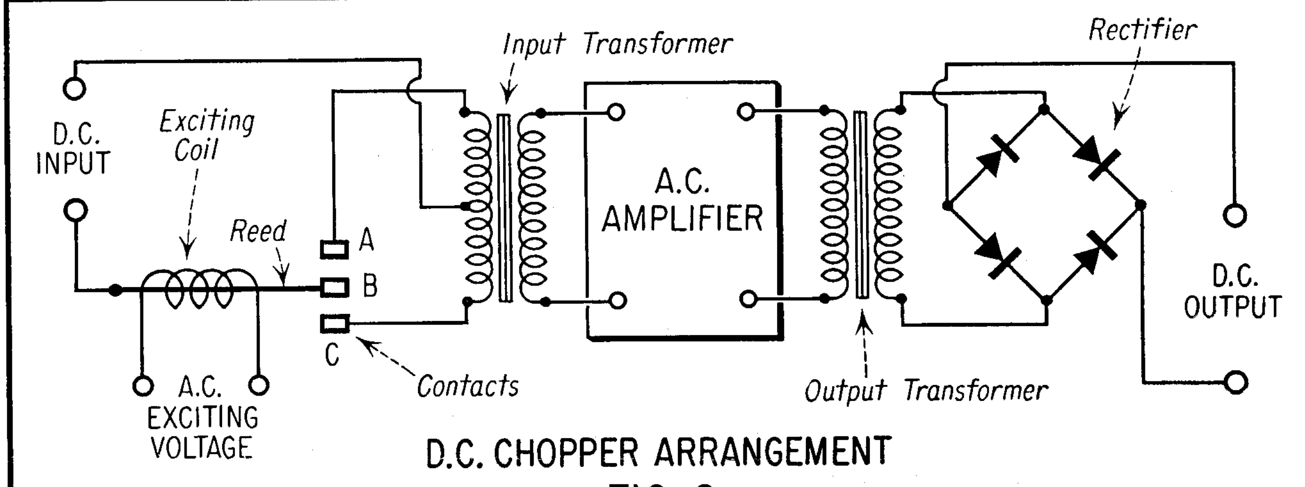


D.C. CHOPPER ARRANGEMENT
FIG. 2

of the high stability of the a. c. amplifier.

Conversion-type d. c. amplifiers presently are in use in science and industry to amplify the tiny d. c. output of such devices as strain gages, thermocouples, self-generating photocells, accelerometers, Ph meters, and moistures sensers. These amplifiers may be employed to actuate either recording or indicating instruments or electromechanical control devices.

Details of Operation

Various types of d. c. - a. c. converters are employed in conjunction with conventional a. c. amplifiers. The representative ones are described in this article.

The a. c. excitation voltage may be derived from the tube-filament circuit of the amplifier section or may be supplied from a separate source. The excitation frequency sets the minimum transient response time of the system. For this reason, the filament-source frequency often is too low to be useful, and excitation must be obtained from some higher-frequency source. Response time also depends upon the time constants of the various coupling networks within the system.

The amplifier section may utilize a standard audio circuit (either RC- or transformer-coupled) for use at excitation frequencies between 20 and 20,000 cycles, but must be a radio-frequency amplifier when extremely rapid d. c. fluctuations must be accommodated and the excitation frequency accordingly must be extended into the kilocycle or megacycle region. The amplifier design is simplified, however, by the fact that this unit is essentially single-frequency in operation.

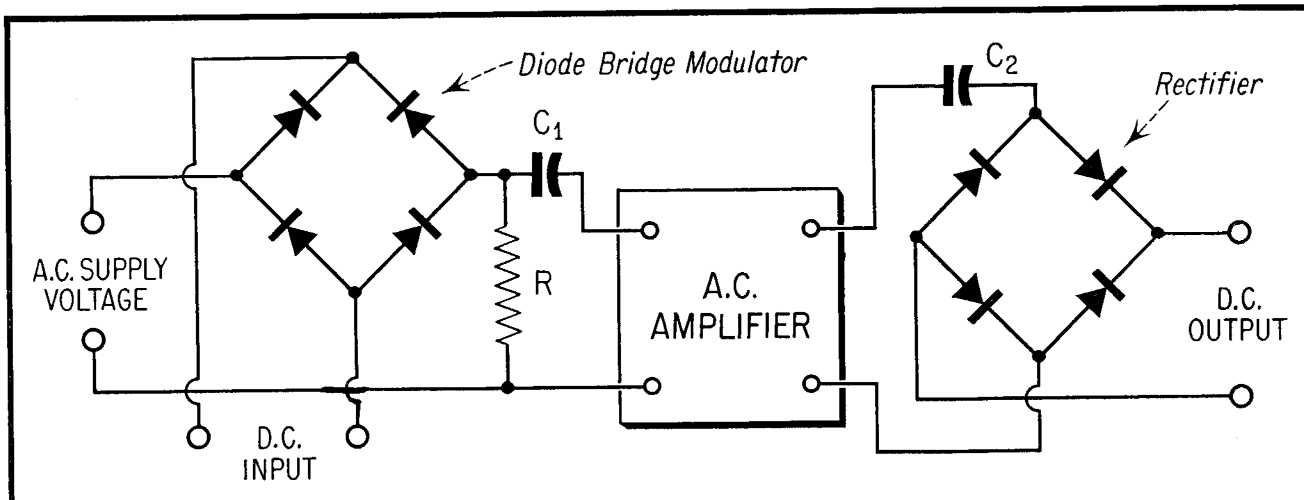
After a. c. amplification, the signal is rectified. The rectified section may take any one of the several conventional forms — from simple half-wave to voltage multiplication. Also, the rectifier may be transformer-coupled or capacitance-coupled to the amplifier output. Figures 2 to 7 show full-wave bridge rectifiers for illustration. When non-pulsating d. c. output is desired, the rectifier output may be filtered with either RC or LC networks.

Configurations of Systems

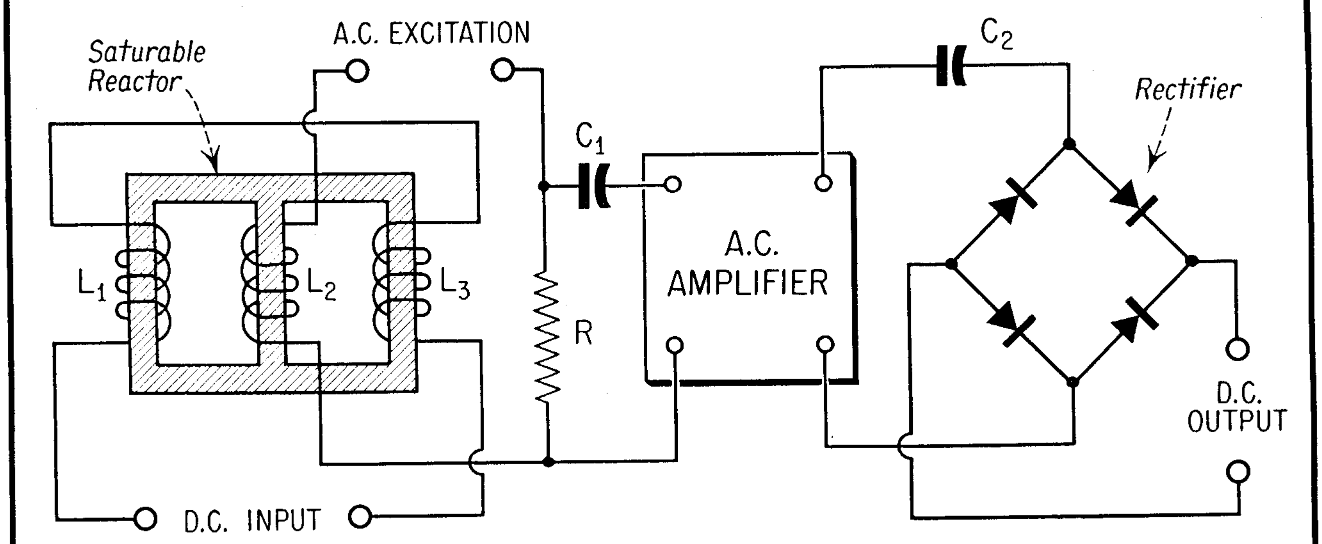
Figures 2 to 7 show various arrangements for conversion-type amplifiers. These will be described separately.

D. C. Chopper Converter. Figure 2 shows the arrangement which perhaps is in widest use at the time of this writing.

The converter is a "full-wave" vi-



DIODE-BRIDGE MODULATOR AS CONVERTER
FIG. 3



3-LEGGED SATURABLE REACTOR AS CONVERTER

FIG. 4

brator which chops the applied d. c. into pulses of current which flow through the primary winding of the input transformer. The resulting a. c. voltage developed across the secondary of this transformer is applied to the input of the a. c. amplifier.

Basically, the chopper unit consists of a thin iron or steel reed securely fastened at one end and provided with a contact (B) on its free-swinging end. A coil, usually containing many turns of fine wire, surrounds a portion of the reed, but does not touch it, and is supplied with alternating current from an excitation source. The alternating magnetic field due to this excitation current sets the reed into vibration, causing contact B to swing alternately between contacts A and C. This action switches the direct current alternately through the upper and lower halves of the input-transformer primary.

This is a rudimentary type of chopper, as shown here, and serves only to illustrate the principle. Many refinements are incorporated into commercial chopper-type converters to insure stability and long operating life. Some converters are driven from a second d. c. source, instead of being excited with a. c., in such a way as to cause self-vibration often at rates such as 400, 800, and 1000 cycles.

The chopper-type converter has the disadvantage that it contains moving parts and make-and-break contacts. These factors sometimes act to limit its life; and, in some instances, make necessary special provisions for mechanical noise silencing, spark suppression, and vibration damping. Its advantages are comparatively small size, simplicity, and the complete absence of an output signal unless a d. c. is applied.

Diode-Bridge Modulator. The semiconductor diode-bridge modulator, normally used with two a. c. signals, can be employed as a d. c. — a. c. converter by substituting the d. c. input for one of the a. c. signals. The a. c. excitation voltage may be derived from the filament circuit of the a. c. amplifier with which the converter is used, or from a separate source.

This simple device (See Figure 3) delivers an a. c. output which has the same frequency as the excitation source and an amplitude proportional to that of the d. c. signal. The a. c. output voltage may be developed across a resistor, R, as in Figure 3, and coupled through a capacitor, C, into the a. c. amplifier. Or, for isolation, a coupling transformer may be used between the diode bridge and the amplifier input.

The bridge modulator may be regarded as a type of electronic switch in which the a. c. excitation current cycles turn the applied d. c. on and off. This action is accomplished through the polarity-sensitivity of the diodes, each pair of which conducts on alternate half-cycles of excitation. On one half-cycle, the effect is to open the path between the d. c. input and the a. c. amplifier; on the other half-cycle, the path is closed. Thus, the on-off action.

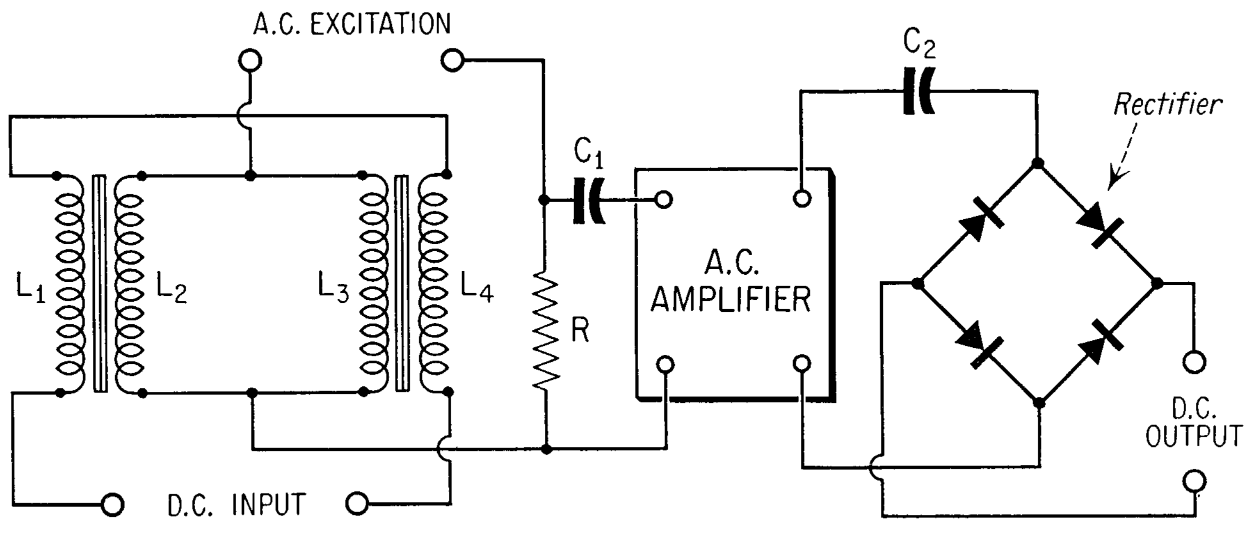
This type of converter can be made with diodes of either copper oxide, germanium, silicon, or selenium types. The germanium and silicon units have the advantage of providing operation up to high radio frequencies, while the upper operating limit of copper oxide is 5 to 10 kc. and that of small selenium diodes about 50 kc.

All four diodes in the modulator bridge must be closely matched. Single 4-diode assemblies (known by various manufacturers as *quads* or *varistors*) are available with matched EI characteristics in germanium and silicon.

The modulator-bridge type of converter has the advantages of very small size, light weight, long life, high-frequency capability, and simplicity. Its disadvantages are temperature sensitivity, and non-linearity at low current levels. The latter feature often necessitates special calibration of the entire amplifier system using this converter.

3-Legged Saturable Reactor. The magnetic-type converter illustrated in Figure 4 is one of a class of magnetic amplifier devices. Operation of this d. c. — a. c. converter is based upon core saturability.

The input d. c. flowing through one coil of a controllable reactor causes core saturation in varying degrees proportional to the current strength. This saturation changes the inductance, and thereby the impedance, of halves to buck. Thus, any a. c. voltage induced in I_1 by alternating current flowing in the a. c. winding (L_2)



2-TRANSFORMER SATURABLE REACTOR AS CONVERTER

FIG. 5

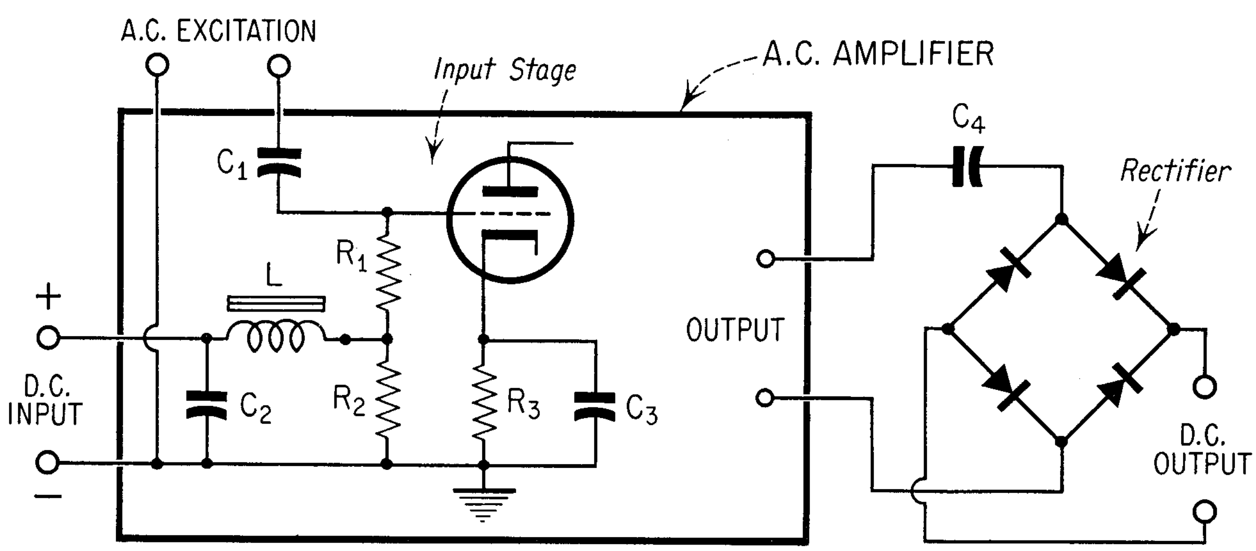
a second coil wound on the same core. A. C. excitation current flowing through this latter coil is controlled by the varying impedance, and the a. c. delivered by the converter accordingly is proportional to the applied d. c.

The a. c. and d. c. coils are wound on a 3-legged core in Figure 3 in an arrangement which prevents the flow of alternating current in the d. c. coil. This is accomplished by separating the d. c. coil into two halves, L_1 and L_3, and connecting these two will be bucked out by an equal and opposite voltage induced in L_3. Therefore, no a. c. appears at the D. C. INPUT terminals.

Converter - output a. c. flows through resistor R across which it sets up a voltage drop. The signal is coupled from this resistor, through capacitor C_1, into the a. c. amplifier channel. Transformer coupling also can be employed.

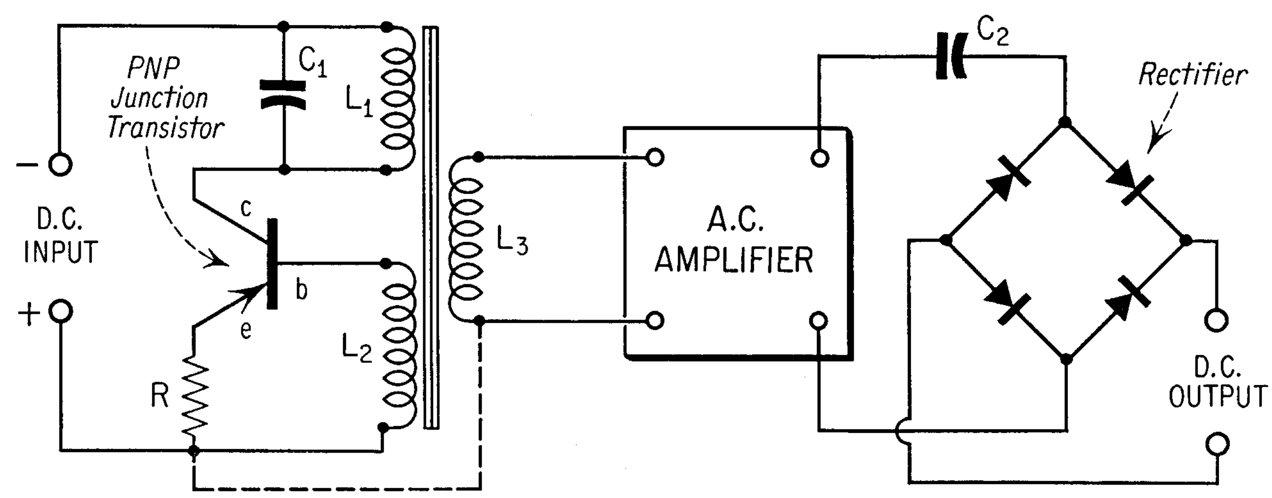
Like the diode modulator, the magnetic-amplifier type of converter has the advantage of freedom from moving parts. It is simple and compact, can be made small in size, and has no life limitation. Its only disadvantages are restricted response time and its low frequency characteristic (limited by the core characteristics to audio frequencies).

Transformer-Type Saturable Reactor. Figure 5 shows another magnetic-type converter. This arrangement employs two small-sized audio transformers which have cores capable of d. c. saturation. Transformers such as the U. T. C. subouncer



TUBE-BIAS-TYPE CONVERTER

FIG. 6



TRANSISTOR-OSCILLATOR CONVERTER

FIG. 7

and sub-subouncer series, having special alloy cores, are suitable for this application. I_1 and L_4 are primary windings (lesser number of turns), while L_2 and L_3 are secondaries (greater number of turns).

The secondaries are connected to buck, so that any a. c. induced in one by alternating current flowing through the paralleled primary windings (L_2 and L_3) will be cancelled by an identical a. c. induced in the other. In this way, no a. c. appears at the D. C. INPUT terminals.

This converter operates in the same general manner as the one shown in Figure 4. That is; the direct current flowing in I_1 and L_2 causes varying amounts of core saturation and thus alters the impedance of the a. c. windings L_2 and L_3. This action causes a variation of alternating excitation current flowing through L_2-L_3 and resistor R. The a. c. signal voltage across R thus is proportional to the applied d. c.

The converter-output a. c. signal voltage is coupled, through capacitor C_1, into the a. c. amplifier channel. Transformer coupling also can be employed without somewhat greater complexity.

The advantages and limitations of this converter are identical with those of the unit shown in Figure 4 and described in the preceding Section.

Tube Bias-Type Converter. The d. c. signal to be amplified may be employed to vary the control grid bias of the input stage of the a. c. amplifier section and thereby to yield an a. c. output voltage proportional to the applied d. c. The a. c. amplifier is assumed to be transmitting a signal derived from the a. c. excitation source. This scheme is illustrated in Figure 6.

Here, the major amount of bias is developed by the input-stage cathode resistor, R_3. The d. c. input signal voltage is applied across R_2 in series with the self bias of the tube. A. C. excitation voltage is applied through coupling capacitor C_1. The filter network, LC_2, prevents this a. c. from reaching the D. C. INPUT terminals.

The a. c. excitation is a constant voltage, usually of millivolt level. As the d. c. input signal varies, the grid bias is shifted, and amplification of the excitation signal varies proportionately.

This system has the advantage of relative simplicity. It may be applied readily to an existing a. c. amplifier, occasioning few circuit alterations. It requires some care, however, in the selection of the static bias level, in order that changes resulting from input d. c. signal fluctuations might produce linear variations in a. c. output amplitude over a desired range. A particular advantage of this system is its adaptability to r. f. as well as a. f. amplifiers. At radio frequencies, rapid fluctuations in the d. c. input signal can be followed. In this case, the a. c. excitation voltage would be supplied by a radio-frequency generator.

Transistor - Oscillator Converter. Junction transistors will oscillate at audio frequencies down to very low levels of d. c. collector voltage and at only a few microwatts of collector power. An interesting d. c. — a. c. converter can be made by using the d. c. signal voltage as collector supply voltage for the transistor. The strength of oscillation, and thus the a. c. output, will be proportional approximately to the d. c. voltage. This scheme is illustrated by Figure 7.

The transistor is connected in a common - emitter, tickler - feedback type of audio oscillator circuit. The operating frequency is determined former winding L_1 and the shunt chiefly by the inductance of transcapacitance, C_1. The third winding, L_3, serves as output coupling.

The circuit is inoperative until a d. c. signal is applied. Indicated polarity of the D. C. INPUT terminals is correct for PNP junction transistors. The polarity must be reversed for NPN junction transistors. Point-contact transistors are not suitable for this circuit or application, since they will not oscillate at the very low d. c. voltages applied to the D. C. INPUT terminals. The input d. c. signal is the only transistor voltage required!

This type of converter has the advantages of small size and compactness. It may be built into a small container and mounted at the front end of the a. c. amplifier. Its disadvantage is temperature sensitivity of the transistor characteristics. However, this is compensated to a degree by the emitter degenerative resistor, R, which serves to stabilize the oscillator output not only against temperature effects but also against variations in individual transistor replacement units.

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