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Junction Transistor Circuits

By the Engineering Department, Aerovox Corporation

THE former tightness of the transistor situation has been eased favorably for the non-military experimenter and manufacturer by the present excellent availability of the new junction-type transistors. The lower price of these components, compared with the almost prohibitive price of the earlier point-contact transistors, should stimulate private development of transistor circuits. It is expected that prices will drop further in proportion to the number of circuit applications which can be developed to utilize the wide spread in coefficients resulting in transistor manufacture.

The author has devoted several months to the checking of circuits employing the Type CK722 junction transistor and now is in a position to present practical circuit data in the *Research Worker*. The Editors feel that this information will fill the prospective user's need for definite circuit constants, since much of the material previously published in electronic literature has contained only skeleton diagrams leaving the reader confused as to actual values of components.

The circuits included here have been made to work satisfactorily and can be duplicated. It should be borne in mind, however, that these circuits satisfied one set of typical conditions and do not necessarily represent the best or only way of applying the transistor for the purpose intended. Considerable flexibility in individual design is possible. In addition, some readjustment of constants may be required when transistors of various manufacturers are used. The circuits described are intended especially for junction-type transistors and some of them often will not operate equally well with point-contact triodes. In presenting this material, we feel that it will be invaluable in guiding the newcomer to transistor circuitry and will be of provocative importance as well.

Features of the Junction Transistor

Several characteristics of the junction transistor distinguish it from the point-contact type. One of the most important of these is the increased ruggedness of the junction type. In the junction transistor, the three conduction layers (P, N, and P in the case of the CK722) are parts of the same germanium wafer. There accordingly are no whiskers or sandwich sections which might be displaced accidentally.

A dramatic property of the junction transistor is its high efficiency and its ability to operate at very low values of applied d.c. voltage. A class "A" amplifier using a junction type, for example, will operate close to the theoretical 50% efficiency point, as compared with a vacuum-tube amplifier giving 25 to 30 percent. Practical amplifiers and oscillators can be operated from a single 1½-volt cell with current drains so low that in some arrangements the cell will give shelf life. Audio oscillators can be made to operate at such low d.c. levels that, in demonstrations, the "power supply" current has been furnished by a self-generating photocell, thermocouple, or makeshift wet cell made from two coins separated by a piece of paper moistened with saliva.

The temperature sensitivity of the junction transistor makes the latter somewhat poorer than the point-contact type, but the junction type is not as noisy. The maximum ambient temperature allowed for the CK722 is 50°C. The 1000-cycle noise factor is 22 db. (Compare the noise factor of 65 db. which is given for the CK716 point-contact transistor).

Frequency response of the junction transistor appears to be lower than that of the point-contact type and is limited by such factors as the increased capacitance of the junction layers and the differences in mobil-

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ity of the carriers. Our tests indicate that the CK722 is suited particularly to audio and *low-frequency* r. f. applications, of which there are many in each category. As a radio-frequency oscillator, this unit has given good performance in our circuits as high as the upper limit of the standard broadcast band, but beyond that point its operation has not been encouraging.

Figure 1 shows a family of collector current-vs-collector voltage curves for the CK722. These curves are plotted for eight values of constant base current (0, 50, 100, 200, 300, 350, 400, 450, and 500 microamperes). Note that these curves have the general appearance of pentode vacuum-tube curves. The collector voltage (V_c) values are negative. The corresponding collector currents (I_c) also are designated as negative.

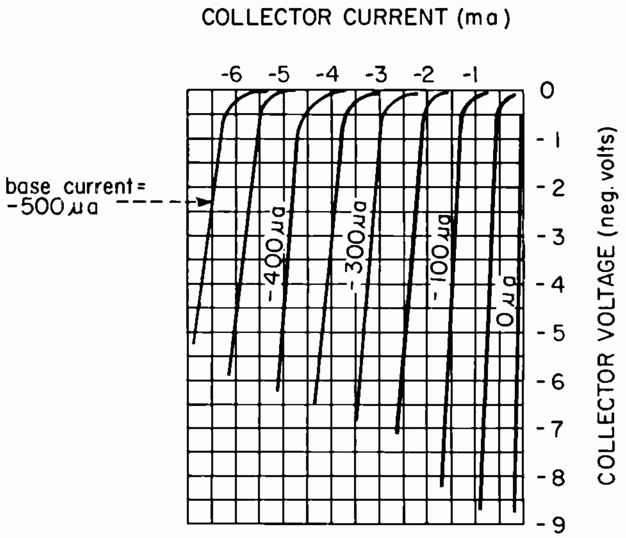
The Table in Figure 2 lists important operating data for the CK722. One listing is apt to confuse the reader who has had some prior contact with transistor literature. This is the current amplification factor, always mentioned as less than unity for junction transistors, which is given here as 12. The reason for this higher figure is that the factor given in Figure 2 is not *alpha* (which is less than 1) but *beta* which applies only to the grounded-emitter (base-input) operation shown. Beta (b) is related to alpha (a) approximately as follows: b = 1/(1-a).

Junction Triode Circuits

Figures 3 to 9 show several selected amplifier and oscillator circuits. Additional circuits will be described in forthcoming issues of the *Research Worker*. These preliminary circuits can serve as building blocks for more complex equipment. Note that each of these arrangements uses the low d. c. voltages at which the junction transistor is capable of operating.

Single Amplifier Stages. Figure 3 is a resistance-coupled, grounded-base audio amplifier circuit. The grounded-base arrangement is the progenitor of all transistor circuits.

The grounded-base circuit has an input impedance of approximately 1000 ohms and an output impedance of 5000 to 10,000 ohms, depending upon individual transistor collector characteristics. Higher operating impedances are possible in the output with higher R_2 values, but with somewhat reduced gain. Operating into a high-impedance load (100,000 ohms or higher), this stage, as shown, has a voltage gain of 40, although the gain may vary between 36 and 44 with individual transistors. At lower load resistance values, the gain drops proportionately.



TYPICAL COLLECTOR CHARACTERISTICS OF CK722 TRANSISTOR

FIGURE 1

With 1-microfarad input and output capacitors (C_1 and C_2), the frequency response is such that the gain at 100 cycles is 25% of the 1000-cycle value, and at 20,000 cycles is 92% of the 1000-cycle value. With 10-microfarad capacitors, the 20-cycle gain is 67% of the 1000-cycle value, and the 20,000-cycle gain 98% of the 1000-cycle value. Miniature, low-voltage electrolytic coupling capacitors may be used for the high values.

Because the grounded-base amplifier requires two batteries, there is some objection to its use. Current drain of the emitter battery is 150 microamperes, and of the collector battery 100 ua. The grounded-base

CK722 OPERATING DATA

ABSOLUTE MAXIMUM RATINGS

Collector Voltage (V_c)	—20 volts
Collector Current (I_c)	—5 ma.
Collector Dissipation	30 mw. at 30° C.
Emitter Current (I_e)	5 ma.
Ambient Temperature	50° C.

TYPICAL GROUNDED-EMITTER AMPLIFIER CHARACTERISTICS

Collector Voltage (V_c)	—1.5 volt
Collector Current (I_c)	—0.5 ma.
Base Current	—20 ua.
Current Amplification Factor (beta*)	12
Power Gain	1000 (30 db.) Source 1000 ohms; Load 20,000 ohms.

Noise Factor 22 db. at 1000 cycles

*This rating applies only to the grounded-emitter circuit. The current amplification factor *alpha* for the grounded-base connection is, of course, less than 1 for the junction transistor.

Figure 2

inductive-feedback type of circuit. Figure 8 shows two audio-frequency oscillators employing this principle. Figure 9 is a radio frequency oscillator employing inductive ("tickler") feedback.

Audio transformers are used in Figure 8 (A) and 8(B). In each instance, the high-impedance winding is connected to the collector. A satisfactory transformer is the type used to couple a single triode plate to 500- or 600-ohm line. Satisfactory results may be obtained also with a carbon-microphone transformer. The transformer must be phased properly for oscillation. If oscillation is not obtained immediately upon application of battery voltage, reverse the connections of *either* the primary or secondary. With a microphone transformer at T in each circuit, a 700-cycle signal was generated. The "natural" frequency will depend upon the inductance of the windings and their distributed capacitance, and may be lowered by means of capacitors connected at C_1.

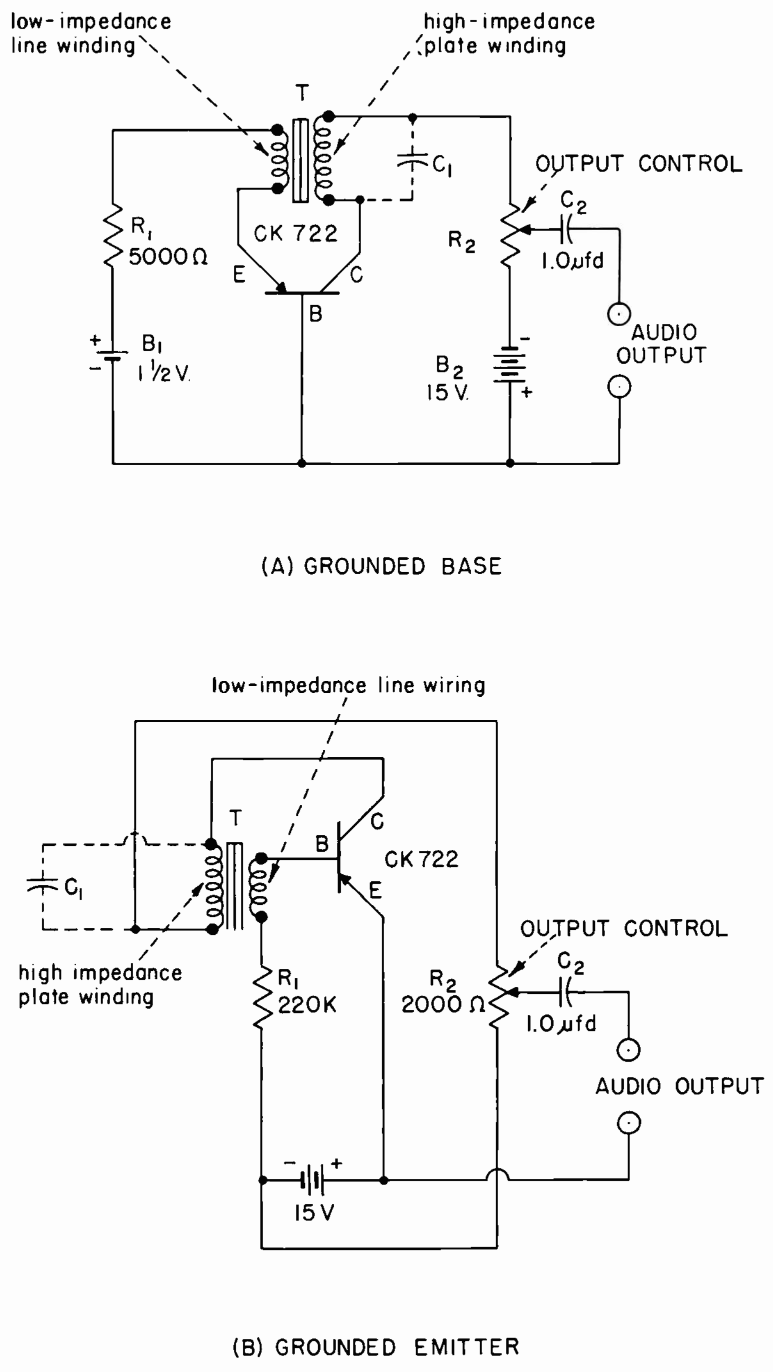
Figure 8 (A) shows a grounded-base oscillator; Figure 8(B) a grounded-emitter oscillator circuit. The first circuit requires two batteries but is somewhat less temperature-sensitive than the second.

Air-wound coils are used in the radio-frequency oscillator, Figure 9. The top frequency at which this circuit has been operated with the CK722 is 1500 kc. No frequency data are published on this transistor.

Tight coupling is employed between coils L_1 and L_2, the former being wound on top of the latter. The output coupling coil, L_3, is wound on the same form close to L_2. By making these coil sets plug-in, frequency bands between 50 and 1500 kc. may be covered.

A good broadcast-band oscillator may be made with L_2 a 540-1750 kc. antenna coil. L_3 is the slip-on primary normally supplied with the antenna coil. L_1 consists of 75 turns of No. 30 enamelled wire closewound on top of the manufactured coil L_2. Coil I_1 is insulated from L_2 with Scotch tape. C_2 is a 365-uufd. tuning capacitor.

An interesting regenerative broadcast receiver having good sensitivity can be made by connecting antenna and ground to the two terminals of L_3, and a pair of 2000-ohm (or higher, magnetic) headphones in series with the collector and L_2. Regeneration can be controlled by means of a 1-megohm potentiometer substituted for the 220,000-ohm fixed resistor shown in Figure 9. A transistor audio amplifier may be added by substituting the amplifier input transformer for the headphones. Near the vicinity of strong local stations, an outside antenna and ground are not required, an ac-dc antenna hank, connected to one terminal of L_3 being sufficient. The other terminal of L_3 then would be connected to positive terminal of the battery, as shown in Figure 9.



TRANSISTOR AUDIO OSCILLATORS

FIGURE 8