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. 23, No. 4 AND 5 — APRIL - MAY, 1953 — Subscription By Application Only

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-

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

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

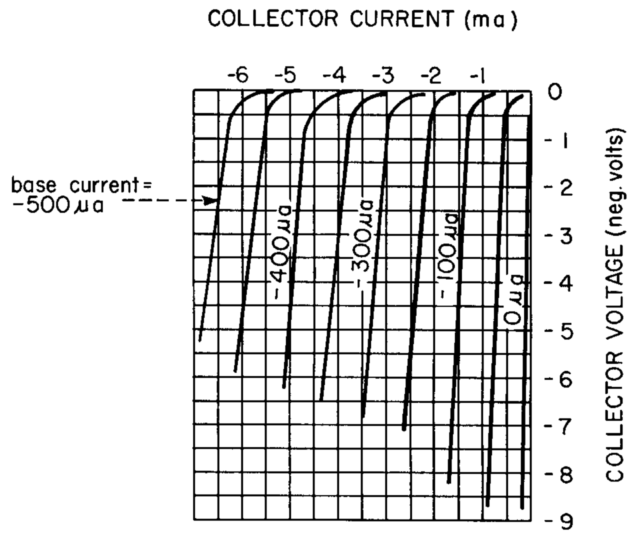
Figures 3 to 9 show several selected amplifier and oscillator circuits. Additional circuits will be described in forthcoming issues of the *Research Worker*. These preliminary circuits can serve as building blocks for more complex equipment. Note that each of these arrangements uses the low d. c. voltages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

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



TYPICAL COLLECTOR CHARACTERISTICS OF CK722 TRANSISTOR

FIGURE 1

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.

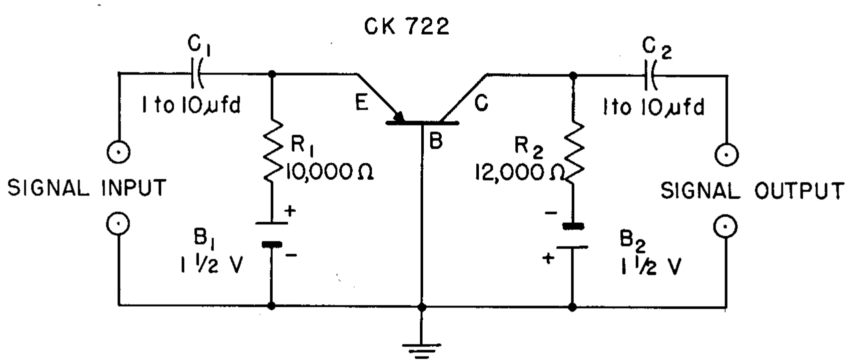
TYPICAL GROUNDED-EMITTER AMPLIFIER CHARACTERISTICS

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

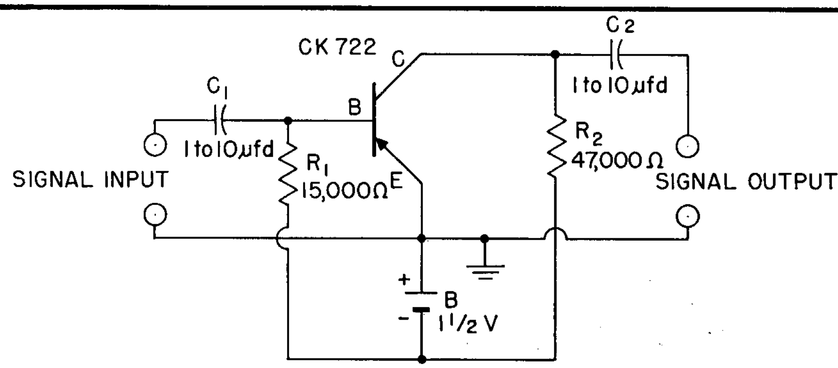
*This rating applies only to the grounded-emitter circuit. The current amplification factor *alpha* for the grounded-base connection is, of course, less than 1 for the junction transistor.

Figure 2



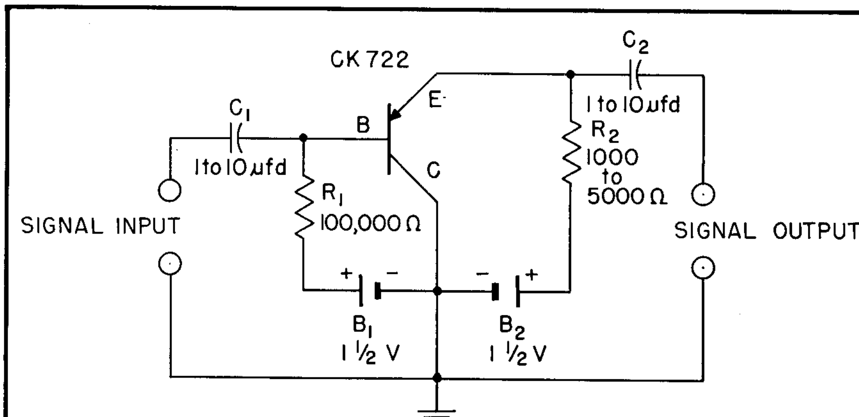
SINGLE-STAGE GROUNDED-BASE AMPLIFIER

FIGURE 3



SINGLE-STAGE GROUNDED-EMITTER AMPLIFIER

FIGURE 4



SINGLE-STAGE GROUNDED-COLLECTOR AMPLIFIER

FIGURE 5

amplifier offers the maximum power gain possible with a given transistor.

Figure 4 shows a grounded-emitter amplifier. An important advantage of this circuit is its ability to operate with a single battery at a drain of 10 to 80 microamperes, depending upon the individual transistor employed. Input impedance is of the order of 1000 ohms; output impedance 20,000 to 40,000 ohms. Higher output impedance values are possible with higher values of R_2 but with reduced gain.

With the constants given in Figure 4, voltage gain of this stage is 40 to 50 when B is 1½ volt, and 80 to 100 when B is 3 volts. These gains are obtained only when the stage is worked into a high load impedance (100,000 ohms or higher).

Frequency response is the same as that quoted for the grounded-base amplifier in the foregoing paragraphs.

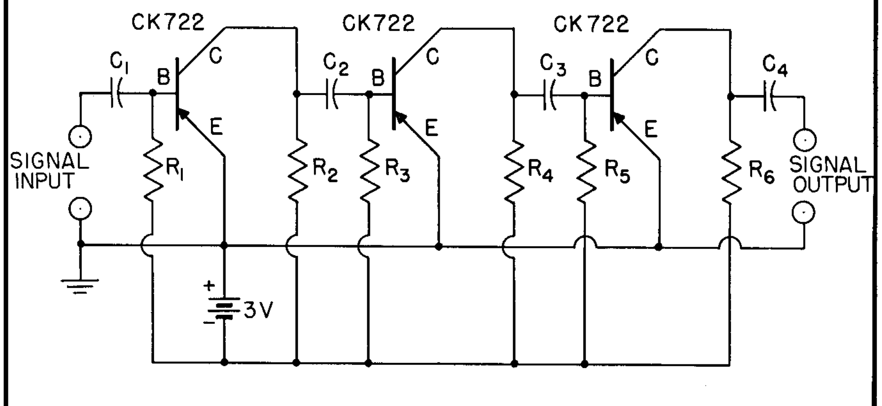
Figure 5 shows a grounded-collector amplifier. This circuit has high input impedance (of the order of 50,000 ohms) and low output impedance, 1000 ohms. It thus is equivalent to the cathode-follower vacuum-tube amplifier. Like the cathode follower, the grounded-collector circuit provides no voltage gain ("gain" of the stage shown in Figure 5 is 0.2 to 0.3). It does afford power gain, however, of the order of 15. The frequency response of this stage is the same as that stated earlier for the grounded-base circuit.

A slight disadvantage of the grounded-collector type of circuit is its requirement of two batteries (B_1 and B_2). But its relatively high input impedance suits it very well to use as the input stage of a transistor amplifier whenever the loss in voltage gain is of no consequence.

We did not discover that bypassing either of the power supplies in any of the circuits shown offered improvement in performance at any frequency between 20 cycles and 20 kc.

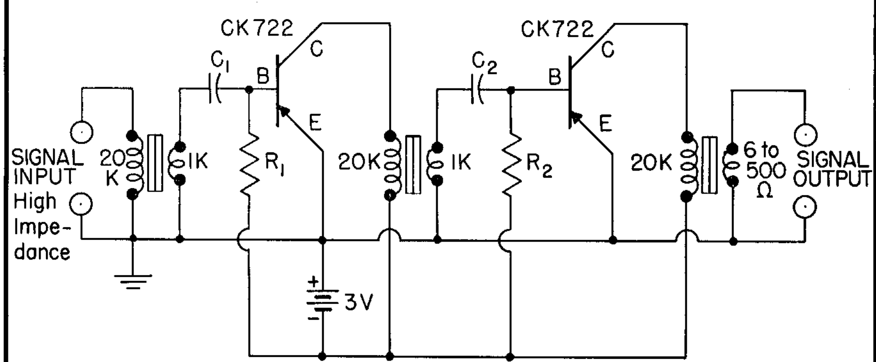
Cascaded Amplifiers

The circuits given in Figures 3 to 5 are fundamental building blocks. Like tube circuits, transistor amplifier stages may be cascaded for increased voltage gain and power gain. The difference with transistors, however, rests in the fact that in grounded-base and grounded-emitter stages, the output impedance is higher than the input impedance. This requires an impedance stepdown between stages. While resistance coupling may be employed as well as transformer coupling between stages, the greater power gain will be obtained with interstage transformer coupling,



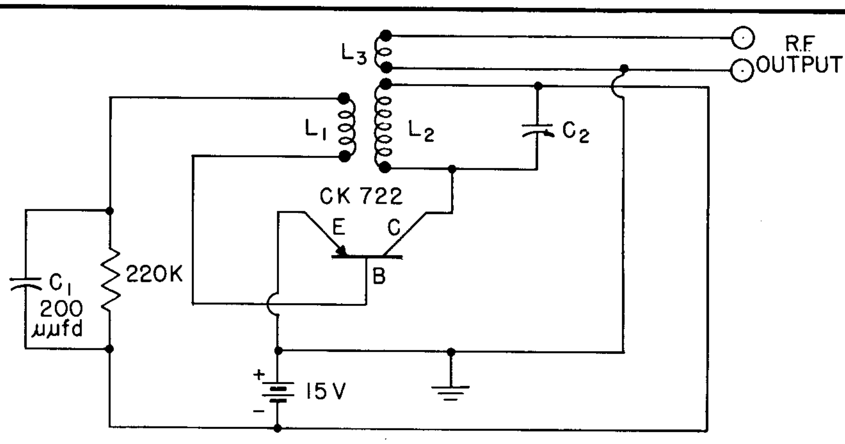
3-STAGE RESISTANCE-COUPLED, GROUNDED-EMITTER AMPLIFIER

FIGURE 6



2-STAGE TRANSFORMER-COUPLED, GROUNDED-EMITTER AMPLIFIER

FIGURE 7



GROUNDED-EMITTER TRANSISTOR R.F OSCILLATOR

FIGURE 9

since the latter has the lower step-down ratio and offers best power transfer. In resistance coupling, at least one additional transistor stage usually is necessary to provide the same overall power gain afforded by transformer coupling.

Figure 6 shows one method of resistance-coupling three junction transistor stages. Overall power gain is approximately 60 db. Collector resistors R_2, R_4, and R_6 each is 20,000 ohms. Base resistors R_1, R_3, and R_5 each is 150,000 ohms. For best results, each of these resistors should be adjusted carefully for the best gain and lowest noise output with the individual transistors used. Capacitors C_1, C_2, C_3, and C_4 each is 10 microfarads. This amplifier will deliver approximately 2½ milliwatts output to a high-impedance load. A 1000- or 2000-ohm headphone may be connected in place of R_6 and C_4 to obtain approximately the same output in such applications as hearing aids, pocket radio receivers, etc.

Figure 7 shows a transformer-coupled 2-stage transistor amplifier. This unit has an overall power gain of approximately 50 db. The interstage transformers have primary impedances of 20,000 ohms each, and secondary impedances of 1000 ohms each. For experimental setups, good results can be obtained with carbon-microphone transformers connected backward. The output transformer has a 20,000-ohm primary. Its secondary may have the proper value required to match a small loudspeaker, headphones, line, or other device. If desired, a 1000- or 2000-ohm headphone may be connected in place of the primary of the output transformer, T_3. Suitable subminiature transformers for use in the transistor amplifier intended for hearing aids, pocket receivers, are available at most parts distributors. A high-impedance crystal microphone may be coupled into the first transistor by using a 200,000- to 1000-ohm input transformer at T_1.

In Figure 7, capacitors C_1 and C_2 each is 10 microfarads. Resistors R_1 and R_2 each is 150,000 ohms.

Using the fundamental building blocks, a number of combinations of cascaded amplifier stages is possible to suit individual requirements. For example; grounded-base, grounded-emitter, grounded-collector, resistance-coupled, and transformer-coupled stages may be combined, as needed.

Transistor Oscillator Circuits

The CK722 junction transistor appears to oscillate most readily in an 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.

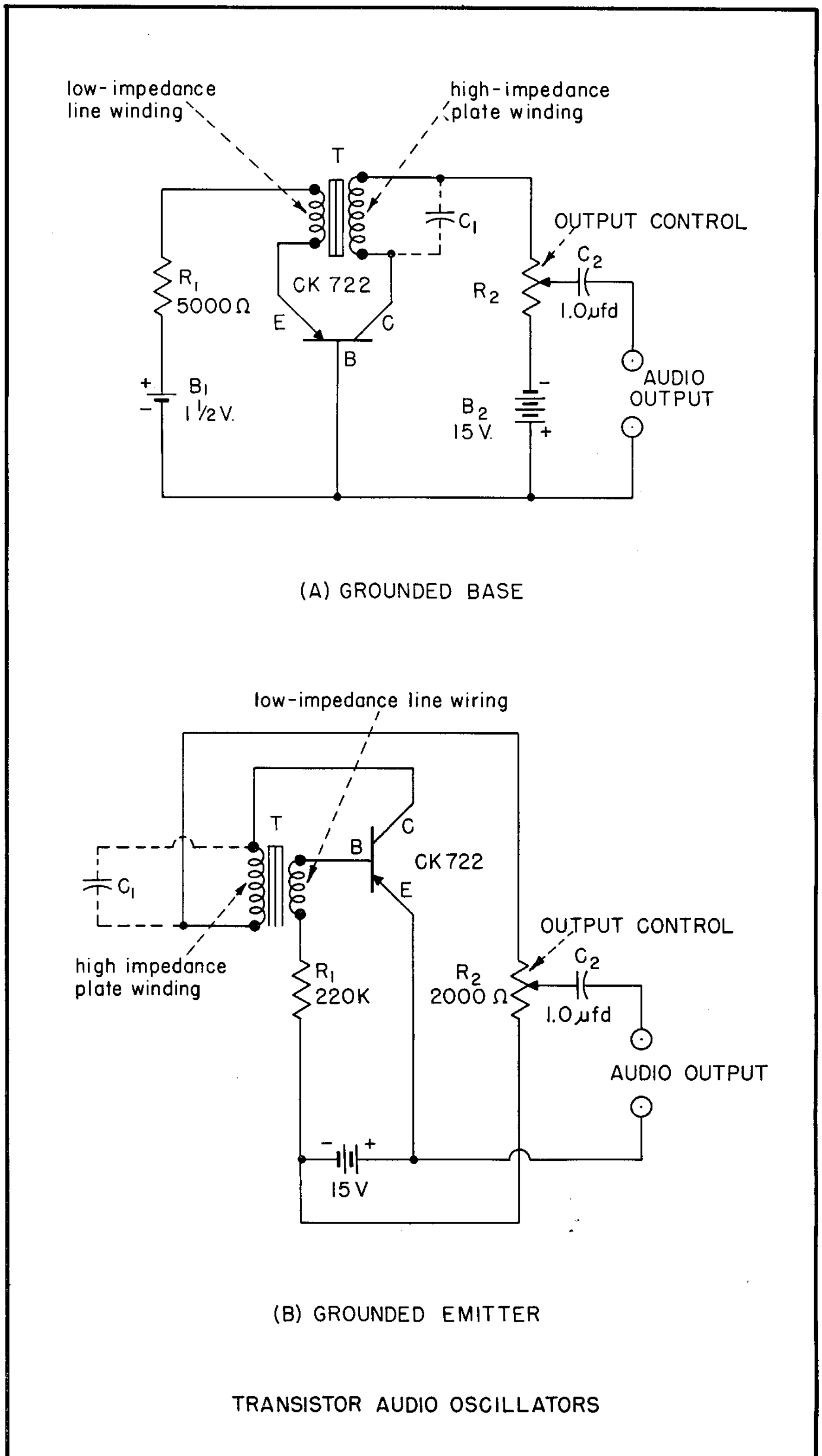
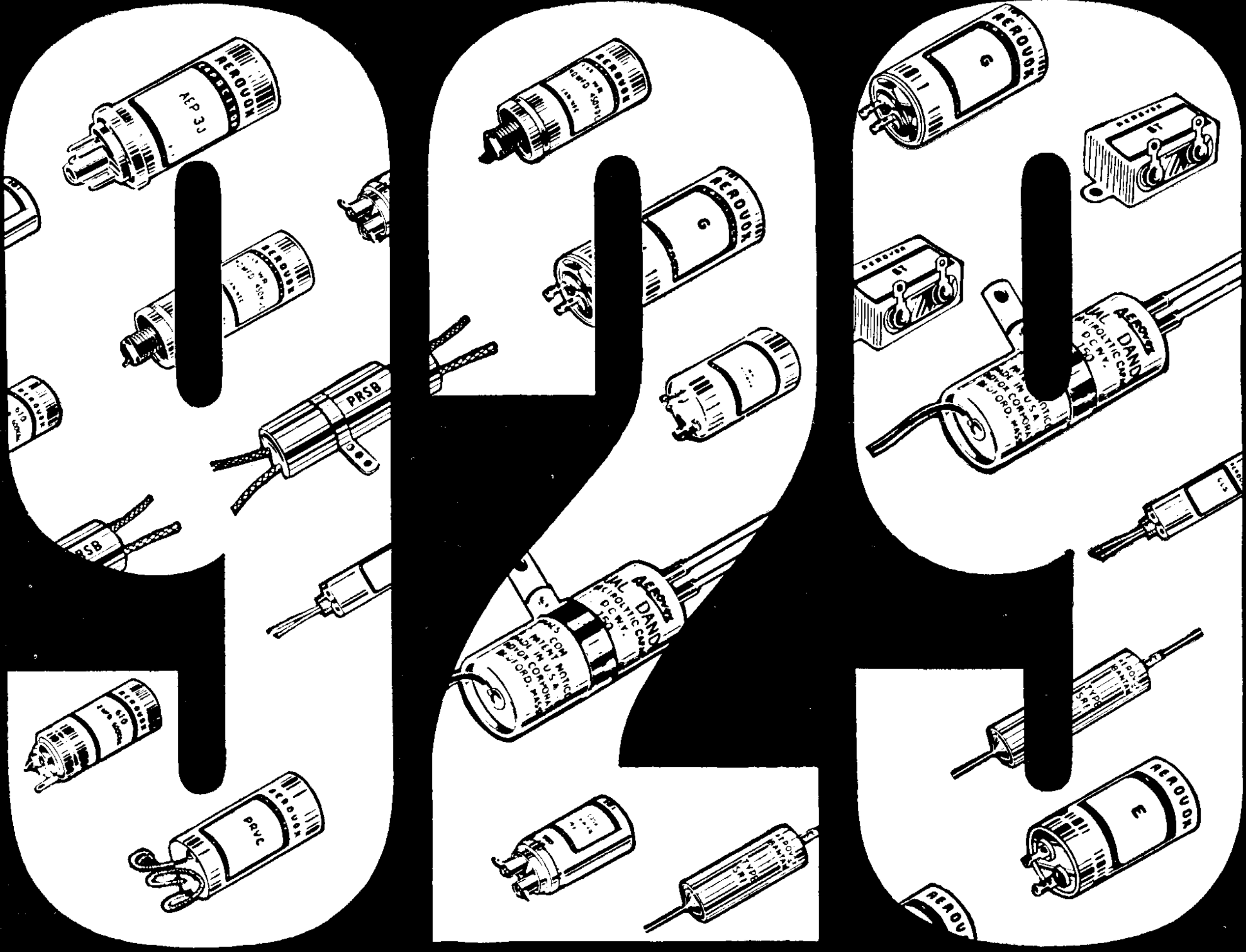


FIGURE 8

The COMPLETE Aerovox Capacitor Line includes



ELECTROLYTIC CAPACITORS

Select the electrolytic capacitor that really fits your needs, from the **929 different yet standard electrolytic listings** of the COMPLETE Aerovox Capacitor Line. That total represents 14 different styles and 71 voltage ratings in the widest range of capacities.

And it's typical of all other Aerovox types, such as 329 tubulars, 1188 oil-filled, 313 metallized-papers, 398 micas, 215 ceramics, 36 filters, etc. **Plus** 1151 different resistor numbers in the wire-wound, carbon, and precision deposited-carbon categories. Then, to meet military requirements, there are thousands of Aerovox JAN numbers available on short notice.

The Aerovox COMPLETE Capacitor Line lists **4559 standard catalog numbers!** Most of them are stocked by your Aerovox distributor. And the remaining numbers are carried in our factory inventory for prompt shipment to and through your distributor to you.

Get just the capacitor you need by taking advantage of the COMPLETE Aerovox Capacitor Line!

AEROVOX CORPORATION
NEW BEDFORD, MASS.

HI-Q® DIVISION
OLEAN, N.Y.

WILKOR DIVISION
CLEVELAND, OHIO

Export: 41 E. 42nd St., New York 17, N.Y. • Cable: AEROCAP, N.Y. • In Canada: AEROVOX CANADA LTD., Hamilton, Ont. JOBBER ADDRESS: 740 Belleville Ave., New Bedford, Mass.