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## Application of the Four-Electrode Receiving Tube (UX-222)

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### PART I

THE latest receiving tube of unique character to appear on the market in this country is the Radiotron UX-222 (Cunningham CX-322). It is the purpose of this paper to discuss the theory, characteristics, and uses of this tube. The UX-222 is a two-grid tube designed primarily as a screen-grid amplifier, but it is suitable for use in most of the other applications of two-grid four-electrode tubes.

Fig. 1 is a photograph of the UX-222 in its various stages of construction. In outward appearance it differs little from ordinary three-electrode tubes, having a standard UX-base and the same bulb as the UX-201-A, except for the addition of a metal cap at the top of the bulb. Fig. 2 is a sectional diagram showing the arrangement of the elements. There is a straight filament, surrounded by a coarse mesh grid (the control grid) which is supported from the glass bead only and is connected to the cap at the top of the bulb. Around this grid is another grid of fine mesh supported both from the bead and stem. At the upper end of this grid is a metal disk con-

nected to it and extending out over the top of the plate. The plate, which is considerably larger than the second grid, surrounds it and is supported from the stem only. Around the plate is a cage-like extension of the disk reaching below the bottom of the plate. The second grid connects to the regular grid pin of the UX base, the plate being connected in the usual way. The filament is of thoriated tungsten with a rating of 0.132 amperes at 3.3 volts—the same as the UX-120.

The principal uses of the UX-222 are as a screen-grid tube and as a space-charge-grid tube. These two uses will be discussed separately.

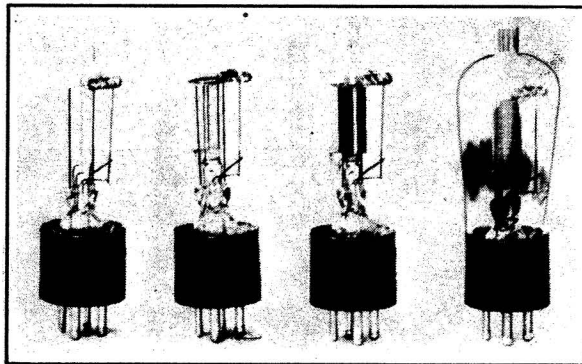


FIG. 1

#### AS A SCREEN-GRID TUBE

SCREEN-GRID tubes were first investigated by Schottky in Germany and later developed into a more generally useful form by Dr. A. W. Hull of the General Electric Company Research Laboratory. The UX-222 is a development of Dr. Hull's tubes into a commercially practicable form.

In any radio-frequency amplifier using tuned plate and grid circuits the

problem of oscillation due to feed-back of energy from the plate circuit to the grid circuit is one of fundamental importance. When all external sources of feed-back have been eliminated there still remains the plate-grid capacity of the amplifier tube. In the past there have been two general methods of preventing oscillation due to this capacity—the “losser” method, and the “neutralization” method. In the former, sufficient losses are introduced into the cir-

of metal between the grid and plate without preventing the flow of plate current, a grid-like screen, consisting of many turns of fine wire, is used. This is practically as effective in reducing capacity as a solid sheet. The plate-grid capacity is not affected by the introduction of a bias voltage since the screen is still grounded as regards an impressed a.c. signal. In addition to the screen directly between plate and grid, the outer surface and the ends of

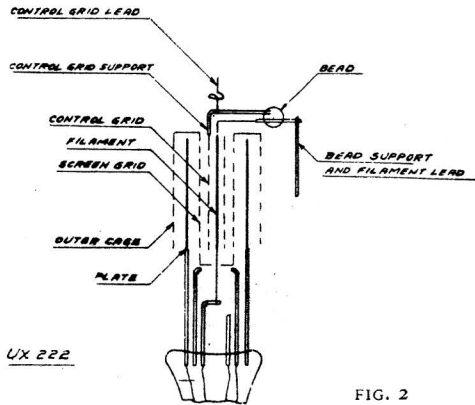


FIG. 2

cuit to keep the amplification down to a safe value, while in the latter, the feed-back due to the internal capacity of the tube is balanced by a feedback of equal magnitude, but opposite in phase, introduced outside the tube. Stability with the ux-222 as a screen-grid tube is obtained by eliminating the feed-back capacity.

This elimination of plate-grid capacity may be understood better by reference to the following example. Between any two parallel plates (see “a,” Fig. 3) there exists a capacity which may be measured by the alternating current which flows (in Fig. 3) through the ammeter “A” for some alternating voltage “V” at any definite frequency. If another plate is placed between the two and connected as in “b,” Fig. 3, the effect is now of two condensers in series, but the capacity between *o* and *n* is shorted out of the circuit and the current indicated by the ammeter drops to zero, and we may say that the effective capacity between *m* and *n* has been reduced to zero by the addition of the plate *o* connected as shown. It may be said that *n* is shielded, or screened, from *m* by *o*.

In the ux-222 this method of reducing the capacity between plate and grid is employed. Since it is obviously impossible to place a solid sheet

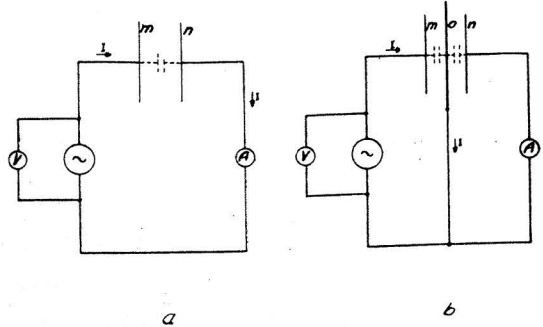


FIG. 3

the plate are screened from the control grid and its lead. To make this possible, the control grid lead is brought out of the top of the bulb. So effective is this screening that the direct plate-grid capacity in the ux-222 is only 0.02 mmfd. compared to 8 mmfd. in the ux-201-A.

Fig. 4 is of interest in showing some stages of the development of the ux-222. The tube of Hull's at the left has a disk over the top of the plate which extends to the walls of the bulb, permitting a continuous shield, except for the thickness of the glass, both inside and outside the bulb. The next three developmental tubes show varying amounts of screening outside the plate, the second tube having no outside screening, the third only a small strip shielding the leads in the bead, and the fourth having a complete disk very similar to the Hull tube, except that it was intended to be used in a pear-shaped bulb. The last tube to the right is the final form, the ux-222, showing the top disk made smaller in diameter and extended down as a cage around the plate.

The introduction of the screen causes interesting and important differences between the characteristics of the ux-222 and those of a three-electrode tube. For the most generally useful condition when the plate is at a higher potential than the screen these differences may easily be explained. The voltage of the plate has very little effect on the space

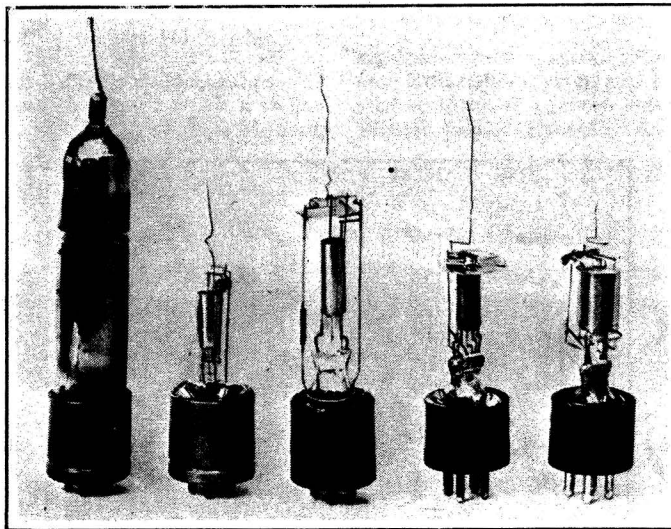


FIG. 4

within the screen because of the shielding effect of the screen. Thus, with a positive voltage on the screen, the screen attracts the electrons from the filament exactly as does the plate in a three-electrode tube. These electrons travel to the screen with relatively high velocities and most of them pass through the spaces between the wires of the screen. If the plate is at a higher voltage than the screen these electrons pass on to the plate and constitute the plate current. It may be said that the screen attracts the electrons and the plate merely acts as an accumulator of them after they have passed through the screen. Changes in plate voltage have little effect on the plate current, and consequently the plate resistance ( $\Delta e_p / \Delta i_p$ ) is very high. With voltages on the plate less than that of the screen various secondary emission effects may exist. Such characteristics do not affect the practical operation of this tube.

The desirability of high plate resistance in a screen-grid tube is to be seen from the expression for the voltage amplification of a vacuum tube and load circuit:

$$A_v = \frac{\mu R_p}{r_p + R_p}$$

where  $A_v$  is the voltage amplification,  $\mu$  the amplification factor of the tube,  $r_p$  the internal plate resistance of the tube, and  $R_p$  the resistance of the load circuit. This expression may be rewritten:

$$A_v = \frac{g_m r_p R_p}{r_p + R_p}$$

where  $g_m$  is the mutual conductance of the tube. In a three-electrode tube it is impossible to increase  $r_p$  without lowering  $g_m$ , so that it is undesirable to have a value of  $r_p$  above a certain point depending on the value of  $R_p$ . In the screen-

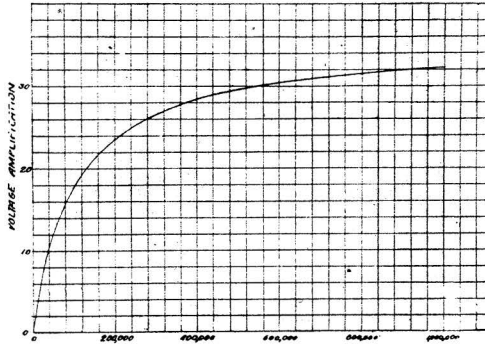


FIG. 5

grid tube, however, an increase in plate resistance does not result in a decrease in mutual conductance, so that the result is an increase in voltage amplification. Fig. 5 shows how voltage amplification varies with internal plate resistance, the mutual conductance remaining constant for the UX-222, assuming a load resistance of 100,000 ohms. It will be seen that at 850,000 ohms  $r_p$ , the voltage amplification, is 31.3, while at 100,000 ohms  $r_p$  it is only 17.5.

Fig. 6 shows the mutual characteristics of the UX-222 taken at 45 volts on the screen. Fig. 7 gives the plate characteristics at the same screen voltage and Fig. 8 gives the same characteristics at 22.5 volts on the screen. Fig. 9 gives the plate-current screen voltage characteristics. Fig. 10 shows how plate resistance, mutual conductance, and amplification factor vary with the several voltages.

It will be seen from these curves that the only unique characteristic of the tube is the plate characteristic. The mutual characteristic is normal, except that the several curves are spaced very closely together, showing the small effect of changes in plate voltage. The screen characteristic is very similar to the plate characteristic in a three-electrode tube.

Table No. 1 (page 32) gives the standard operating voltages and the constants of the UX-222 as a screen-grid tube.

The most general use of the UX-222 is as a radio-frequency amplifier, since here its two outstanding characteristics—low feed-back capacity and high amplification factor—may be utilized to best advantage. At radio frequencies, or in any case where amplification is desired over only a small frequency band, it is possible to build up relatively high impedances by resonant circuits. Fig. 11 shows the relation between load impedance and voltage amplification for

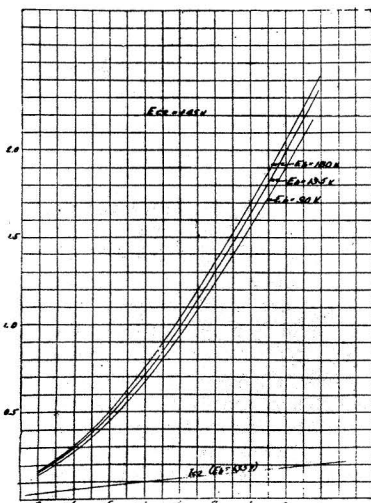


FIG. 6

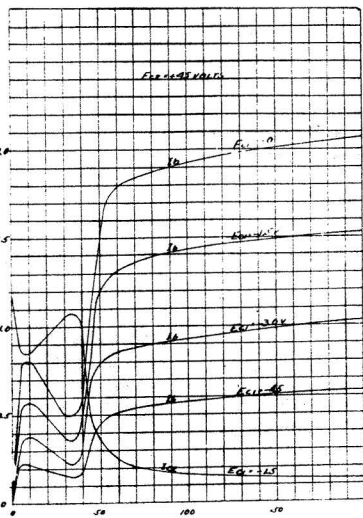


FIG. 7

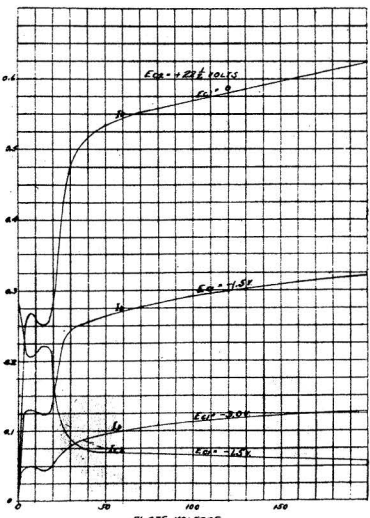


FIG. 8

such resonant circuits at recommended operating voltages for the UX-222, the UX-240, and the UX-201-A. The effect of the high amplification factor of the UX-222 is manifest. This comparison is not entirely just, however. It is customary to use a step-up transformer with the UX-201-A so that the gain may be greater than that shown. Due to the high internal resistance of the UX-222 there is no appreciable gain from using a step-up transformer.

It must not be assumed that the only limit on amplification is the impedance of the resonant circuit, however. Even the very small feed-back capacity of the UX-222 causes a certain amount of regeneration and when the amplification per stage is high enough the circuit will oscillate. If, as is commonly the case, the input and output circuits are both similar tuned circuits, the maximum value of amplification per stage without oscillation is given approximately by the following expression:

$$A\bar{v} = \sqrt{\frac{g_m}{2\pi f C_{pg}} + i\left(\frac{1}{2\pi f C_{pgr}} - 1\right)^2} - \frac{1}{4\pi f C_{pgr}}$$

It is, of course, assumed that the only feed-back is that through the tube. Fig. 12 shows the relation between voltage amplification and frequency as determined by this expression for the UX-201-A, the UX-240, and the UX-222. The advantage of the UX-222 is obvious. At a frequency of 100 kc. the UX-201-A will give an amplification of about 3 per stage without oscillating, while the UX-222 permits a voltage gain of about 52. At 20,000 kc. the UX-201-A permits practically no amplification while the UX-222 may give as high as 12 per stage without oscillation. At 40 kc. both tubes are stable at any possible amplification. By the use of step-up transformers it is possible to get a somewhat greater amplification with the UX-201-A than is indicated, but this gain is not large. Due to the high plate resistance of the UX-222, step-up transformers do not give any appreciable increase in amplification. It is to be understood that by the use of neutralized circuits greater gain can be gotten from the UX-201-A than the values indicated. Using the best transformers, and neutralization, the practical limit on the UX-201-A is a voltage amplification of about ten per stage at 1000 kc.

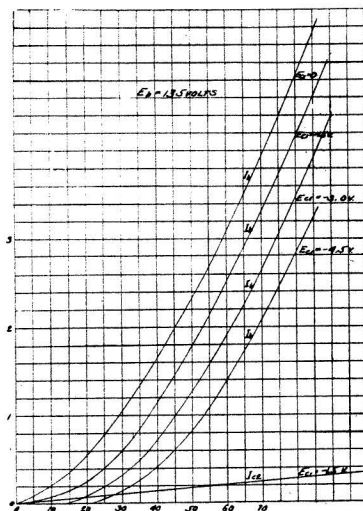


FIG. 9

By referring once more to Fig. 11, it will be seen that a voltage amplification of 52 in the UX-222 corresponds to a load impedance of 180,000 ohms, while 12 corresponds to a load of 30,000 ohms. This means that these are approximately the maximum loads which may be used at 1000 kc. and 20,000 kc. respectively. This is more of an apparent limitation than an actual one, however, for 180,000 ohms represents very nearly the maximum impedance which may be built up in a resonant circuit at 1000 kc. by ordinary means, as does 30,000 ohms at 20,000 kc. Hence, it may be said that at any frequency and with any common load circuits the UX-222 will operate as a stable amplifier without neutralization, provided all external sources of feed-back are eliminated.

There are three general sources of

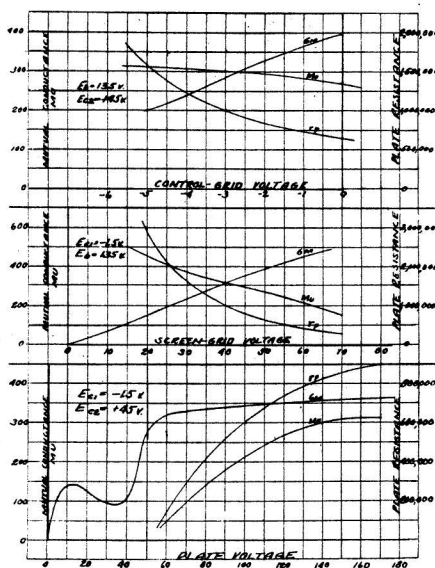


FIG. 10

feed-back other than the plate-grid capacity which must be kept at a minimum. These are: (1) Capacitive coupling between the plate and grid leads; (2) inductive or capacitive coupling between the plate and grid tuned circuits, and (3) coupling due to the impedance of the B supply. The first two causes may be eliminated by proper shielding. Because of the high amplification of the UX-222, the importance of thorough shielding between all parts of the grid circuit and the plate circuit cannot be overstressed. It is recommended that the tuned grid circuit be completely enclosed in one metal compartment, while the tube and the plate circuit are enclosed in another, with a shielded grid lead extending through to the grid terminal. Insulated wire with a metallic braid or tinfoil covering may be used for this purpose. The

| TABLE NO. 1               |              |         |            |
|---------------------------|--------------|---------|------------|
| SCREEN-GRID UX-222        |              |         |            |
| Filament Voltage          | ( $E_f$ )    | 3.3     |            |
| Plate Voltage             | ( $E_b$ )    | 135     |            |
| Control-Grid Voltage      | ( $E_{c1}$ ) | -1.5    |            |
| Screen-Grid Voltage       | ( $E_{c2}$ ) | +45     |            |
| Plate Current             | ( $I_p$ )    | 1.5     | mA.        |
| Plate Resistance          | ( $r_p$ )    | 850,000 | Ohms       |
| Mutual Conductance        | ( $g_m$ )    | 350     | Micromhos  |
| Amplification Factor      | ( $\mu$ )    | 300     |            |
| Effective G-P Capacitance | ( $C_{gp}$ ) | 0.025   | mmfd. max. |

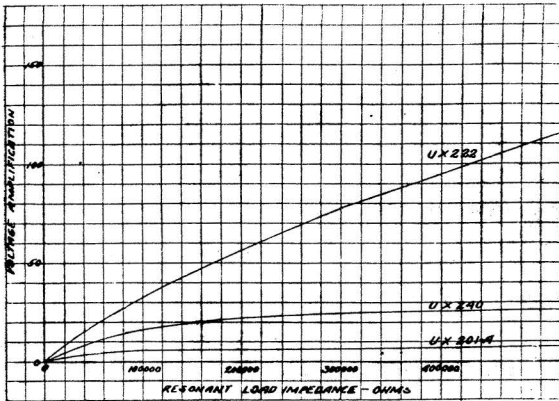


FIG. 11

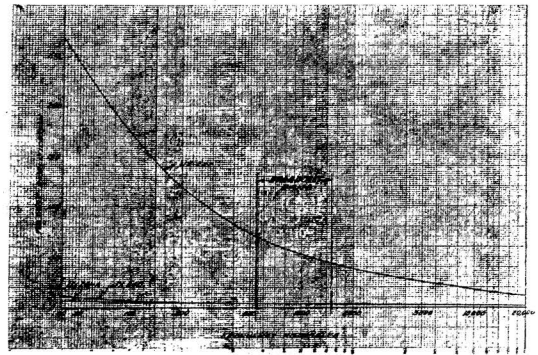


FIG. 12

remaining difficulty, coupling through the B supply, is a problem only in a case where two or more stages of r. f. amplification are used. This coupling may be eliminated by simple filters in the plate-supply leads where they pass through the shields.

It is of great importance also that the impedance of the screen-grid circuit be kept very low at the frequency to be amplified, as any such impedance tends to destroy the screening effect, reducing the amplification and increasing the effective plate to grid capacity.

A simple amplifier circuit for broadcast frequencies is shown in Fig. 13. The method of coupling may be called impe-

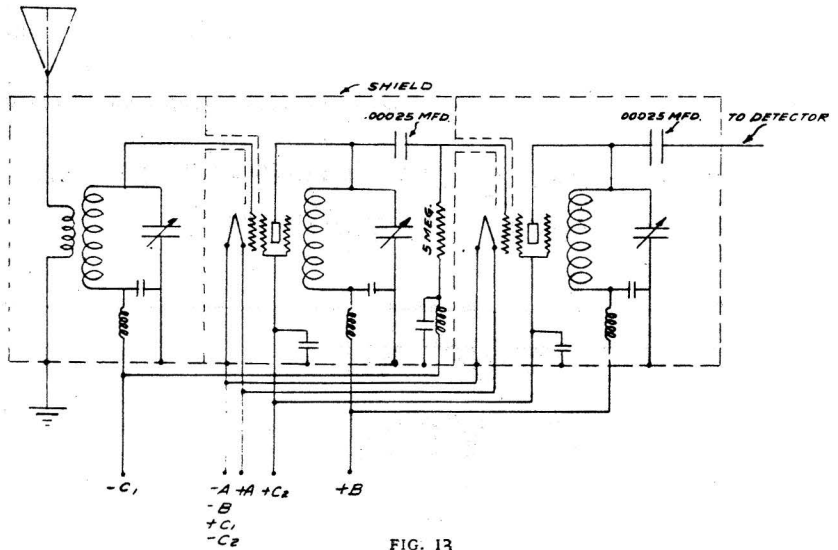


FIG. 13

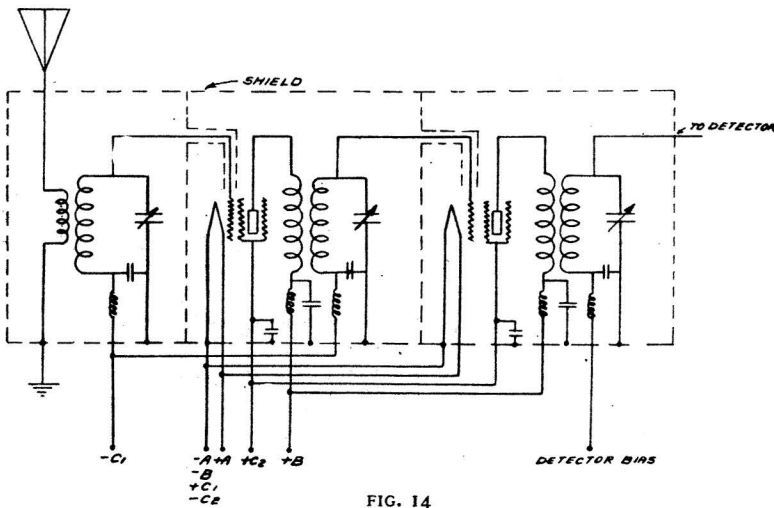


FIG. 14

dance coupling. The possible objections to this type of coupling are that the circuit may oscillate at some frequency below radio frequencies due to the coupling between plate and grid through the B supply, as is the case of "motor-boating" in a resistance-coupled amplifier (and for the same reason) and that the circuit may amplify some frequencies other than those intended if choke and condenser filters are in the plate leads, since these filters will resonate at some relatively low frequency. These difficulties may be largely obviated by the use of transformer coupling, as shown in Fig. 14.

(To be concluded in the April issue)