# A Complete 20-Watt 'Phone Operating on 110-Volt D.C. Mains

## Illustrating the Wide Adaptability of the New Gas Triodes in Audio- and Radio-Frequency Circuits

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*The experimental transmitter described in this article, employing the new RK-100 mercury-vapor type triode tubes in a variety of practical applications, illustrates the adaptability of the new tube to typical circuit arrangements and suggests the opening up of new fields for amateur experimentation. The transmitter is not intended especially as a model for complete reproduction but employs the simplest type of construction for the frank purpose of showing the extent to which usual practice can be used in handling the new tube. It will be of the highest immediate interest to the many amateurs handicapped by having only 110-volt d.c. supply available for transmitter operation.*—EDITOR.

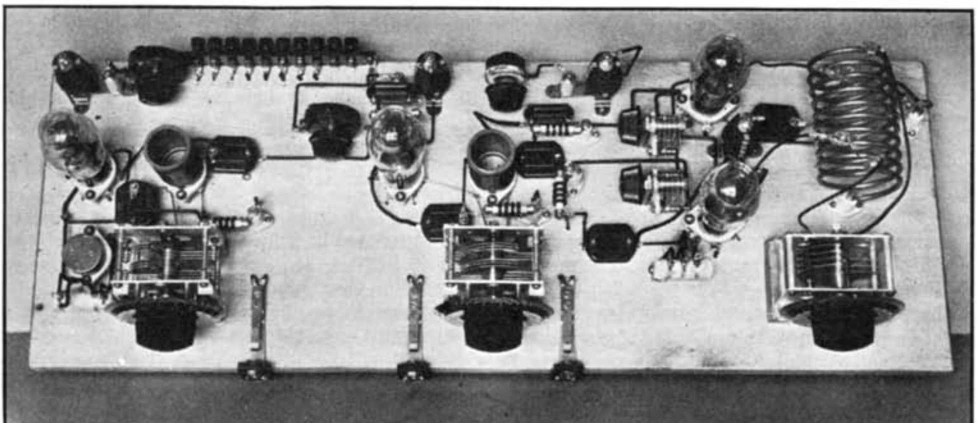
THE amateur building his first transmitter to-day has a choice of equipment and tubes which, placed end to end, would permit him to tap messages from coast to coast with a hammer—never minding the r.f. So we may think, at least those of us who live in areas supplied with a.c. But the picture hasn't been so bright for the man whose QRA is in a d.c. district of one of the large cities or in a locality equipped with a small 110-volt d.c. light plant.

Elsewhere in this issue of *QST* is described a new tube, just released from the laboratory, which is designed to help the amateur with a 110-volt d.c. power source. The RK-100 gas triode (or perhaps it should be called a tetrode, because it really has four elements) can be operated directly from the 110-volt d.c. socket.

The writers, with the new tubes available and prompted by that same curiosity which makes eight out of ten amateurs rebuild on a regular semimonthly basis, decided to give them a test on 14-megacycle 'phone in a transmitter that would do business on 110-volt d.c. plate supply—first with conventional a.c. supply equipment at West Newton, Mass., and then in New York City on the 110-volt d.c. mains prevailing in sections of that metropolis as it does in many other business districts.

### THE TUBE AND THE CIRCUIT

Examination of the RK-100 characteristics indicated the same general parts line-up might be used as for a transmitter with conventional high-vacuum triodes. Of course crystal control was voted essential. The next step called for a doubler-buffer stage and then a final with two RK-100



THE BREAD-BOARD R.F. SECTION ASSEMBLY OF THE EXPERIMENTAL TRANSMITTER USING RK-100 MERCURY-VAPOR TUBES IN ALL THREE STAGES

*The 7-mc. crystal oscillator is at the left, buffer-doubler in the center, and 14-mc. output stage at the right. The resistor lamps and fuse blocks, not shown, are connected in the 110-volt d.c. supply leads.*

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tubes in push-pull. It was estimated that the power input to the final would run around 30 watts. For plate modulation that meant 12 watts or so of audio power with just one way to get it at 110 volts d.c.—more RK-100's in the audio system. Most ham transmitters—like Topsy—just grow up. This one is no exception except for the fact that the audio inter-coupling transformer is connected "backwards." While that effective cathode, combined with the small spacing of the elements, provides an exceptionally low plate impedance. In the load circuits of this transmitter, therefore, the only unusual factor to be taken into account is the low plate impedance characteristic. It will be noted from the circuit diagram that in the r.f. section the plate connection to the crystal oscillator is tapped down on the plate coil, and that in the final stage the plates

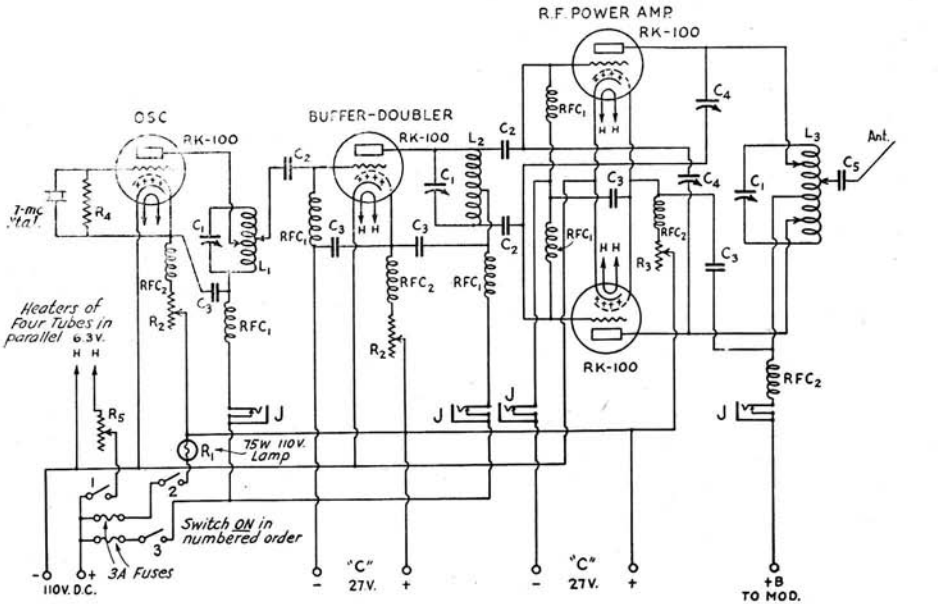



*FIG. 1—CIRCUIT OF THE R. F. SECTION*

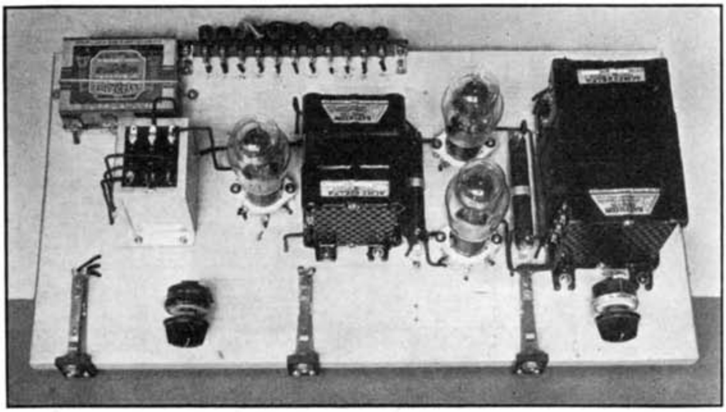
*$C_1$—70-μμfd. max.*
*$C_2$—100-μμfd. mica.*
*$C_3$—0.002-μfd. mica.*
*$C_4$—18-μμfd. neutralizing.*
*$C_5$—0.01-μfd. mica.*
*$R_1$—75-watt 110-v. lamp.*
*$R_2$—250-ohm rheostat, 200-ma. max. (10 watt).*
*$R_3$—100-ohm rheostat, 400-ma. max. (15 watt).*
*$R_4$—3000-ohm 2-watt.*
*$R_5$—47.4-ohms (approx.) 2.5 amp. (See text).*
*$RFC_1$—Midget r.f. choke (Hammarlund or National).*
*$RFC_2$—R.f. choke with current capacity of 300 ma. (May be omitted in cathanodes. See text).*
*$L_1$—18½ turns No. 20 enam., 1½-inch diameter, winding length 1½ inches.*
*$L_2$—9½ turns No. 20 enam., 1½-inch diameter, winding length 1½ inches.*
*$L_3$—9 turns 3/16-inch copper tubing 2-inch diameter by 4 inches long.*

happens accidentally now and then, this time it is deliberate and an advantage, as will be pointed out later.

The RK-100 tube contains mercury vapor. It might be expected, therefore, that there would be some radically peculiar circuit connections, or at least that the circuit would deviate considerably from conventional circuits used in amateur equipment. This is not the case for the simple reason that the plate, grid and cathanode or effective cathode are so close together that ionization of the mercury vapor cannot occur between them. The grid or input circuit to the RK-100 operates at a fairly high impedance just as it would with a high vacuum tube. Similarly, the plate circuit impedance is in no way affected by the presence of ionized mercury vapor at the center of the tube. However, the unusually large surface of the are connected in from the end of the plate tank.

Fig. 1 gives the circuit of the radio frequency section of the transmitter, the connections and resistance values being proper for operation at 110 volts d.c. In the first layout, which used a.c. and rectified a.c. for operation, there was but one difference. The heater circuits were operated from a 6.3-volt transformer with the center tap connected to B-minus. Tests were made with the cathanode ionizing voltage taken both from the d.c. plate supply and from a separate 24-volt rectifier similar to the type used for theater storage battery eliminators. With a Variac connected in the primary of the plate supply unit, it was possible to vary the plate voltage to the whole transmitter over a range of from 110 volts to 500 volts d.c., although in the tests on the air with the transmitter the plate voltage was kept at 110 volts and adjustments were made with the effective cathode resistors or rheostats for maximum power output.

Just to make it harder, the crystal stage of the transmitter operates in the 40-meter band. Reference to the characteristic curves for the tube indicate that it is very easily excited. With an amplification factor of approximately 50 and plate resistance which may vary from approximately 400 ohms down to 80 ohms, depending on the bias used, the mutual conductance is extremely high. As would be expected from these characteristics, it was the writers' experience in constructing the transmitter that the RK-100 is more easily driven by the crystal than any other oscillator tube employed in the regular transmitters at either station. To satisfy the low plate impedance of the tube, it was found desirable to connect the plate of the crystal oscillator tube to the plate tank coil at a point about half-way between the high- and low-voltage ends of the coil. The connection for excitation to the following stage was placed at the midpoint also. Although this point was chosen arbitrarily, it was found to give very satisfactory results and no change was made. The oscillator plate current varies exactly as it does in a high-vacuum tube when the plate tank circuit is tuned.



*THE SPEECH AMPLIFIER AND MODULATOR UNIT OF THE TRANSMITTER, THE INPUT STAGE BEING AT THE LEFT AND OUTPUT AT THE RIGHT*

*Operated directly from 110-volt d.c. mains, it delivers 12 watts or more of audio power with double-button carbon mike input. The battery at the left is for the micro phone, bias supplies and dropping resistors being separately mounted.*

The doubler-buffer stage is conventional in every respect. The grid-bias circuit is completed to the effective cathode through a small radio frequency choke and by-pass condenser. Battery bias of 27 volts negative is applied to this stage between the lower end of the radio-frequency choke and the supply terminal carrying positive voltage for the ionization of the space between the effective cathode and the cathode of the tube. The plate tuning coil is tapped at the center for the plate supply voltage and at the ends for excitation connection to the final stage.

The final push-pull stage has its grid-bias circuits completed through small radio-frequency chokes and is supplied with negative bias of 27 volts from C batteries. This stage operates as a "straight" amplifier on 14 mc. and therefore requires neutralization. The neutralizing condensers are midgets, double-spaced seven-plate units with a maximum capacity of approximately 35 $\mu\mu$fd. In tuning the transmitter it was found the tubes were properly neutralized with the condensers set at half capacity. In another layout this adjustment might be found to differ slightly because of length of leads and capacities between leads.

The plate tank circuit is similar to the circuit which would be used with any high vacuum tubes except for the fact that the plates are tapped in from the ends of the tank. In this particular case it was found that the power output was maximum when the plates were connected in on the second turn from each end. The antenna used in the tests on the air employed single-wire matched impedance feed. The antenna tap was connected to the final tank at a point which gave proper loading with no evidence of standing waves on the feeder.

In Fig. 1, resistance $R_4$ is a 75-watt 110-volt lamp. This drops the line voltage from 110 volts to approximately 15 volts d.c. for ionization of the space between the cathanode and the heated cathode. Resistor $R_5$ is a variable unit used to drop the 110-volt d.c. supply to 6.3 volts for the tube heaters. Reference will be made later to the value of this resistor.

It will be noted in Fig. 1 that the cathanode elements in the tubes are fed through radio frequency chokes. These radio frequency chokes should be capable of passing at least 300 ma. The necessity for them is questionable and if the transmitter were to be built again, they would be omitted experimentally in the new layout. Their use in this transmitter was based on the desirability of eliminating any possibility of radio frequency current in the effective cathode circuit.

#### AUDIO CIRCUITS

Fig. 2 shows connections used in the speech amplifier and modulator of the transmitter. Three transformers are employed, two of them connected in the conventional manner. The first transformer, $T_1$, is a standard microphone input transformer for a double-button microphone. The speech amplifier tube, also an RK-100, operates with a negative grid bias of 4.5 volts from a C battery. The intermediate coupling transformer, $T_2$, is a Class-B input transformer designed originally for coupling two Type 2A3's to the grids of two 203-A tubes. It is unnecessary to use a transformer as large as this one, but this particular type happened to be available and, since it had the proper connections, it was used. It will be noted that the normal secondary winding has been used for the plate circuit of the speech amplifier tube and that the primary is connected to the following grids in the modulator stage. The secondary on the transformer was split, permitting connection of the two secondary sections in parallel, with resulting reduction in impedance on the plate side of the transformer. On the grid side the "B-plus" connection is used for "C-minus," and the two "plate" ends are connected to the grids of the modulator tubes.

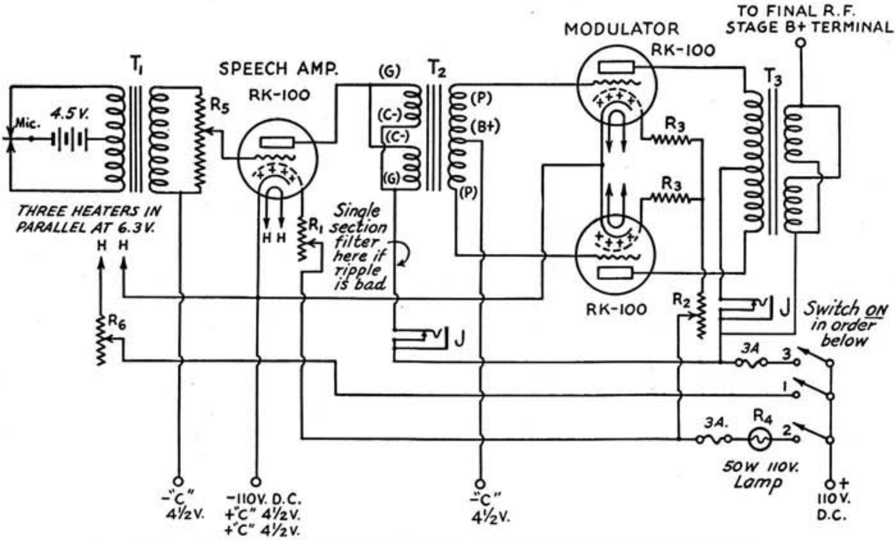



FIG. 2—THE SPEECH AMPLIFIER AND MODULATOR CIRCUIT

*$T_1$—Input transformer. Double button microphone to single grid.*
*$T_2$—Interstage transformer. Class-B input, split secondary. Usual "secondary" windings connected in parallel for plate circuit. "Primary" used for following push-pull grid circuit. (See text).*
*$T_3$—Modulation transformer. Class-B output suitable for 46's (See text).*
*$R_1$—250-ohm rheostat, 200-ma. max. (10 watt).*
*$R_2$—100-ohm rheostat, 400-ma. max. (15 watt).*
*$R_3$—50-ohm 200-ma. max. (5 watt).*
*$R_4$—50-watt 110-v. lamp.*
*$R_5$—100,000-ohm potentiometer (Volume control).*
*$R_6$—66.6 ohms, 2-amp. capacity (See text).*

The modulator stage is also operated with the grids biased at negative 4½ volts by a "C" battery, and with the plates connected to the plate terminals on a standard Type 46 Class-B output transformer, $T_3$. This transformer, which happened to be made up with two separate secondary windings, was connected so that the two secondaries were in parallel, providing a load resistance of approximately 4000 ohms for matching purposes. The experimental nature of this transmitter becomes evident at once when the match between the secondary of the modulation transformer and the actual load is considered. Figuring the input to the final r.f. stage at 100 volts plate and 250 ma. maximum, the load resistance is 440 ohms. The result of this mis-match is a presumable loss in power and it might be expected that the quality would be affected also. However, in the test of the transmitter on the air, the stations worked reported the quality as exactly like that of the main transmitter.

In Fig. 2 the resistor designated $R_4$ is a 50-watt 110-volt lamp, used to drop the 110-volt d.c. supply to approximately 15 volts for the cathode circuit. Resistor $R_5$ is the series unit used to drop the voltage from 110 volts d.c. to 6.3 volts for the heaters of the three tubes in the speech amplifier and modulator section. The value of this resistor for different tube combinations is covered in the section to follow.

### HEATER SUPPLY

Practically all 110-volt d.c. lines operate at fluctuating voltages running between 120 volts and 105 volts. Because of this variation, it is essential that the tubes operated from the line be run at approximately 6.3 volts for the average line-voltage value. It is almost essential that the filament voltage be measured with a reliable meter kept permanently in the circuit. Fortunately, d.c. meters of this type are cheap and are

(Continued on page 68)

BRS 1399, 360; BRS 822, 120. Germany. (d) DE 1836.R, 5202; DE 1857.J, 3768; DE 1818.I, 2950; DE 2220.I, 1830; DE 1729.U, 1800; DE 1555.D, 980; DE 2161.J, 944; DE 1943.H, 868; DE 1616.M, 820; DE 2194.V, 804; DE 2089.K, 540; DE 1872.U, 480; DE 2322.F, 456; DE 2192.P, 404; DE 2327.M, 296; DE 2454.V, 258; DE 2078.K, 351; DE 2409.F, 292; DE 1231.C, 232; DE 1971 C, 56.

CONTEST NOTES

Some interesting statistics from logs: 210 stations sitting on the key at once would draw 35,973 watts of final amp. plate power! Of those 210 168 use CC, 22 prefer SE, and 20 MOPA. 130 of them chose Zepps, 51 S.W.F. Hertz, 7 Doublets, 12 end fed Hertz, 1 Marconi, 1 indoor, 1 600 footer and 1 260 ditto. Then again, 84 use TRF, 64 superhets, 38 det and audio, 22 det and 2 audio, 1 det and 3 audios and 1, ie, G6HP, likes just the one toob. The average of the 210 chaps gave an input power of 171 watts per man, thanks to several kilowatt merchants from the U. S. A.! VK3MR worked 38 countries, VK3GQ 36, VK3JQ 29 and VK3HL 23. W9FM, "VK7RC and a few others put the m.a. neddle (detector plate current) up to .6 millamp with each dot and dash." G2YL and W5VV hope the contest will be an annual one. XLA1Y worked with less than 3 watts input to his CC rig. VK3OC reported him R7/8 on occasions. MX2A was the only station heard from Manchoukuo.

## Complete 20-Watt 'Phone

*(Continued from page 12)*

reliable. If the line voltage is 120 volts, it will be necessary to secure a drop of 113.7 volts across the resistor in the heater circuit. For a single Type RK-100 tube drawing 0.6 ampere, the series resistor will have a value of 189.7 ohms. In Fig. 1, resistor $R_5$ passes the current for four tubes. It is only necessary, therefore, to divide the value for one tube (189.7 ohms) by four to secure the proper value for resistor $R_5$, which is 47.4 ohms. Similarly, in Fig. 2, resistor $R_6$ passes the current for three Type RK-100 tubes, each drawing 0.6 ampere. It is necessary then, to divide 189.7 ohms by three, giving 66.6 ohms as the proper value of resistance. If the line voltage drops to 105 volts the value of the series resistor for a single tube is 164.7 ohms. Dividing this value by four for the number of tubes shown in Fig. 1 gives 41.2 ohms as the proper value of resistor $R_6$ in Fig. 1. In the speech amplifier and modulator section shown in Fig. 2, the value of $R_6$ for the three tubes shown will be 164.7 ohms divided by 3, or 54.9 ohms, for a 105-volt line.

At the present time it is necessary to operate the heaters of the RK-100 tubes in parallel. Series operation would be more economical of current but it is not to be used with the present tube construction.

It will be noted in each of the circuit diagrams that fuses are shown for the 110-volt d.c. supply and for the branch which supplies the effective cathode ionizing current. These fuses, which may be either 3- or 5-ampere types, can be the small automobile cartridge fuses or the standard screw-base type. It is essential that they be used for the protection of the transmitter. In this connection it is well to remember that where we operate a transmitter from a.c. with a conventional power supply containing rectifier tubes and filter components, the power supply itself has relatively poor regulation. Consequently, in case of a short circuit the voltage output from the power supply drops to a very low level and usually nothing very serious happens. In this case, however, the transmitter and speech equipment is being operated directly from the light supply line with the whole power plant behind it—with an excellent possibility that the fuses in the main supply circuit are 30-ampere or larger size. And 30 amperes at 110 volts d.c. can do a very thorough job on any short-circuited transmitter.

### OPERATING ADJUSTMENT

Jacks are inserted for measuring plate or grid current in the individual stages, only one meter being used for current measurements with meter connections to a plug of the standard type. The plate current to the crystal oscillator when loaded will be approximately 40 to 50 ma., the buffer double stage will run at 75 to 100 ma. and the final push-pull stage will draw between 200 and 300 ma. depending on the antenna load.

The procedure in placing the transmitter in operation is exactly like that used in the conventional transmitter. The cathode power in the tube must be started first in any case, which involves turning on not only the heater circuit but also the supply voltage to the effective cathodes or cathanodes. Initially the heaters should be lighted at least 15 minutes before any other voltage is applied—that is, when the RK-100 tubes are first put into operation—in order to give the mercury a good "cooking." The writers followed this procedure and on operating the transmitter after this first time, the heaters were allowed to operate for approximately two minutes before any other voltage was applied. The second step is to apply voltage to the effective cathodes. In the transmitter described, this was done by throwing on the switch which is shown, in Fig. 1 and Fig. 2, next to the lamp used for dropping voltage. As soon as the effective cathodes receive positive voltage, the space between the cathanode and cathode in each tube will show ionization of the mercury vapor by the characteristic blue glow. The plate voltage can now be applied, placing the transmitter in operation. When receiving, the heaters are left on but it is desirable to turn off both the plate and effective cathode voltages, unless operation is duplex. It should not be necessary to cut off the effective cathode voltage during reception unless the line ripple is extremely bad.

The amateur's familiarity with mercury-vapor tubes might lead him to expect that these tubes would be extremely noisy to reception and productive of "hash." While this is true of mercury-vapor tubes when operated on alternating current for purposes of rectification, in the present instance direct current is used on the effective cathode circuit for ionization of the section between effective cathode and the cathode so that the ionization is constant. Under these conditions, there is absolutely no noise. It may be desirable at this point to bring out again the fact that the behavior of this tube is exactly like that of a conventional high-vacuum tube of very low plate resistance and that it is not at all related to the conventional grid-controlled rectifiers which are available for certain control purposes. Like the latter, however, it is affected by bulb temperature and might refuse to start in an unheated shack on a cold morning, if the mercury should not vaporize.

### RESULTS

The writers, like most other amateurs, were more interested in results than in the fine points of construction of the transmitter or in a discussion of the theory of operation of the tube. Accordingly, no time was wasted in getting it on the air at the QRA of W1GBE. Results were most gratifying with excellent QSO's being had with stations as far south as Miami, Fla., and throughout the middle-west. In each case, the station contacted was raised with the 110-volt transmitter and, following reports and some conversation with the small transmitter, the antenna was switched over to the permanent higher-power transmitter in the station. The comparisons showed the low-voltage job to be fully effective and the results were most gratifying, although there was really nothing new other than efficient low voltage operation.

### OTHER POSSIBILITIES

Experiences with the RK-100 in this transmitter indicate a number of interesting possibilities. For one thing, the writers expect to experiment with it in the crystal oscillator stage of both our "standard" transmitters with voltages as high as 300 or possibly 400 volts. It is apparent that the tube will deliver a very satisfactory power output as a triode crystal oscillator without developing sufficient voltage across the crystal to damage it or even heat it noticeably. To the man who has only 110-volts d.c. available, and who is experimentally inclined, the new tube offers a number of distinct advantages in addition to the opportunity to overcome voltage limitations. For instance, it was found, in experimenting, that the tube would oscillate freely on wave-lengths as short as 2 meters. Good output was obtained at this short wavelength despite the close spacing of the elements. While such spacing raises interelectrode capacities, electron transit time is reduced to a low value. This short transit time can be attributed both to the narrow spacing of the elements and to the fact that the electrons emerging from the ionized space, between the effective cathode and the heated cathode, pass through the effective cathode at fairly high velocity. There is also opened up to the man with the 110-volt d.c. line the possibility of developing a fair amount of driver output with line-voltage plate supply and with it driving a larger vacuum-tube stage, on which is the full capacity of a dynamotor or converter supply.

All in all, this new development will be of interest to a great many amateurs. The writers will be glad to help in any way possible if questions arise regarding the operation of the experimental transmitter described.