Deluxe Amateur TRANSMITTER

By JAMES N. WHITAKER, W2BFB
Eng. Dept., Hammarlund Mfg. Co.

Part 1. Design data for a 1-kw. transmitter. The most practical circuits for amateur service are incorporated in building this unit.

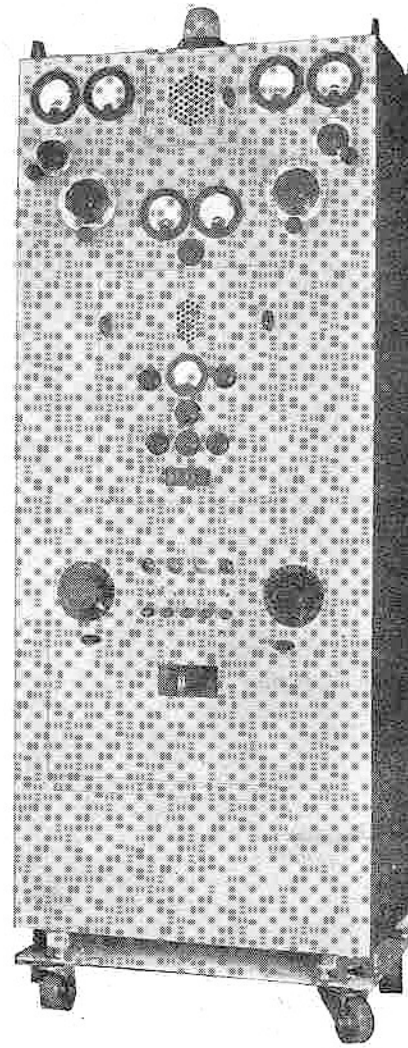


Fig. 1. Panel view of home-built 1-kilowatt transmitter. This unit may be operated entirely by the amateur from a remote position, or in the regular fashion if it is desired.

WITH the resumption of radio amateur activities following the conclusion of World War II, the amateur is confronted with a great variety of available component parts consisting of new items as well as war surplus materials from which he must select a few useful items to be incorporated in his postwar station. He has also been presented with a rather bewildering array of technical literature released as a result of the removal of wartime secrecy restrictions. These two factors coming along together as they do are quite bewildering to say the least and before starting out on a shopping expedition it will be wise for him to consider very carefully just what end result is desired. The cost of component parts on the surplus market is low enough to make possible the selection of high quality items which will permit the construction of equipment often dreamed about but seldom realized in amateur circles. A few of the most desirable features to be incorporated in a transmitter for amateur service can be roughly listed as follows:

1. *The radiated signal must be as pure as possible.* The a.c. ripple and spurious noise modulation must be below 1%. The harmonic content of the emitted carrier must be relatively low. There must be no radiations at spurious frequencies (parasitic oscillations, etc.) Modulation of the carrier must be linear and free from parasitic oscillations which so frequently are present during the modulation peaks.

2. *The p.a. efficiency must be high.* Since amateur transmitters are limited in power to 1000 watts of plate input to the final amplifier, considerable time should be allotted to obtaining the highest possible efficiency in this stage. This immediately rules out the typical "ham" method of operating the output tubes at considerably beyond the manufacturer's published ratings.

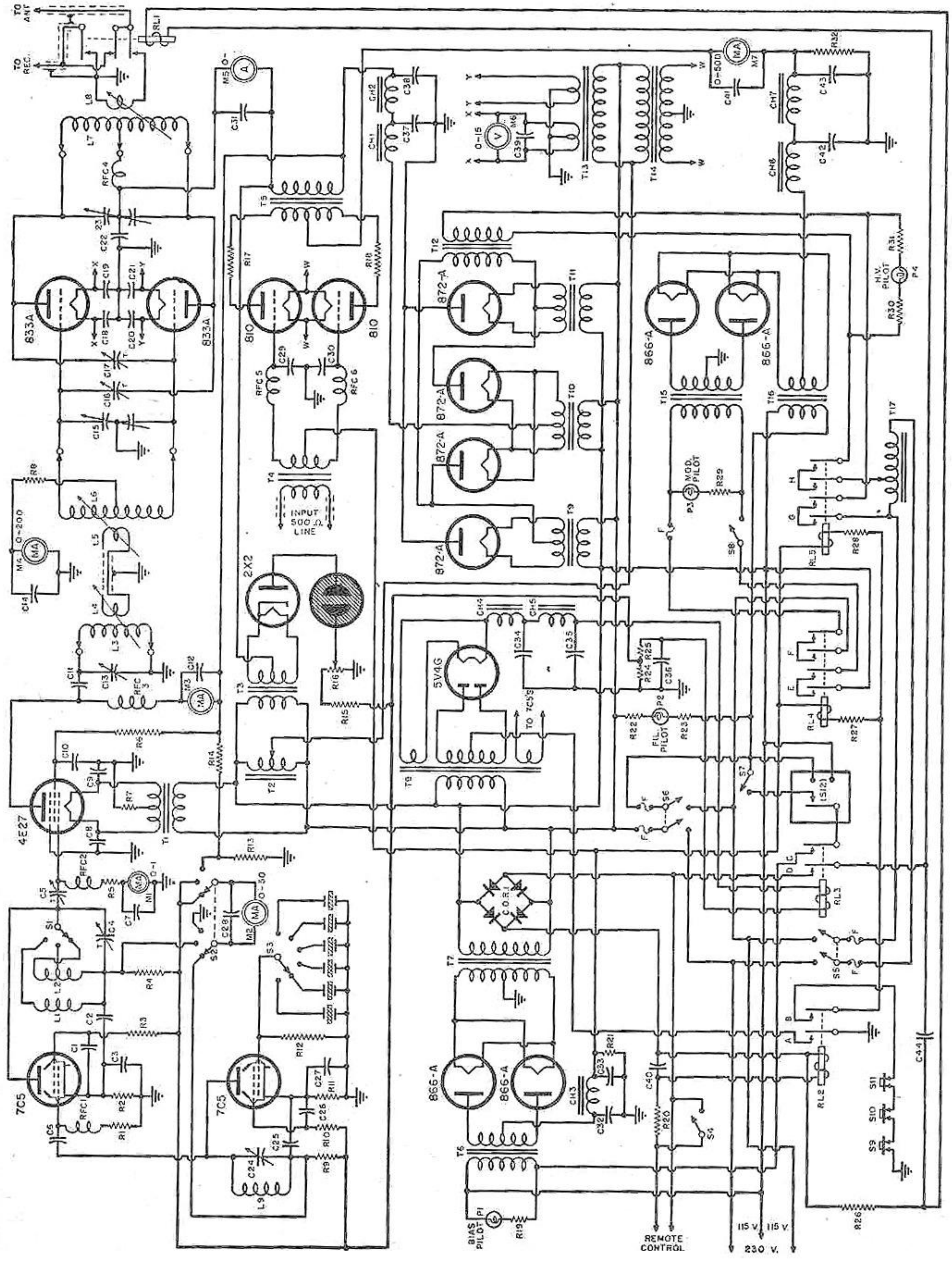
3. *The frequency must be stable.* Even a slow drift in one direction is likely to cause considerable annoyance not only to the receiving station where the receiver must be continually tuned to follow the transmitted signal, but also to other stations which might be receiving interference from the transmitter. To achieve real stability the old concept of a high-powered crystal controlled oscillator must be discarded for the more recent understanding of the prime reason for the use of crystals. They are a frequency stabilizing element rather than a source of power. The same is generally true of self-excited oscillators. Any oscillator will provide a maximum of stability only when it is supplying a minimum of power.

4. *The method of power control must be positive and properly sequenced.* This usually indicates the use of several relays, interconnected with each other in such a manner as to apply power to the various sections of the transmitter in a proper sequence for starting up the transmitter and for removing the power in an order not necessarily the reverse of the starting sequence, when shutting down the transmitter, as will be shown later.

5. The speech amplifier should be a separate unit and should not have a linear frequency characteristic. This may sound strange, but a careful analysis of the problem will disclose the truth of this statement. All modulation applied to the carrier tends to distribute the emitted power in the form of sideband energy. The entire audio frequency range is not required for good voice intelligibility. The more power used in needless sidebands the less power will be available for the necessary speech frequencies. The speech amplifier should, therefore, discriminate against frequencies below 200 cycles and above 3000 cycles. Such an amplifier will permit a higher average of modulation before the peaks of the voice frequencies cause serious over-modulation. The peaks in voice frequencies are generally in the form of high frequency transients against which such an amplifier will discriminate.

6. *A very definite and simple overmodulation indication must be provided.* The indicator must show any overmodulation peak no matter of how short duration rather than the average modulation. Overmodulation peaks are the cause of serious sideband "splatter" and contribute greatly to the interference often experienced in nearby broadcast receivers. The overmodula-

Fig. 2. Complete schematic diagram of the 1-kw. deluxe transmitter. Outstanding features are a voltage doubler final amplifier supply, the use of a copper oxide rectifier to supply d.c. for operation of relays, a positive overmodulation indicator, and control of input power. Parts list is shown on page 71.



tion indicator should provide a positive indication of overmodulation regardless of the power used, and should not require adjustment when the power is increased or decreased.

7. *The transmitter should not be unnecessarily large.* Compactness is essential not only from the standpoint of the conservation of space but also for the purpose of obtaining the shortest possible electrical connections between components within the equipment.

8. *Shielding and isolation of circuits.* All r.f. sections should be carefully and completely shielded to prevent spurious radiations and to prevent reaction between the various circuits within the transmitter. It is impossible to overstress the importance of complete isolation of circuits in a transmitter. Academically, perfect isolation of circuits can probably never be realized, but the careful use of shielding and r.f. bypassing and filtering will result in practical perfection along these lines. In any event, the isolation of circuits should be carried out to the extent that no spurious oscillations will occur in any circuit or combination of circuits during normal operation, or in the event of failure of the oscillator.

A solid ground connection between units is required, and all bypass connections should be made directly to the chassis at the nearest possible point as well as to the running ground. Although the base metal of the chassis may be steel or other relatively low conducting material, the mass of the chassis will provide a lower resistance path than a copper conductor of convenient size. It is wise to use both a running ground and chassis connection, or a chassis connection and a running ground between chassis. In most instances a running ground will offer little if any improvement when the chassis is used for a ground connection, and all chassis are bonded together.

With these eight requirements in mind, the writer set out to design and construct the transmitter to be described. The over-all operation and the results obtained have proven how very worthwhile it is to allot an appreciable amount of time to the careful planning of the transmitter before parts are purchased and the actual construction is started.

The transmitter will be described briefly as a composite unit followed by specific descriptions of each section and will include reasons for the selection of the particular system or circuit used as well as other suitable circuits which may be substituted. It

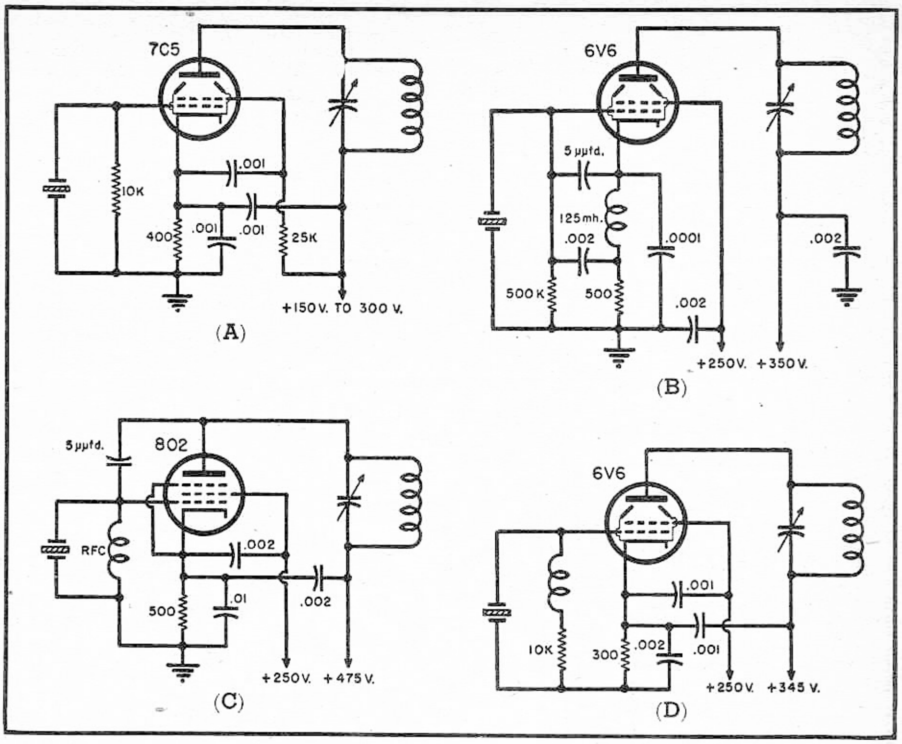


Fig. 3. Schematic diagram of several oscillators that were tried. Circuit shown in (A) proved most satisfactory and was the one finally adopted. Circuits (B), (C), and (D) could be used. The advantages and disadvantages of each are covered in text.

Complete parts list for schematic diagram appearing on opposite page.

R_1, R_5—250,000 ohm, 1 w. metalized res.
R_2, R_{11}—400 ohm, 1 w. metalized res.
R_3, R_{10}—25,000 ohm, 1 w. metalized res.
R_4, R_9—50 ohm, 1 w. metalized res.
R_6—100,000 ohm, 25 w. w.w. res.
R_7—1200 ohm, 100 w. w.w. res.
R_8—3000 ohm, 100 w. w.w. res.
R_{12}—10,000 ohm, 1 w. metalized res.
R_{13}—400 ohm, 25 w. w.w. res.
R_{14}, R_{32}—Four 25,000 ohm, 100 w. w.w. res. in series
R_{15}—100,000 ohm, 1 w. metalized res.
R_{16}—50,000 ohm pot.
R_{17}, R_{18}—50 ohm, 10 w. w.w. res.
R_{19}, R_{22}, R_{23}, R_{29}, R_{30}, R_{31}—500 ohm, 5 w. w.w. res.
R_{20}—800 ohm, 10 w. w.w. res.
R_{21}—250 ohm, 100 w. w.w. res.
R_{24}, R_{25}—10,000 ohm, 20 w. w.w. res.
R_{26}, R_{27}, R_{28}—700 ohm, 10 w. w.w. res.
C_1, C_2, C_3, C_8, C_9, C_{14}, C_{25}, C_{26}, C_{27}—.001 μfd., 600 v. mica cond.
C_4, C_{24}—50 μμfd. midget var. cond.
C_5—15 μμfd. midget var. cond.
C_6—.0001 μfd., 600 v. mica cond.
C_7, C_{12}, C_{28}, C_{30}, C_{41}—.01 μfd., 600 v. mica cond.
C_{10}—.001 μfd., 5000 v. mica cond.
C_{11}, C_{22}—.0001 μfd., 10,000 v. mica cond.
C_{13}—50 μμfd. var. tuning cond.
C_{15}—50 μμfd. (per section) dual tuning cond.
C_{16}, C_{17}—15 μμfd. neutralizing cond.
C_{18}, C_{19}, C_{20}, C_{21}—.001 μfd., 2500 v. mica cond.
C_{23}—40 μμfd. (per section) dual tuning cond., spacing 15,000 v.
C_{29}, C_{30}—.0001 μfd., 2500 v. mica cond.
C_{31}—.01 μfd., 2500 v. mica cond.
C_{32}—4 μfd., 600 v. elec. cond.
C_{33}—Three 125 μfd., 150 v. dry elec. cond. in parallel
C_{34}, C_{35}—3 μfd., 600 v. Dykanol or Pyranol cond.
C_{36}—6 μfd., 600 v. Dykanol or Pyranol cond.
C_{37}—4 μfd., 3000 v. Dykanol or Pyranol cond.
C_{38}—Three 4 μfd., 3000 v. Dykanol or Pyranol cond. in parallel
C_{40}, C_{44}—8 μfd., 300 v. dry elec. cond.
C_{42}—4 μfd., 3000 v. Pyranol cond. (General Electric)
C_{43}—8 μfd., 3000 v. Pyranol cond. (General Electric)
T_1—Fil. trans. 115 v. to 5 v. @ 10 amps. c.t.
T_2—Variac (General Radio 200B)
T_3—Fil. trans. 115 v. to 2.5 v. @ 2 amps. c.t., 10,000 v. insulation
T_4—500 ohm line to class "B" grids input trans.
T_5—Mod. trans. 750 w., .5 db. from 100 to 4000 cycles
T_6—Special bias trans. 115 v. pri. to 110-0-110 v. @ .5 amp.
T_7—Trans. 110 v. a.c. to 2.5 v. @ 10 amps. c.t., 2000 v. insulation
T_8—Low voltage power trans. 115 v. pri., 475-0-475 v. @ 200 ma.; 6.3 v. @ 3 amps.; 5 v. @ 3 amps.
T_9, T_{10}, T_{11}—Fil. trans. 115 v. to 5 v. @ 20 amps., 15,000 v. insulation
T_{12}—Pole trans. 220 v. to 2200 v. 2 kva.
T_{13}—Fil. trans. 115 v. pri., 10 v. @ 10 amps. c.t.; 10 v. @ 10 amps. c.t.
T_{14}—Fil. trans. 115 v. to 10 v. @ 10 amps. c.t.
T_{15}—Plate trans. 115 v. to 2000-0-2000, 5 kva.
T_{16}—Fil. trans. 115 v. to 2.5 v. @ 10 amps. c.t., 15,000 v. insulation
T_{17}—Variac, 100-200 v. @ 9 amps.
P_1, P_2, P_3, P_4—6 w. @ 110 v. pilot lamps
L_1—28 mc. tank coil wound on 1" form
L_2—14 mc., tap for 21 mc., tank coil wound on 1" form
L_3—Plug-in tank coil (3 used, 28, 21, and 14 mc.)
L_4, L_5—2 t. coupling link
L_6—Plug-in grid coil (3 used, 28, 21, and 14 mc.)
L_7—Plug-in plate tank coil (3 used, 28, 21, and 14 mc.)
L_8—Var. output coupling link
L_9—7 mc. osc. coil wound on 1" form
RL_1—D.p.d.t., ant. relay, 110 v. a.c. coil
RL_2, RL_3—D.p.s.t. normally open relay, 28 v. d.c. coil
RL_4, RL_5—4 p.s.t. normally open relay, 110 v. a.c. coil
$C.O.R._1$—Full-wave copper oxide rect., 1 amp.
CH_1—3-8 hy., 500 ma. swinging choke (25 ohms d.c.)
CH_2—18 hy., 500 ma. filter choke (50 ohms d.c.)
CH_3—8 hy., 500 ma. filter choke
CH_4, CH_5—14 hy., 100 ma. filter choke
CH_6—8 hy., 600 ma. filter choke
CH_7—16 hy., 600 ma. filter choke
RFC_1, RFC_2—2½ mh. pi-wound r.f. choke
RFC_3—2½ mh., 500 ma. pi-wound choke
RFC_4, RFC_5, RFC_6—500 ma. pi-wound r.f. choke
S_1—S.p. 3 pos. sw. ceramic insulated
S_2—D.p. 3 pos. sw. ceramic insulated
S_3—S.p. 6 pos. sw. ceramic insulated
S_4, S_7, S_8—S.p.s.t. toggle sw., 25 amps.
S_5, S_6—D.p.s.t. toggle sw., 25 amps.
S_9, S_{10}, S_{11}—S.p.s.t. interlock sw., normally open
S_{12}—Motor driven time delay sw. set for 30 sec. delay
M_1—0-1 ma. meter 2½" bakelite case
M_2—0-50 ma. meter 3½" bakelite case
M_3—0-250 ma. meter 3½" bakelite case
M_4—0-200 ma. meter 3½" bakelite case
M_5—0-1 amp. meter 3½" bakelite case
M_6—0-15 v. a.c. meter 3½" bakelite case
M_7—0-500 ma. meter 3½" bakelite case
2—7C5 tubes
1—4E27 tube
2—833A tubes
2—810 tubes
1—5V4G tube
4—872A tubes
4—866A/866 tubes

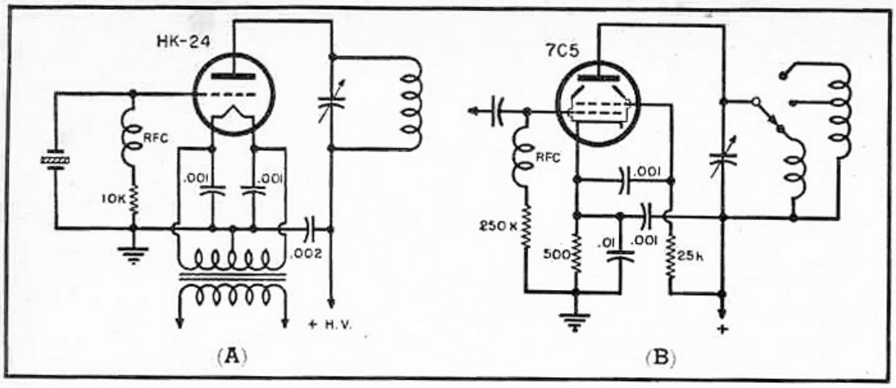


Fig. 4. (A) High powered triode oscillator capable of outputs up to 30 watts. (B) The bandswitching frequency multiplier used to drive the 4E27 buffer stage.

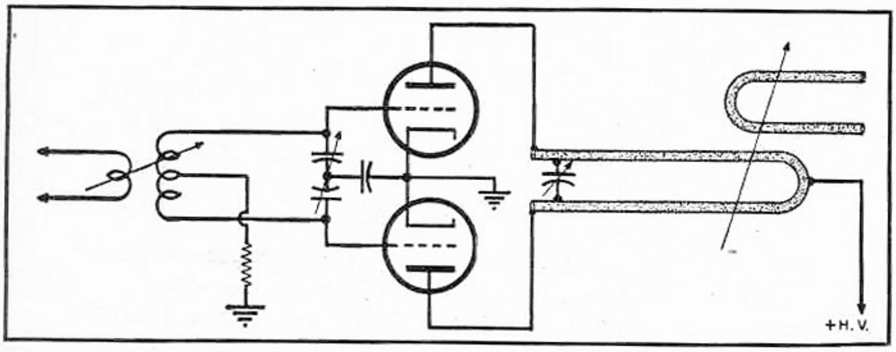


Fig. 5. Schematic diagram of a frequency multiplier system which will provide odd harmonic outputs. It is adaptable to high and ultra-high frequency circuits.

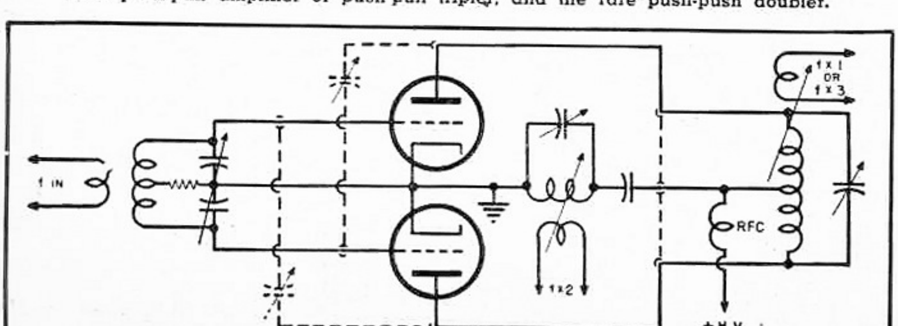
is hoped to thereby indicate possible modifications of the described setup which may better suit the particular needs of the individual who wishes to build a similar transmitter, and to provide a practical guide for the proper construction of any transmitter, regardless of power, up to the maximum power permitted for amateur use. This transmitter is shown schematically in Fig. 2.

The transmitter consists of a 7C5 crystal-controlled oscillator operating in the 7 mc. band, the 7C5 frequency multiplier, a 4E27 amplifier, and a final amplifier consisting of two 833A tubes in push-pull, modulated by two 810 tubes in class "B." Separate power supplies are provided for the oscillator and multiplier stages, the two amplifier stages and for the class "B" modulator.

A bias supply provides the negative grid bias for the class "B" modulator tubes as well as power for some of the control relays. The remote control and antenna changeover relays receive their power from a disc type copper oxide rectifier. A small variac is used for the adjustment of the filament supply for the modulator and power amplifier tubes and a large variac is used for the adjustment of the power input to the final and intermediate amplifier stages.

The speech amplifier is a separate unit mounted on the operating table and connected to the modulator unit through a 500 ohm shielded line. The transmitter output circuit is designed to operate into a large size (RG-14U) 52 ohm coaxial cable. The antenna changeover relay is mounted in the transmitter near the output coupling link and a small coaxial cable connector is mounted on the transmitter for connecting the antenna to the receiver.

Fig. 6. Schematic diagram of modified version of unit shown in Fig. 5. This system provides outputs at 1, 2, and 3 times the input frequency. It is a combination of a push-pull amplifier or push-pull tripler, and the rare push-push doubler.



The Oscillator

During the past several years it has been the writer's good fortune to have the opportunity of investigating oscillator circuits too numerous to mention. Each circuit has been carefully analyzed and data taken on output power, frequency stability, crystal current, etc. Each circuit was found to possess advantages and disadvantages. Any circuit used represents a compromise of some sort. The problem resolves itself into the selection of the most favorable compromise for the application in mind. In order to make an intelligent selection, the requirements must be studied carefully. In this case the requirements were briefly as follows:

1. The oscillator must be stable and free from self-oscillation when the crystal is removed or when the crystal is in place but ceases to oscillate.

2. The power required from the crystal must be so small that there will be negligible internal heating of the crystal. The r.f. current through the crystal must be as low as possible and must not exceed 10 ma. of r.f. current under normal operating conditions and 25 ma. under any condition. (The r.f. current through the crystal must not be confused with the d.c. grid current of the oscillator tube although the two may bear some relationship). The r.f. potential developed across the crystal must never reach a value sufficient to produce a corona discharge or any burning of the crystal or the electrodes.

3. The crystal must start oscillating immediately upon the application of power to the oscillator plate and screen circuits. There must be no sluggishness in the crystal action. (A good test for sluggishness is to key the oscillator circuit at high speed with the keying arranged to open and close the cathode-to-ground circuit of the oscillator tube.)

4. The tuning of the oscillator circuits must not be critical and the oscillator must not be affected materially by the loading produced by the following stage whether or not the following stage is operating properly.

5. The oscillator must deliver sufficient power to drive a multiplier stage and at the same time fulfill the requirements set forth in the preceding paragraph.

A careful analysis of all circuits tested indicated that the most satisfactory circuit was one that was developed early in 1941 and which is shown schematically in Fig. 3A. In this circuit a 7C5LT beam tube is used in a more or less conventional crystal oscillator circuit. A 6V6 tube may be used in the same circuit with almost, but not quite, as good results. The new 50B5 tube will perform as well as or possibly better than the 7C5 tube and is useful in connection with a 50B5 multiplier tube where it is desirable to connect the heaters in series for operation from a 110 volt power line to eliminate a filament transformer. (If this is done a 100 ohm, 10 watt resistor should be connected in series with the tube heaters). A miniature type beam tube such as the 50B5 is undoubtedly superior as an oscillator tube in this circuit where it is desired to use crystals having a fundamental frequency above 8 mc.

A 400 ohm cathode biasing resistor bypassed by a .001 μfd. mica capacitor is connected between the oscillator cathode and ground to provide a normal bias between the grid and cathode of the oscillator tube. With this arrangement no damage can occur to the tube when the excitation is removed and also the crystal is not required to supply the full operating bias for the tube. A 10,000 ohm, non-inductive resistor is connected between the oscillator grid and ground. This resistor performs two functions. One function of this resistor is to provide a path from grid to ground. The other function is to provide a relatively low resistance load for the crystal. This load prevents the r.f. potential across the crystal from reaching a high value. A resistor of 5000 ohms may also be used with good results in many cases but 10,000 ohms seems to be the best value for positive operation.

The plate and screen potentials are obtained from a 150 or 300 volt power supply depending upon the power required from the oscillator. It is desirable, although not necessary, to regulate this potential. Slightly greater stability will be realized if this supply is regulated. Sufficient regulation may be obtained by the use of an OD3 regulator tube for 150 volt operation, or two OD3 tubes in series for 300 volt operation.

Note that both the screen grid and the plate tank circuits are bypassed directly to the cathode of the oscillator tube. Also note that the plate tank tuning capacitor is connected directly across the oscillator coil, without a series blocking capacitor. These are two important features.

If the screen and plate tank circuit bypass capacitors are connected to ground instead of to the cathode, there is a chance of regeneration and even of self-oscillation if the cathode bypassing capacitor is faulty or if the leads in the cathode-to-ground circuit are not very short.

The positive potential is applied to the screen grid of the oscillator tube through a 25,000 ohm series dropping resistor.

In normal operation, the r.f. current through the crystal is somewhat less than 1 ma., and never exceeds 15 ma. under any conditions, even with a 300 volt plate and screen supply. With a 150 volt plate and screen supply, the normal r.f. current through the crystal is practically unmeasurable, and does not exceed 10 ma. under any condition of tuning.

The oscillator will deliver over 5 watts of power to the multiplier stage when a 300 volt supply is used for the plate and screen potentials, and over 2 watts when a plate supply of 150 volts is used.

With a plate potential of 350 volts, and an r.f. load of 6 watts, the plate current is 37 ma., the screen grid current is 4 ma., the r.f. crystal current is approximately 1 ma., and the plate efficiency is approximately 46%.

Other Oscillators

For those wishing to use other oscillator circuits, the following circuits and operating data is offered.

Harmonic Oscillator. (Fig. 3B)

This is one of the many versions of the controlled oscillator type, where the circuit is either self-oscillating or where the regeneration is almost sufficient to produce self-oscillations, and where output is obtained at multiples of the crystal frequency. There are so many versions of this type of oscillator that space does not permit the inclusion of all data and other pertinent information. The circuit shown was selected because of its general performance and stability, together with a relatively safe value of crystal current. The output will vary between 2 and 5 watts, depending upon the output frequency.

With a 3.5 mc. crystal, any multiple of the crystal frequency up to 21 mc. may be obtained with an output power of 2 watts or over. The plate current will range from 20 ma. at 7 mc. to 40 ma. at 21 mc., and the r.f. crystal current will range from 25 ma. at 7 mc. to 38 ma. at 21 mc.

When testing oscillator circuits of this or any other type employing regeneration a 60 ma. pilot bulb should be connected in the crystal-to-ground circuit as a protection against accidental overloading of the crystal.

802 Crystal Oscillator. (Fig. 3C)

One of the more popular crystal oscillators utilizes the 802 type tube. If properly shielded, this oscillator provides a relatively high output with low crystal current. The regeneration within the tube is of such a low value that an external feedback capacitor is required to produce and sustain oscillations. Care must be exercised in the selection of the feedback capacitor, as too much feedback will produce high r.f. crystal currents which may damage the crystal.

With a plate potential of 475 volts and a screen grid potential of 250 volts, and an r.f. load of 8 watts, (3.5 mc. crystal, and output at the fundamental frequency) the plate current will be 34 ma., the screen grid current 15 ma., and the r.f. crystal current will be 6 ma. The plate efficiency under these conditions is approximately 49%.

6V6 Oscillator. (Fig. 3D)

Using a 6V6 oscillator in the circuit shown in Fig. 3D, the following data was obtained: (3.5 mc. operation)

With a plate potential of 345 volts, and a screen potential of 250 volts, the plate current is 45 ma., the screen current is 5 ma., and the r.f. crystal current is 1 ma. with a 6 watt r.f.

(*Continued on page* 154)

Deluxe Transmitter

(Continued from page 76)

load. The plate efficiency is approximately 38%.

Higher Power Triode Oscillator.

Among the triode oscillators, the HK24 or *Eimac* 25T or similar tube appears to have the most promising characteristics. The circuit is shown in Fig. 4A.

The data is as follows: (3.5 mc. operation)

With a plate potential of 750 volts, and an r.f. load of 17 watts, the plate current is 42 ma., the r.f crystal current is 8 ma., and the plate efficiency is approximately 53%.

With a plate potential of 1000 volts, and an r.f. load of 30 watts, the plate current is 60 ma., the r.f. crystal current is 16 ma., and the plate efficiency is approximately 50%.

From the above data it will be seen that for lowest crystal current, which results in the greatest frequency stability, the choice lies between the circuits using the 802, 6V6, or 7C5 tubes.

In the 802 circuit, the regeneration control may require adjustment for operation on different frequencies. Since this control is rather critical, a tube not requiring external regeneration is preferable. There is little choice between the 6V6 and 7C5 oscillators at 3.5 mc., but at higher frequencies, the 7C5 type offers some advantages, since the base insulation is superior, and the internal leads of the tube are shorter.

It is very important when using beam tubes or pentodes, to take care that the screen dissipation is not exceeded. If the tube is overdriven, or if the voltage is too high, secondary emission will result.

Frequency Multiplier Stage

With the tubes now available, it is no longer necessary to use a series of frequency doubling stages in order to obtain the desired output frequency. It is a relatively simple matter to obtain multiplication of from 2 to 20 in a single stage. The selection of the multiplier tube will depend upon the amount of multiplication desired as well as the output required from the multiplier. The most satisfactory tubes for use in a multiplier circuit appear to be either a 7C5 or the new 2E26 beam tetrode. The new 50B5 beam tube would probably be even more satisfactory than the 7C5 where a higher order of multiplication is required and where the power output can be relatively low.

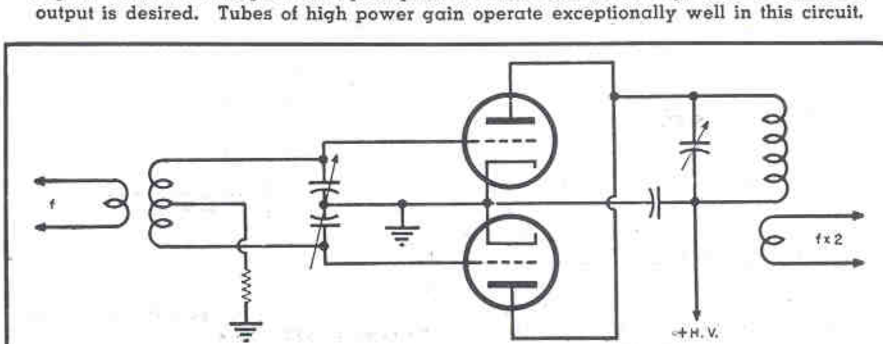
If the following amplifier stage requires very low driving power as in the case of a beam power amplifier and where the multiplication is not greater than 5 to 8, the 7C5 (and also the 50B5 tube) will be quite satisfactory. Where a power of 10 to 15 watts is required from the multiplier stage, the 2E26 tube will be found more satisfactory. Where it is desirable to obtain high orders of multiplication a single 2E26 may be used as a multiplier to drive a 2E26 amplifier. With this combination an output of 15 to 20 watts is obtainable at multiples of the oscillator frequency up to and including 25.

For the transmitter being described a 7C5 multiplier tube follows the oscillator stage and supplies more than sufficient drive to the 4E27 amplifier stage at multiples of 2, 3, and 4 times the crystal frequency. The circuit is shown schematically in Fig. 4B. In the original setup, a 2E26 was used in the multiplier stage but it was found difficult to reduce the drive to the 4E27 stage to a sufficiently low level for satisfactory operation. For this reason the 2E26 was replaced by a 7C5 multiplier tube. The plate tank circuit of the multiplier stage is arranged with a tap switch in such a manner that operation at 14, 21, and 28 mc. may be obtained without physically changing the coils. When the transmitter was placed into operation it was found necessary to further reduce the drive to the 4E27 amplifier. This was done by dropping the plate voltage applied to the 7C5 multiplier to 150 volts.

Other Frequency Multiplier Systems

Frequency multiplier systems are generally so well-known and have been treated so thoroughly in previous publications that little more need be said about them, except in a general way. Almost any single-ended amplifier circuit will operate satisfactorily as a frequency multiplier at frequencies up to 30 mc., with the pentode and beam tubes probably heading the list in performance. At the higher

Fig. 7. Schematic diagram of a push-push doubler used where high second harmonic output is desired. Tubes of high power gain operate exceptionally well in this circuit.



frequencies, the problem of obtaining satisfactory operation of frequency multipliers becomes more difficult, if any appreciable output power is required. If an extremely low output will be sufficient, the low capacity receiving type of tube may be used quite satisfactorily.

For those desiring to operate on the higher frequencies, and particularly where the multiplier is to be used as a driver and must supply an appreciable amount of power, the push-pull tripler will be found very satisfactory. The basic circuit is shown schematically in Fig. 5.

In this system, the ability of a push-pull amplifier to suppress the second harmonic and at the same time generate third harmonics is utilized.

The grid bias should be somewhat higher than in a conventional doubler stage for proper operation. This system is particularly suited to the frequencies where best operation dictates a conversion from the conventional coil tank circuits to resonant lines, such as from 48 mc. to 144 mc. A conventional coil is used in the grid circuit, while a tuned line is used in the plate circuit. This provides an arrangement with the tube capacities effectively in series, and permits the use of a sufficiently high inductance in the plate circuit for efficient operation.

With this arrangement, using two HK24s or similar tubes with a plate potential of 650 volts, an output power of 25 watts is available at frequencies up to 170 mc.

A modification of this system provides outputs at 1, 2, and 3 times the input frequency. This arrangement is shown in Fig. 6, and is a combination of a push-pull amplifier or push-pull tripler, and the almost forgotten "push-push" doubler arrangement, which may become popular if the proposed 21 mc. band is opened to the amateurs, as it will provide output on 7 mc. for instance, as a neutralized amplifier, 14 mc. as "push-push" doublers, and 21 mc. as a push-pull tripler.

The "push-push" doubler is an old standard where large output is desired from a doubler, but with the high efficiency of the pentode and beam type of tubes, and has all but been forgotten. It should be remembered however that the new tubes having high power gain will also operate exceedingly well in this circuit. Just as a reminder, the "push-push" doubler circuit is shown schematically in Fig. 7. It is particularly well suited to the 829B type of tube, as well as any of the twin triode types.

(Concluded next month)

ANSWERS TO BIZ QUIZ

1. c	6. b	11. c	16. c
2. b	7. c	12. c	17. b
3. b	8. b	13. a	18. a
4. a	9. b	14. b	19. b
5. c	10. a	15. a	20. c

ARE YOU A SALESMAN? Give yourself 5 points for each answer you had checked correctly. A score of 45 is average, and 75 or better is very good indeed.

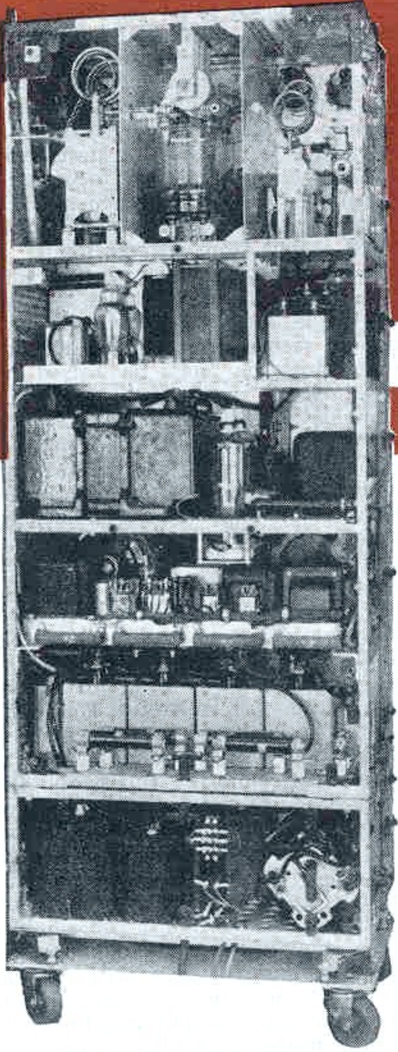


Fig. 1. Rear view of transmitter. Front view of this unit was shown last month.

Deluxe Amateur TRANSMITTER

By JAMES N. WHITAKER, W2BFB
Eng. Dept., Hammarlund Mfg. Co.

Part 2. Concluding article covering the design principles for a 1-kw. amateur type transmitter.

IN CONTINUING the discussion of deluxe amateur transmitter design begun last month, we would like to point out to our readers that the circuit diagram for the complete transmitter was given in the April installment, along with a discussion of the oscillator and frequency multiplier stage. Reference should be made to this discussion before proceeding to a consideration of the driver stage.

Driver Stage

The driver stage uses a 4E27 beam tetrode in a more or less conventional amplifier circuit. When using a tube of this type it is well to observe the manufacturer's recommendations for maximum grid drive. This value should never be exceeded, and satisfactory operation will generally be obtained with driving power considerably below the maximum permitted. In the present instance it was found that the grid current should not exceed 0.3 ma. for optimum operation. With this value of grid drive the 4E27 tube is capable of delivering approximately 225 watts of r.f. power to the final amplifier. The plate and screen grid power for the driver stage is obtained from the high voltage power supply which supplies plate power to the final amplifier. The full potential is applied directly to the anode of the tube while the screen grid potential is applied to the tube through a 100,000 ohm resistor. A 1200 ohm cathode biasing resistor is connected between the filament center tap and ground to provide normal operating bias for the tube. A 250,000 ohm grid resistor is also used to prevent excessive grid current when the plate potential is reduced and the drop across the cathode biasing resistor decreases correspondingly.

There has been much controversy regarding the use of the new beam type of tubes versus a neutralized triode. Unquestionably much of the reluctance to incorporate these new and wonderful tubes in equipment is due largely to a lack of understanding as to just how they may be satisfactorily incorporated in the equipment. The general complaint seems to be the difficulty in eliminating the tendency toward self-oscillation.

In designing any equipment using a beam tube, always bear in mind the fact that the power sensitivity of this new type of tube exceeds by far the power sensitivity of any tube heretofore known. It is this extremely high power sensitivity that makes this tube so highly desirable, and at the same time so apparently difficult to operate satisfactorily.

In order to successfully design an amplifier using a high-powered beam tube, it is extremely important to bear in mind that a very small amount of feedback, which in a triode amplifier would be practically undetectable will be a very serious amount indeed for a high gain beam tube.

The isolation of the input and output circuits must be as nearly perfect as possible. The r.f. bypassing must be complete with all leads as short as possible. Each filament terminal must be bypassed directly to the chassis as close to the socket terminal as possible. The screen grid must be bypassed to the filament terminals as well as to the chassis, and if the suppressor grid is not directly connected to the filament, it must also be bypassed directly to the filament as well as to the chassis.

If the isolation between input and output circuits is complete, the amplifier will operate as smoothly as a conventional neutralized triode amplifier and the driving power required will be almost unbelievably small compared to the power required to drive any other type of amplifier having an equivalent power output.

If the designer is unable to eliminate feedback entirely, there are several ways to suppress spurious oscillations. One way is to insert a 50 ohm, non-inductive resistor in the screen grid circuit, between the screen grid terminal and the bypass condenser. Another method is to insert a 50 ohm resistor (around which has been wound eight or ten turns of wire forming a small inductance shunted by a 50 ohm resistor) in the grid or plate circuit.

Any of these suppression methods are subterfuges, serving to remove the symptoms rather than the ailment, and are, in reality, an admission that the equipment has not been properly designed.

It is possible to obtain satisfactory operation from a triode amplifier when departing widely from the manufacturer's recommended ratings regarding driving power, grid bias, and plate voltage.

In a beam power amplifier, such departures are a direct invitation to trouble, and should be attempted only by those completely familiar with every detail of the operational theory of a beam tube. Perhaps one of the most difficult things for the amateur to grasp is that the grid drive must be kept well within the maximum limits specified by the manufacturer

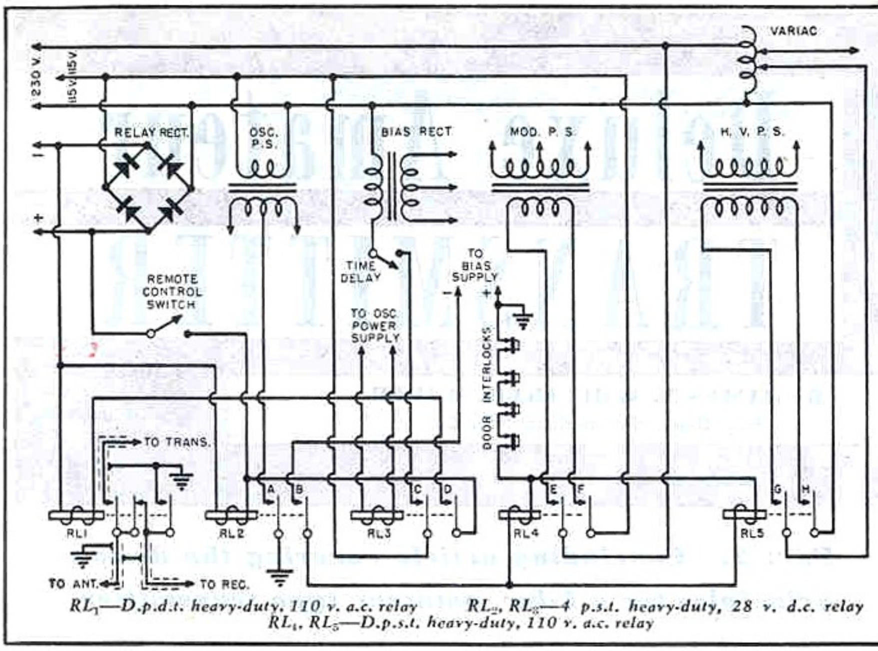


Fig. 2. Complete schematic diagram of remote control system. A copper oxide rectifier supplies power for the remote control relay and the antenna changeover relay.

of the tube. Excessive grid drive can not be tolerated by a beam tube regardless of other operating conditions, and the most satisfactory operation is generally obtained with a grid current of less than one milliampere. The manufacturer's maximum grid current rating is generally the maximum permissible current which will not damage the grid structure or cause sufficient heating of the grid leads to crack the glass seal.

Power Amplifier Stage

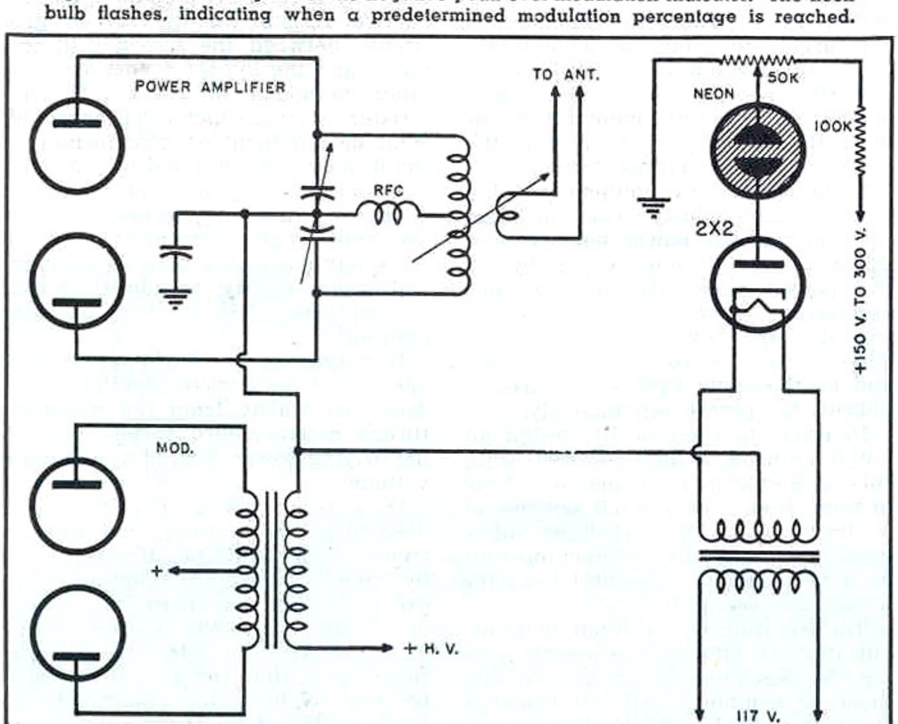
A rather wide selection of tubes is available for use in the power amplifier stage. The choice of tubes depends largely upon the efficiency desired and the power output needed. Since the 4E27 driver stage is capable of supplying sufficient power to drive almost any 1 kw. amplifier stage, any tube or tubes of sufficient power capabilities may be used. One point to bear in mind is that amateur transmitters are limited to a maximum plate input of 1000 watts. For this reason one must consider the efficiency of the final amplifier rather than economy of tubes in order to obtain the greatest possible power output with the permissible input. In order to obtain the best possible efficiency it is necessary to use tubes capable of considerably more power than is required. Another very good reason for using relatively high powered tubes is that the output need not be decreased in order to obtain satisfactory high-level modulation. This is not necessarily the most economical way to design a transmitter but it is the most satisfactory way of obtaining a maximum power output from a given input.

The power amplifier stage in a telephone transmitter should be a push-pull stage in order to discriminate against second harmonic radiations. Some objection may be raised because of the possibility of a third harmonic radiation from a push-pull amplifier but these radiations are never as serious as the second harmonic radiations because of discrimination against the higher frequencies in both the plate tank and antenna circuits.

In designing the power amplifier it is important to consider very carefully some arrangement for completely shielding the input and output circuits from each other and from the rest of the transmitter. The most satisfactory method of shielding is to arrange the power amplifier so that the input circuit, the tubes, and the output circuit are effectively in separate compartments with the neutralizing system in the compartment with the tubes. It will be found that with this arrangement the nearest approach to true neutralization is obtainable. If the shielding is not complete, the apparent neutralization will not be true neutralization since a certain amount of input-output coupling will be compensated for in the neutralizing. When this occurs there is danger of feedback, parasitic oscillations, and various other difficulties when the plate power, grid drive, or output coupling is changed. This is a condition which most commonly produces parasitic oscillations during modulation peaks which is easily understood when one remembers that high-level modulation actually varies the input power to the amplifier in accordance with the applied modulating power.

In a push-pull amplifier it is necessary to very carefully design the circuits to provide equal grid driving power to both tubes. The plate loading must also be equal. In practice it is very difficult to design a center tapped coil in such a way as to obtain a perfect electrical balance in each half of the coil. This may not be too serious at frequencies below 14 mc. but at higher frequencies irregularities which are almost unnoticeable may produce a serious unbalance. For this reason it is well to depend on a split stator tuning capacitor to provide electrical center tap rather than to bypass the center tap of the coil to ground. Tuning capacitors are manufactured to very close tolerances and are generally assembled with the aid of very accurate jigs and therefore, for all practical purposes, may be

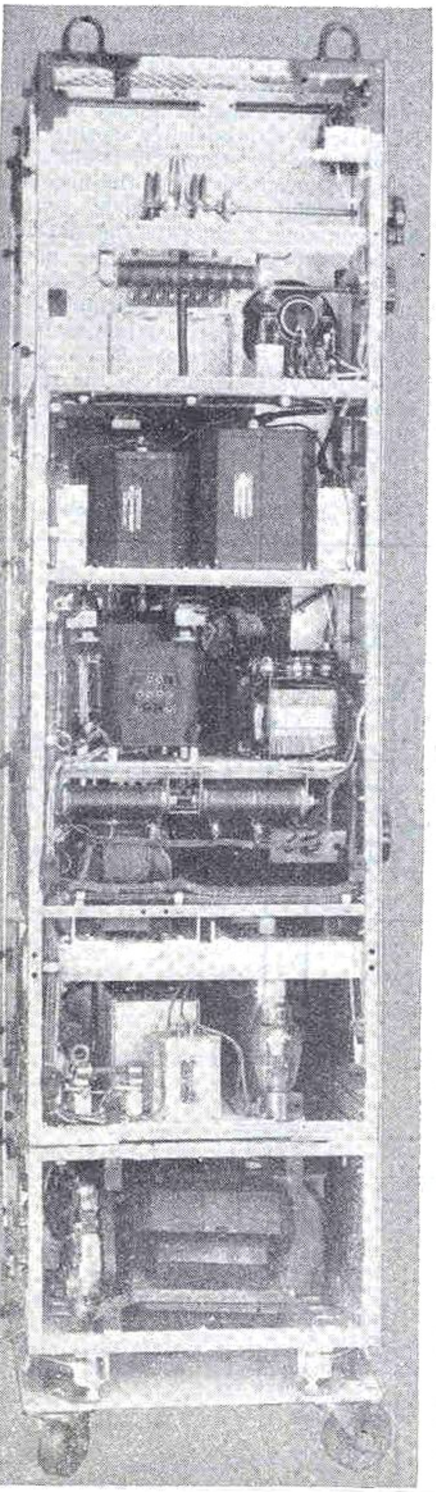
Fig. 3. Schematic diagram of the negative peak over-modulation indicator. The neon bulb flashes, indicating when a predetermined modulation percentage is reached.



considered as being perfectly balanced electrically as well as mechanically insofar as capacity is concerned.

Any tuned r.f. circuit is more efficient when the tuning capacitor is connected directly across the inductance. In order to do this it is usually necessary to insulate the rotor of the variable capacitor from ground instead of grounding the rotor section and connecting one side of the inductance to the rotor through a fixed capacitor. This is more important in the higher power stages because of the higher circulating currents but it is important in any stage since there is always a certain amount of loss in even the highest grade of mica capacitors. This is also important in high power stages as it prevents grounding the high voltage power supply in the event that a flash-over of the capacitor occurs.

Fig. 4. Left side view of transmitter.



The antenna coupling circuit should be variable by means of a dial or knob accessible from the front panel. The number of turns and diameter of the coupling coil will depend upon the method of feeding the antenna and if the connection to the transmitter is by means of a coaxial transmission line, the coupling coil will be smaller or will contain fewer turns than if a higher impedance line is used. Where the same antenna is to be used for the receiver and the transmitter, the antenna changeover relay should be mounted inside the transmitter and as close as possible to the coupling coil. The relay and the connection should be adequately shielded from the power amplifier plate tank circuit. The location of the antenna changeover relay adjacent to the output coupling coil is very important where coaxial transmission line is used. If the relay is located outside the transmitter, it will cause a discontinuity of impedance which may result in serious standing waves along the transmission line.

Power Supply System

The power supply systems for a high-powered transmitter do not necessarily have to be complicated. Primary consideration should be given to designing the power supplies so that there will be a minimum of reaction between stages. This is particularly true of the reaction between the oscillator and the amplifier stages. It is always well to provide a separate power supply for the oscillator and multiplier stages rather than to attempt to use a common power supply for the entire transmitter. It is also well to use some sort of voltage regulation in the oscillator power supply although this is not absolutely necessary when using the oscillator circuit previously described. It should not be necessary in any case to use an elaborate vacuum tube voltage regulator. A regulator tube such as the OD3/VR150 or two such tubes connected in series should be ample. The intermediate or driver amplifier and the final amplifier may be operated successfully from a common power supply. It is very desirable to do this where a variac or some other means of primary power control is used.

The class "B" modulator tubes should be operated from a separate power supply unless the main power supply has unusually good regulation and the class "B" modulator tubes are operated with zero bias. Where grid bias is required for the modulator tubes a power supply should be provided to supply this bias and this power supply should be very heavily loaded to prevent a change in bias due to varying grid current.

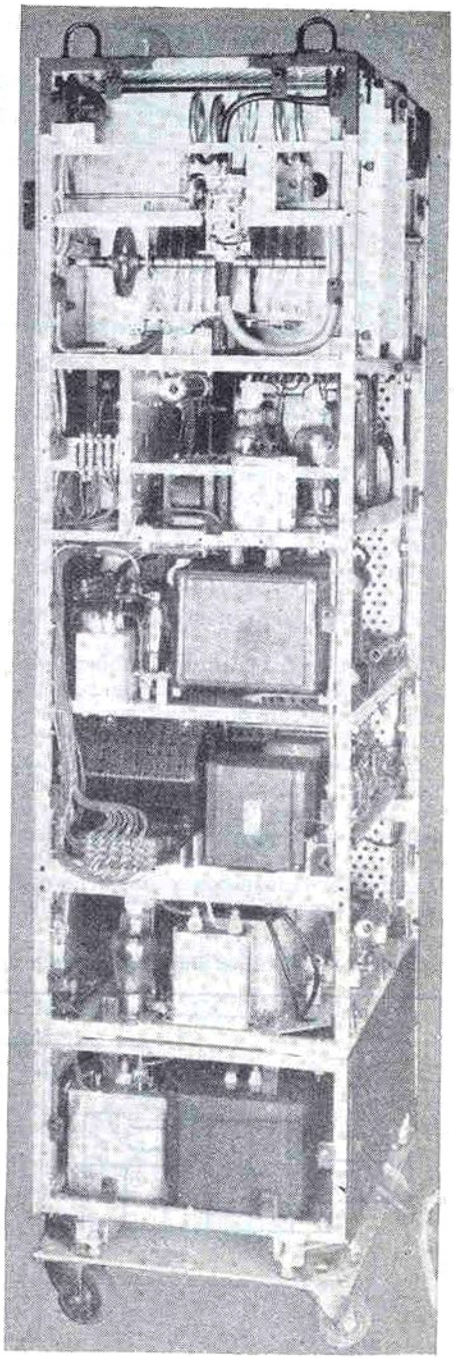


Fig. 5. Right side view of transmitter.

In the transmitter being described a small power supply provides the power for both the oscillator and multiplier stages. The main high voltage power supply provides power for the driver and final amplifier stages. The main power supply is equipped with a variac in the primary circuit to permit easy adjustment of the input power. The class "B" modulator stage has its own power supply and a bias rectifier system provides 60 volts of negative bias for the modulators. The bias supply is loaded with a 250 ohm resistance causing a normal drain of approximately 0.24 amperes. This high bleeder current assures a minimum of fluctuation in the bias supply due to the varying grid current of the modulator tubes. The bias supply also provides power for some of the relays.

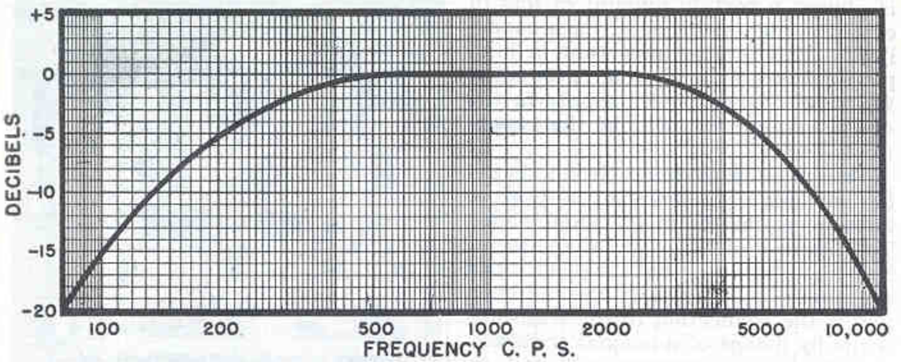


Fig. 6. Audio response curve of speech amplifier. Note that the output falls off rapidly below 300 cycles and over 3000 cycles. This is ideal for voice transmission.

Remote Control System

A positive acting remote control system should be provided in any transmitter in order that the transmitter may be started and stopped from the operating position by means of a toggle switch or other simple device.

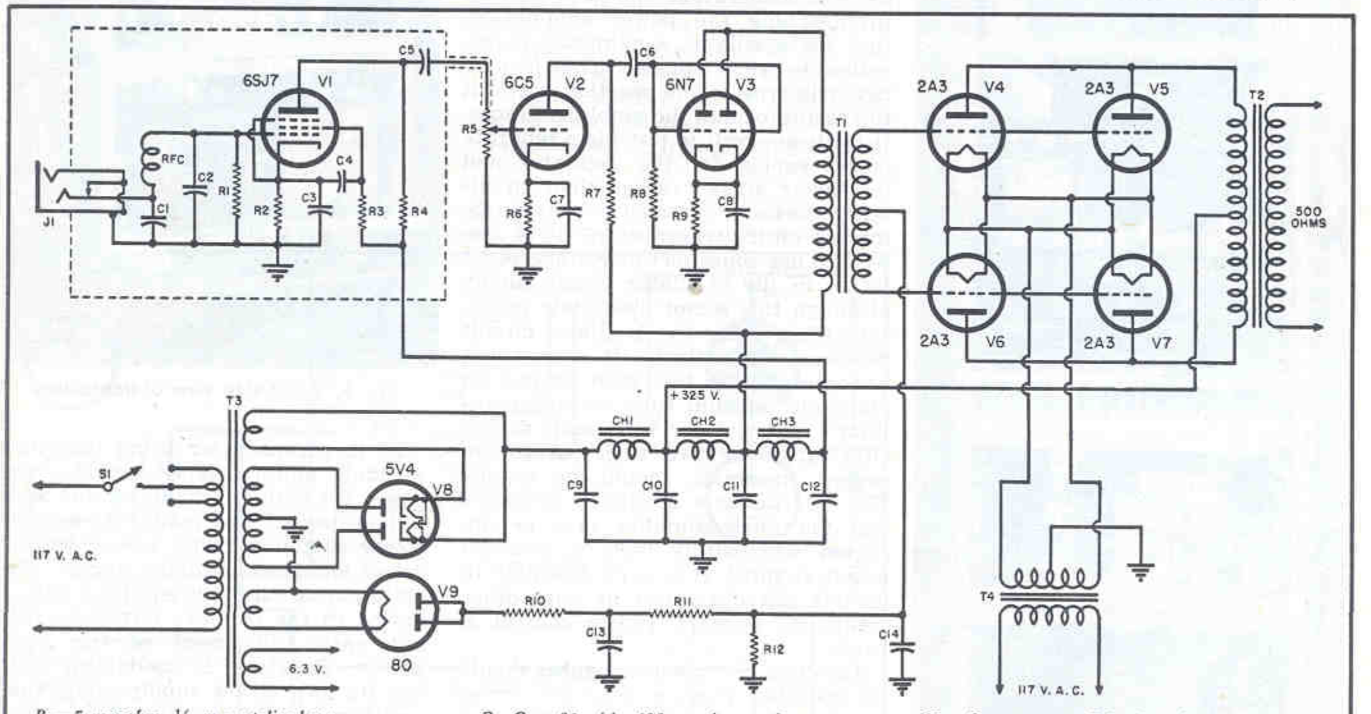
A number of relay combinations may be worked out to suit the particular installation once the proper sequence of operations has been determined. The system should provide a means for applying power to the various parts of the transmitter in such a sequence as to prevent the application of power to the power stages in the transmitter before power has been applied to the oscillator and multiplier stages. It must also provide means of transferring the antenna from the receiver to the transmitter before power is applied to the final stages. The system must also provide a means for removing the power from the final stages before the power is removed from the oscillator and multiplier stages and sufficient time must elapse between the removal of the power from the final stages and the operation of the antenna changeover relay to assure that there will be no power in the antenna circuit when the antenna changeover relay is operated.

The control system in the transmitter being described uses a total of five relays for performing all operations. A copper oxide rectifier supplies power for the remote control relay and the antenna changeover relay. The circuit is shown in Fig. 2.

Relay RL_2 is the remote control relay, receiving its power from the copper oxide rectifier, through the remote control switch. The operating coil of relay RL_3 is connected in the oscillator power supply circuit as a filter section, and receives power when the oscillator power supply is energized. Power for relays RL_4 and RL_5 is obtained from the bias supply, through contacts *B* of relay RL_2.

The operation of the system is as follows: When the remote control switch is closed, relay RL_2 operates, closing contacts *A* and *B*. Contacts *A* are in the center tap of the oscillator power supply transformer. When these contacts close, the power builds up in the oscillator power supply, energizing the operating coil of relay RL_3. Relay RL_3 operates closing contacts *C* and *D*. Contacts *C* close the primary power circuit of the bias supply, through the time delay switch, and contacts *D* operate the antenna changeover relay. When the power builds up in the bias supply, relays RL_4 and RL_5 operate, since contacts *B* of relay RL_2 are closed. When contacts *E*, *F*, and *G*, *H* of relays RL_4 and RL_5 close, power is applied to the modulator and the main high voltage supplies, and the transmitter is in operation.

Fig. 7. Schematic diagram of speech amplifier. The unit has an over-all gain of 100 db. and an undistorted output of 31 watts.



R_1—5 megohm, ½ w. metalized res.
R_2—1500 ohm, ½ w. metalized res.
R_3—2 megohm, ½ w. metalized res.
R_4—500,000 ohm, 1 w. metalized res.
R_5—250,000 ohm pot.
R_6—5000 ohm, 1 w. metalized res.
R_7—100,000 ohm, 1 w. metalized res.
R_8—250,000 ohm, 1 w. metalized res.
R_9—800 ohm, 1 w. metalized res.
R_{10}—2000 ohm, 20 w. w.w. res.
R_{11}—4000 ohm, 20 w. w.w. res.
R_{12}—2500 ohm, 20 w. w.w. res.
C_1, C_2—100 μμfd. mica cond.
C_3, C_7, C_8—8 μfd., 50 v. dry elec. cond.
C_4, C_6—.01 μfd., 400 v. mica cond.
C_5—.002 μfd., 600 v. mica cond.
C_9—6 μfd., 1000 v. Dykanol or Pyranol cond.
C_{10}—10 μfd., 600 v. Dykanol or Pyranol cond.
C_{11}, C_{12}—125 μfd., 350 v. elec. cond.
C_{13}—3 μfd., 600 v. Dykanol or Pyranol cond.
C_{14}—50 μfd., 50 v. dry elec. cond.
RFC—1.5 mh. pi-wound r.f. choke
CH_1—15 hy., 300 ma. filter choke
CH_2, CH_3—25 hy., 50 ma. filter choke
T_1—Audio trans. Single plate to P.P. grid
T_2—Output trans. P.P. plate (1500 ohms plate-to-plate) to 500 ohm line. 35 watt output
T_3—Power trans., 475-0-475 (77 v. tap) @ 300 ma.; 6.3 v. @ 5 amps.; 5 v. @ 3 amps.; 5 v. @ 3 amps.
T_4—Fil. trans. 2.5 v. c.t. @ 10 amps.
J_1—Input jack
S_1—S.p.s.t. toggle sw.
1—6SJ7 tube
1—6C5 tube
1—6N7 tube
1—5V4 tube
1—80 tube
4—2A3 tubes

As we have shown, the sequence of operation is as follows: The oscillator power supply comes up first, then the antenna changeover relay operates, then the bias supply comes up, and finally the power comes up in the modulator and p.a. power supplies.

When the transmitter is shut down, the remote control switch removes the operating power from relay RL_2, which immediately opens contacts A and B of relay RL_2. Contacts B of relay RL_2 open, removing operating power from relays RL_4 and RL_5, causing contacts E, F, G, H to open, removing the primary power from the modulator and main power supply.

As the power in the oscillator power supply dies down, the operating coil of relay RL_3 is de-energized, permitting contacts C and D to open. The opening of contacts C removes the power from the bias supply, and the opening of contacts D operates the antenna changeover relay RL_1.

From the above, we find that the sequence of operation for shutting down the transmitter is not exactly in the reverse of the starting sequence, but is as follows: The oscillator and all high voltage power supplies are shut off simultaneously; then the antenna relay operates and the bias supply is shut off after the oscillator power supply dies down, whereas in starting up, the oscillator power comes on, then the bias comes on and the antenna changeover relay operates, and lastly the high voltage power supplies come on.

With this arrangement, failure of the bias supply will remove the high voltages, and failure of the oscillator supply will shut down the entire transmitter. In this manner, the tubes are all protected from loss of bias, and from loss of excitation due to oscillator power supply failures.

Over-Modulation Indicator

Any transmitter used for telephony should be equipped with a very positive means for indicating over-modulation. An indicator which shows average modulation is not satisfactory for voice operation because of peaks which occur in normal voice frequencies. In order to be certain that serious over-modulation does not occur during the peaks of the voice frequencies, the over-modulation indicator must indicate over-modulation peaks. When an r.f. amplifier is fully modulated, the plate voltage swings from zero to twice the normal value. When over-modulation occurs the plate voltage will actually swing from a negative value to more than twice the normal positive value. Because of this action a negative peak over-modulation indicator may consist of simply a high voltage rectifier and a neon glow lamp as shown in Fig. 3 with a bias voltage applied between the neon lamp and ground. The rectifier filament supply transformer should be insulated for approximately three times the normal plate supply voltage of the transmitter. The filament of the rectifier is connected to the side of the modulation transformer secondary which feeds power to the modulated amplifier. The plate of the rectifier tube connects to one side of an ordinary neon glow lamp. The other connection to the neon glow lamp is to a positive bias. Since the starting voltage of the standard neon glow lamp which is on the order of 30 to 50 volts has been overcome by a biasing voltage, the glow lamp will flash on overmodulation peaks which are hardly detectable by any other means.

The current drawn by a standard neon lamp is very small, and therefore a bias adjusting potentiometer of 50,000 ohms is satisfactory. The bias potential may be taken from any convenient low voltage source such as the oscillator power supply.

With the main high voltage power supply off, adjust the neon bias to a value where the lamp just starts to glow.

With this adjustment, the lamp will flash whenever a modulation peak reaches exactly 100%, regardless of the plate voltage applied to the r.f. amplifier.

If the bias is not used, the overmodulation indicator will be less accurate, but will still be quite satisfactory for use where the d.c. plate potential applied to the r.f. amplifier is 1000 volts or more. If the starting voltage of the neon lamp is 50 volts, and the d.c. plate potential applied to the r.f. amplifier is 1000 volts, the lamp will flash when the peak modulating voltage becomes negative by a value of 50 volts, representing 5% over-modulation on a peak, which can be tolerated. The percentage of overmodulation detectable with an unbiased neon lamp system becomes increasingly less as the d.c. plate potential applied to the r.f. amplifier is increased, and will be 2.5% for a d.c. plate potential of 2000 volts, 1.6% for 3000 volts, etc.

Speech Amplifier

The speech amplifier in a large transmitter should be a separate unit and should be connected to the transmitter proper by means of a standard 500 ohm line. The amplifier should have sufficient gain to permit the use of any of the commercially available crystal microphones. The noise output from the amplifier should be at least minus 60 db. The audio frequency response of the amplifier should not be flat. Since we are interested only in voice frequencies, those frequencies below 200 cycles and above 3000 cycles should be appreciably attenuated. This may be conveniently accomplished by the proper selection of coupling capacitors and resistors in the amplifier without the use of special filter circuits. The amplifier designed for use with the transmitter described has a gain of 100 db. and has an undistorted output of 31 watts. The noise level with the gain control full on and the microphone disconnected is approximately minus 70 db. The audio response as is indi-

(*Continued on page* 165)

regularly; the morning beam, 7-8:15 a.m., is carried on 11.63, 11.72, 15.18, 17.82. (Cooley)

Vatican—HVJ, 9.660 and 5.970, has *English* news daily at 10 a.m.; *English* talks are radiated daily at 1:15 p.m. on these frequencies. On Sundays, commentaries are heard in French, Spanish, *English*, German, and Polish, at 5:15 a.m., followed at 5:30 a.m. by Holy Mass. On Tuesdays, *English* news is radiated at 10.30 a.m. on 17.445. (Salmon)

Yugoslavia—Radio Belgrade, 9.42, is being heard again at 12 midnight in New York; very weak. (Beck)

* * *

Acknowledgement

Sincere thanks go to all contributors to this issue of ISW. —30—

Deluxe Transmitter

(*Continued from page* 78)

cated in the accompanying curve (Fig. 6) falls off rapidly below 300 cycles, reaching minus 15 db. at 100 cycles. On the high frequency end the response falls off rapidly after 3000 cycles reaching minus 15 db. at approximately 8500 cycles and is minus 20 db. at 10,000 cycles. The complete schematic diagram of this amplifier is shown in Fig. 7. Because of this lack of linearity very flattering reports are continually being received regarding the speech quality of transmissions.

The apparent improvement in speech fidelity is brought about by a combination of transmitter and receiver characteristics.

A receiver must have a relatively narrow pass band to be very satisfactory for amateur communication purposes. The pass band in most amateur receivers is either limited to 3000 cycles, or is adjusted to approximately that value by the operator. Under these conditions, all frequencies above 3000 cycles represent wasted energy if actually emitted by the transmitter.

If the a.f. response of the transmitter is linear, the effect so far as the listener is concerned is an accentuation of the lower frequencies, since the receiver has eliminated the higher frequency components. It is then apparent that if the lower frequencies are attenuated at the transmitter, the middle range will be accentuated, and the over-all effect as noted at the receiving station will be that of a much higher quality of reproduction than would be possible with a linear audio frequency response at the transmitter.

—30—

ANSWERS TO BIZ QUIZ

1. b	6. b	11. b	16. c
2. a	7. a	12. b	17. c
3. a	8. c	13. a	18. b
4. c	9. b	14. c	19. c
5. c	10. b	15. b	20. b

ARE YOU A SALESMAN? Give yourself 5 points for each answer you had checked correctly. A score of 45 is average, and 75 or better is very good indeed.