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A Bandpass Transmitter-Exciter Using an RCA 6146

Part I

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Are you planning to build a new VFO, an all-band exciter, or a pi-network final? If so, we're sure that you will find it very worthwhile to read W2PUD's article before you begin. It is intended for those readers who want to build something other than a conventional transmitter.

This article differs from the usual how-to-build-it descriptive article in that it features a thorough discussion of the "groundwork" that preceded the final design. Because of the enthusiasm with which the active ham reads such a discussion, and the improbability of the average ham copying this transmitter to the last detail, this article has been divided into two parts. Part I contains a description of the transmitter; the constructional details will appear in Part II. This arrangement provides ample space for the author to expound on some very interesting ideas on the design of a modern multiband rig. A complete schematic diagram and parts list are included in Part I for those interested in getting an early start.

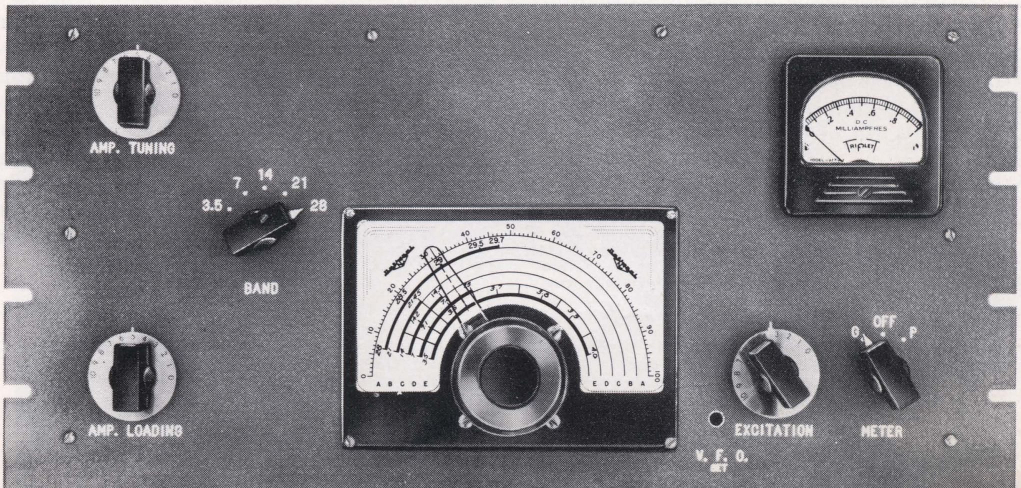
The excellent performance of the RCA-6146 beam-power amplifier at high frequencies, its maximum ICAS rating of 90 watts input for cw operation, its very low driving-power requirement (0.3 watt), and the elimination of the need for special shielding make this tube the logical successor to the 807 for use in an exciter of modern design.

General Requirements

Early in the project, it was decided that the transmitter-exciter to be built around the 6146 should have the following features: (a) operation on the 3.5-, 7-, 14-, 21-, and 28-Mc bands by means of a single handswitch and VFO; (b) provision for break-in operation; (c) freedom from TVI; (d) reasonably simple construction; (e) minimum of tubes and controls.

The transmitter shown in *Fig. 1* provides all of these features. For ease of operation, this unit requires no tuning other than the VFO and the final tank; broadband double-tuned tank circuits are used in the exciter stages, and a tapped pi-L tank circuit provides flexible TVI-proof operation of the final am-

Fig. 1. Pick your band, set the VFO, tune and load the final, and you have an output of 65 watts cw or 45 watts for AM phone operation.



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plifier. A keyed amplifier between the VFO and the first frequency multiplier eliminates any back-wave and permits full break-in operation.

An output of 65 watts cw or 45 watts AM phone is available on all bands.* Power requirements are 6.3 volts ac at 4.1 amp, 250 volts dc at approximately 100 ma for the exciter stages, and either 600 volts at 150 ma or 750 volts at 125 ma for the final amplifier. The 6146 operates well at reduced plate voltages and can be run at the full rated plate current of 150 ma.

Design Considerations

Heterodyne VFO. Keeping in mind the general requirements of the rig, the first consideration was the VFO. Initially, a heterodyne-type VFO was investigated to obtain break-in operation. This unit used an 8.5-Mc crystal beating with a VFO which tuned from 4.5 to 5 Mc to provide output over the 3.5-Mc band.

Several circuits were moderately successful, providing sufficient output and good keying in the mixer stage. Although these tests were carried out on the bench with rather haywire unshielded circuits, it was possible to eliminate the receiver backwave almost completely when the key was up. One of these circuits used a 6AK6 Clapp VFO, a 6C4 crystal oscillator followed by a 6AU6 buffer and a 5763 mixer. The 6AU6 was keyed, and a bandpass tank circuit was employed in the output of the mixer to attenuate the unwanted sideband and the two oscillator frequencies. The use of the 5763 as a mixer, however, required that an amplifer be used to bring the signal up to the proper level to drive the final on 75 meters.

The original lineup, using a 5763 amplifier/multiplier and 5763's in all of the multiplier stages, was viewed with some misgivings because the 5763 oscillated when operated as a straight-through amplifier. Various neutralization circuits were applied to the 5763 without success, the chief difficulty being the maintenance of proper phase opposition in the band-pass coupling circuits over the fairly large bandwidth of the 3.5-Mc band.

An even more serious difficulty arose when the band-pass tank circuit provided inadequate filtering thereby permitting a complex signal (containing both oscillator signals and their sidebands) to be applied to an amplifier which had to be driven hard enough to draw grid current (and thus present a non-linear impedance). Although the desired sideband was partially filtered out in the previous stage, there was sufficient voltage present at the unwanted frequencies, and the heterodyne signal which resulted from this non-linear mixing could only be characterized as a mess.

A little reflection shows that nothing other than the above results can be predicted when a high-level mixing system is used unless a filter having rigid requirements is used in the output of the mixer. (It is entirely possible to build a successful heterodyne VFO; several have already been described in the amateur-radio literature.) Mixing is best accomplished at low level, where unwanted sidebands can be filtered more easily without too much shielding.

The advantage of a mixer VFO lies mainly in the ease of keying and obtaining break-in, and in the stability which is gained by allowing both oscillators to run continuously. However, there are other ways to accomplish the same result with much simpler circuits.

Shielded VFO. The VFO finally chosen for this transmitter is one that has been in use in the author's shack for several years. The system is not novel; in fact, it has been used in several commercially-built transmitters, and has been described in the literature.* The VFO operates on 1.7 Mc. Sufficient shielding is employed so that it can be run continuously —keying is accomplished in the first amplifier stage following the oscillator.

In this system, the oscillator must be relatively free from harmonics and the design must not include any non-linear circuits between the VFO and the keyed stage. The VFO employs a Clapp oscillator which is especially suitable for this application because it is very stable; also, it is essentially a weak oscillator having a rather high Q and very little harmonic output. The particular variety of Clapp VFO chosen for this application has been described previously.** By running the oscillator at low plate voltage (40 volts) and following it with a high-gain keyed stage, it is possible to reduce the radiation to almost nil, so that the VFO may be run continuously without interference when the key is up.

** The reader may ask why the frequency range of this transmitter does not include the 11-meter band. Considerable thought and experiment went into this possibility. In order to cover 3.3 to 4 Mc with a double-tuned circuit, the Q must be lowered to a value that makes the proper degree of coupling between coils very difficult to obtain; furthermore, the skirts of the response curve of the stage would be fairly broad. It was felt that the advantages of 11-meter operation do not justify the increased complexity or compromises in the design, e.g., an extension of the tuning range of the VFO down to 3.3 Mc results in the 14-Mc band occupying a smaller section of the dial.*

** "A Solution to the Keyed-VFO Problem," by R. M. Smith, W1FTX, QST, Feb. 1950, pg. 11.*

*** "Some Notes on the Clapp Oscillator," by R. G. Talpey, W2PUD, QST, Jan. 1949, pg. 45.*

VFO and Keyed Amplifier. The complete circuit for the transmitter is shown in *Fig. 4.* The Clapp oscillator uses a single section of a 12AU7; the other section of this tube is a cathode follower which provides a low-impedance output that "can be led around the chassis" through a shielded cable to the grid of the 6AU6 keyed amplifier.

The use of a high-gain keyed amplifier makes it possible to operate the VFO with an output voltage of about 1 volt, thereby making the shielding problem easier to solve.

It was found desirable to mount the coupling capacitor and grid leak for the keyed-amplifier stage inside the oscillator shield compartment. This arrangement permits a short (¼-inch) length of signal lead to be exposed for connection to the grid of the keyed amplifier. Simple by-pass and decoupling networks in the power leads to the VFO compartment, plus the use of shielded wire for power wiring leaves little possibility for leakage from the oscillator.

The 6AU6 high-gain keyed amplifier operates close to class-A conditions. It provides good shielding and enough output to drive a 5763 (first doubler) which doubles to 3.5 Mc. Impedance coupling is used between the 6AU6 and the first doubler to reduce the number of tuned circuits.

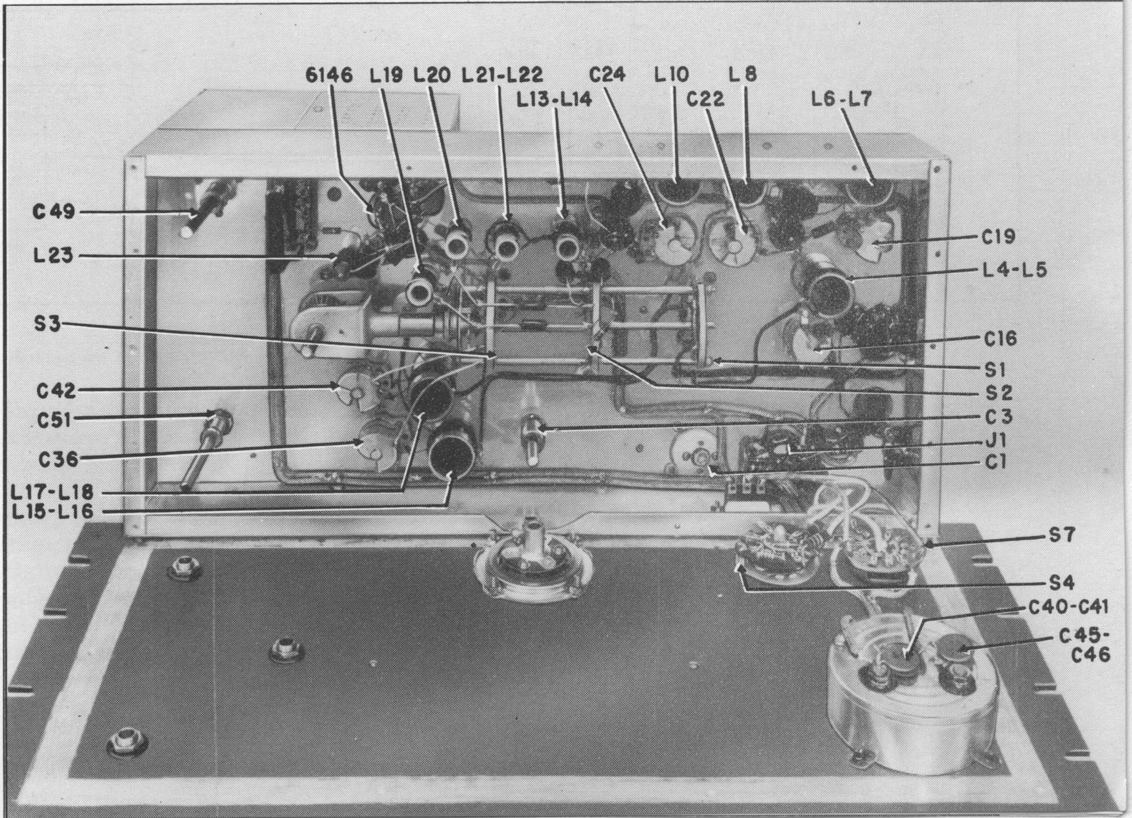
Coupling Methods For Bandpass Operation

In this transmitter, bandpass coupling circuits are used to eliminate the need for retuning the multiplier stages when the frequency of the VFO is changed. This arrangement was employed (instead of ganging the tuning controls of the multipliers with the VFO dial) to avoid a tracking problem and to minimize the number of restrictions on the physical layout of the exciter.

Broadband Tank Circuits. Although broadband resistance-loaded tanks were used in the past, they are no longer recommended because they are rather unsatisfactory for TVI reduction. The low Q's involved do not provide sufficient skirt selectivity and the possibility of transmission of several harmonics of the multiplier frequency can lead to possible misadjustments and considerable harmonic output.

Several exciters using broadband, double-tuned tanks in the multiplier stages have been described in the literature. All of these exciters employ critically-coupled or over-coupled transformers to achieve the broadband performance. The primary and secondary windings of such transformers can be wound on the same coil form or mounted close to each other with their axes parallel.

Fig. 2. Inside view of the transmitter. Note the area where the paint is removed from the panel for contact with the chassis. Also note the meter shield, the meter by-pass capacitors, and the shielded power leads—all essential TVI precautions.



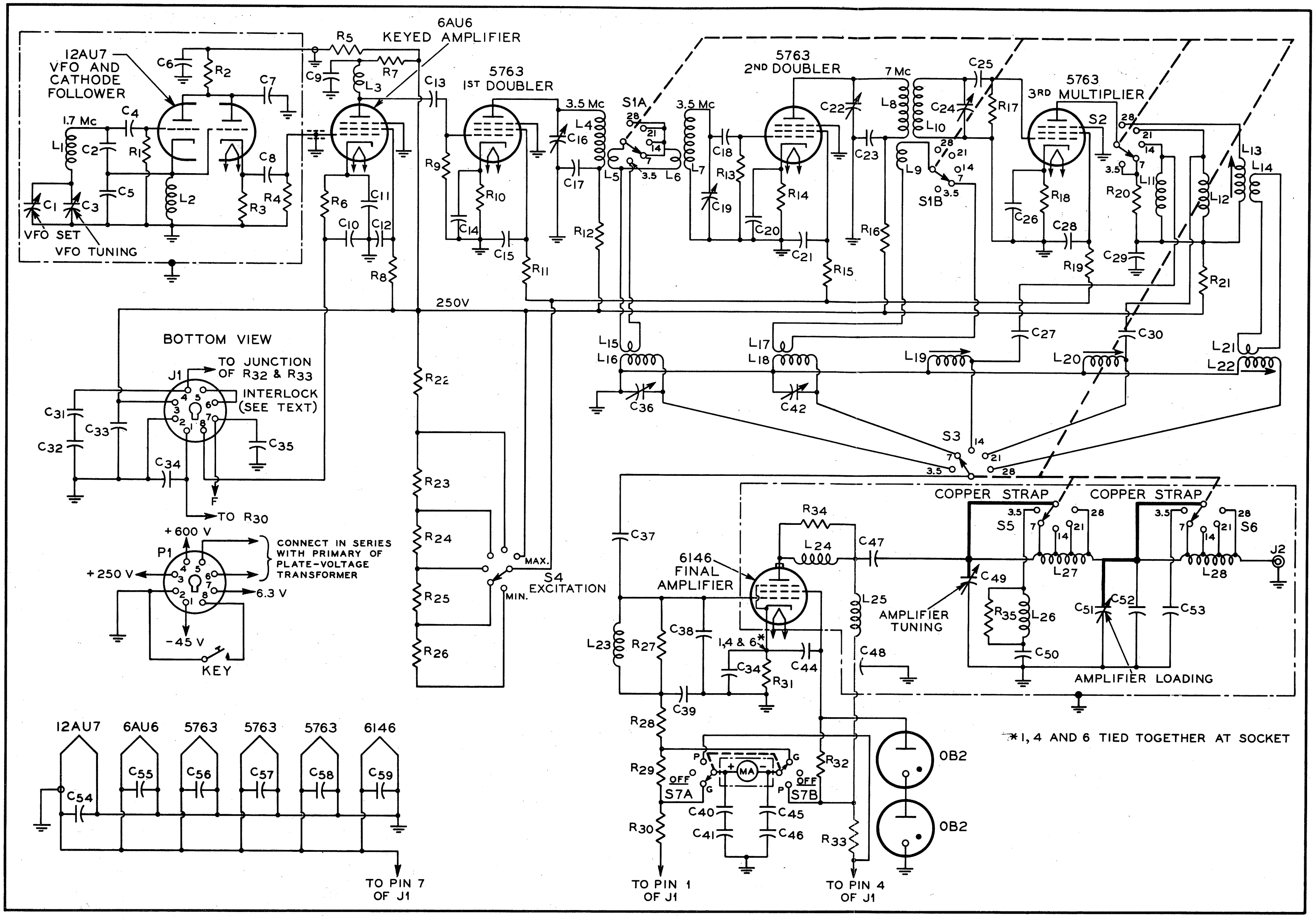


Fig. 3. Complete schematic diagram of the bandpass transmitter-exciter.

When this type of transformer is adapted to a bandswitching system, either of two undesirable conditions usually arises: (1) The number of multiplier stages is increased because of the necessity of switching particular stages in or out of the lineup to obtain the correct output frequency. (2) The complexity of the switching necessitates a compromise in the physical layout.

When adjoining multiplier stages have their coils mounted close to each other (with their axes parallel), sufficient coupling can be provided if the Q's of the coupled circuits can be made high enough to obtain the proper coefficient of coupling.

Link-Coupled, Double-Tuned Coupler. If the primaries and secondaries of the tuned transformers are coupled by low-impedance links, it becomes feasible to build a broad-band exciter covering 3.5 through 28 Mc with only two or, at the most, three tubes—the usual number required for a conventional exciter.

The parts may be arranged for maximum efficiency and short leads, and the link switch may be mounted almost anywhere because it switches only low-impedance circuits.

The link-coupled, double-tuned coupler is considerably easier to adjust than the direct-coupled type because there are no large windings to be moved up and down on the coil forms. The links may be wound with stiff wire and conveniently slid over the primary and secondary windings. After the coupling

C_1, C_{22}, C_{24} C_{25}, C_{42}	50μμf, midget padder (Hammarlund APC).
C_2, C_5	.001 μf, silver mica, 500 v.
C_3	30μμf, variable (Cardwell ET-30-ASP).
C_4, C_{37}, C_{50}	100 μμf, mica, 500 v.
C_6, C_7 C_9-C_{12}, C_{14} C_{15}, C_{17}, C_{20} C_{21}, C_{23}, C_{26} C_{28}, C_{29} C_{31}-C_{35} C_{39}-C_{41} C_{43}, C_{44}-C_{46} C_{54}-C_{59}	.01 μf, disc ceramic, 500 v.
C_8, C_{13}, C_{18} C_{27}, C_{30}	100 μμf, ceramic, 500 v (Erie GPK).
C_{16}, C_{19}, C_{36}	100 μμf, midget padder (Hammarlund APC).
C_{38}	25μμf, silver mica, 500 v.
C_{47}	.001 μf, mica, 2500 wv.
C_{48}	.001 μf, 500 v (Sprague Hypass).
C_{49}	100 μμf, variable, .030" spacing (Bud CE-2004).
C_{51}	300 μμf, variable, .024" spacing (Bud MC-910).
C_{52}	150 μμf, mica, 500 v.
C_{53}	470 μμf, mica, 500 v.
Dial	National SCN.
J_1	8-pin octal plug.
J_2	Coaxial connector (Amphenol 83-1R).
L_1	40 turns No. 24 enamel, 1½" diam, 2½" long (See text).
L_2, L_3 L_{11}, L_{12}	RFC, .5 mh (National R-50).
L_4	40 turns No. 24 enamel on National XR2 form.
L_5	3 turns No. 22 enamel—link, on same form as L_4.
L_6	3 turns No. 22 enamel—link, on same form as L_7.
L_7	32 turns No. 24 enamel on National XR2 form.
L_8	18 turns No. 22 enamel on National XR2 form.
L_9	2 turns No. 22 s.c. enamel—link, on same form as L_8.
L_{10}	22 turns No. 22 enamel on National XR2 form, mounted 1⅜" (on(centers) from L_8.
L_{13}	14 turns No. 22 enamel, spaced to occupy ¾" on Millen 69046 slug-tuned form.
L_{14}	1 turn No. 18 solid insulated—link, cemented in place over L_{13} (See text, Part II).
L_{15}	3 turns No. 22 enamel—link, on same form as L_{16}.
L_{16}	30 turns No. 24 enamel on National XR2 form.
L_{17}	3 turns No. 22 enamel—link, on same form as L_{18}.
L_{18}	14 turns No. 22 enamel on National XR2 form.
L_{19}	16 turns No. 22 enamel, spaced to occupy ¾" on Millen 69046 form.
L_{20}	10 turns No. 22 enamel, spaced to occupy ⅝" on Millen 69046 form.
L_{21}	1 turn No. 18 solid insulated—link, cemented in place over L_{22} (See text, Part II).
L_{22}	8 turns No. 22 enamel, spaced to occupy ¾" on Millen 69046 form.
L_{23}, L_{25}	RFC, 2.5 mh (National R100U).
L_{24}	7 turns No. 24 enamel wound on R_{34}.
L_{26}	7 turns No. 24 enamel wound on R_{35}.
L_{27}	19½ turns of 2"-diam, B & W 3907 coil stock, tapped at 6th, 13th, 16th and 17th turns.
L_{28}	17 turns of 1"-diam, B & W 3105 Miniductor, tapped at 4th, 10th, 13th and 16th turns.
MA	0-1 ma (Triplett 327T).

NOTE All resistors ½ watt unless specified otherwise.

R_1, R_9, R_{17}	56K.
R_2, R_7, R_{12} R_{16}, R_{20}, R_{21}	1K.
R_3	2.2K.
R_4	100K.
R_5	47K, 1 watt.
R_6	220 ohms.
R_8	39K.
R_{10}, R_{14}, R_{18}	330 ohms.
R_{11}, R_{15} R_{19}, R_{22}	15K, 1 watt.
R_{13}, R_{24}	27K.
R_{23}	18K, 1 watt.
R_{25}	33K.
R_{26}	220K.
R_{27}	22K, 1 watt.
R_{28}	8.2K.
R_{29}	Meter shunt (See text, Part II).
R_{30}	560 ohms.
R_{31}	100 ohms, 5 watts.
R_{32}	30K, 10 watts.
R_{33}	Meter shunt (See text, Part II).
R_{34}	22 ohms.
R_{35}	33 ohms.
S_1-S_3	Centralab P123 Index with three type R switch sections spaced 2¼" apart.
S_4	Centralab 1401.
S_5, S_6	Centralab 2510.
S_7	Centralab 1473.

Miscellaneous

Chassis	8" x 17" x 3," aluminum (ICA 29014).
Panel	8¾" x 19," aluminum (ICA 8604).
VFO shield box	4" x 5" x 6," aluminum (ICA 29342).
Final shield box	8" x 6½" x 6" (Made from two ICA 29344 Fleximount cases and 8" x 6½" x .062" aluminum plate; See text, Part II).

is adjusted, the links may be cemented in place.

In this transmitter, it was found convenient to use three different coupling methods; the choice of a particular coupling method for a given portion of the circuit was determined by the layout and required bandwidth.

Bandswitching the Multipliers

The grid of the final amplifier is switched to any of five resonant circuits by bandswitch S_3 and the drive is selected from the appropriate multiplier stage. The first 5763, doubling from 1.7 Mc, drives the final on 3.5 Mc. The link that is coupled to the plate circuit of this doubler is switched by S_{1A} to either the final grid circuit or the second doubler, a 5763 having its grid circuit tuned to 3.5 Mc. The output of this doubler is link coupled through switch S_{1B} to the final for 7-Mc operation.

The plate coil of the second doubler is mounted close to the 7-Mc grid coil of the third multiplier so that the two stages are coupled inductively without the use of a link circuit. This third multiplier is used to double, triple, or quadruple for output on 14, 21, or 28-Mc, respectively.

On 14 and 21 Mc, where the percentage bandwidths are small, the resonant circuit selected by S_3 functions as the tank. A choke (L_{11} or L_{12}) is used to feed plate voltage to the multiplier, and capacitance coupling is used between this multiplier and the grid circuit of the 6146.

On 28 Mc, the multiplier plate circuit is tuned by means of a slug in L_{13}, resonating with the tube capacitance. A link is run permanently to grid tank L_{22}, which is also slug tuned. Link switching is not needed here because this link is used for only one band. Switch S_2 in the plate of the multiplier selects the proper output circuit for operation on 14, 21, or 28 Mc.

The unused multipliers are left idling—a small amount of cathode bias is provided to hold the plate current at a safe value. This plate current, which is the same amount that flows when the key is up, is about equal to the operating plate current. Therefore, there is very little change in power-supply drain and no special regulation is demanded of the exciter power supply. The third multiplier, which is unused on 3.5 and 7 Mc, has a small resistor switched into its plate circuit to maintain plate voltage on the tube and to prevent the screen current from becoming excessive. A short circuit could have been used in place of the resistor, but it was felt that high-frequency parasitics might be encountered if a low-inductance plate circuit were used.

Excitation Control

Excitation to the final is controlled by adjustment of the screen voltage of the frequency multipliers. The screen grids of all the multipliers are supplied from a common bus, the voltage of which is controlled by tap switch S_4 and series resistors R_{22}-R_{26}. If it were not for the desirability of controlling the excitation to the final, the idle multipliers could be switched off when not in use, thus effecting some saving in the power drain; however, this arrangement would require two more switch sections.

6146 Bias

Grid bias for the 6146 is provided by three different means: cathode bias, a small amount of fixed bias (45 volts), and grid-leak bias. The original design contemplated the use of screen clamping of the final to eliminate the need for fixed bias. However, experience showed the combination method to be better suited to the 6146. Because of the husky cathode in the 6146, screen control is not as effective as in some other tetrodes, and ordinary clamp tubes do not reduce the plate current to a safe value when excitation is removed.

Even the use of a VR tube in series with the screen does not suffice where complete plate-current cutoff is desired. There seems to be a small amount of screen emission which allows the screen to assume a slightly positive potential, thus preventing complete cutoff. With the series VR tube and an ordinary clamp arrangement, the unexcited plate current is about 25 ma. Under this condition, the 6146 amplifies the noise generated by the high-gain multipliers and produces an annoying hiss in the receiver.

A small amount of fixed bias, conveniently obtained from a 45-volt battery (such as an RCA VS 114) obviates all this trouble, provided the screen voltage is not allowed to rise above the operating value and change the cut-off characteristic. A pair of miniature voltage-regulator tubes are used to hold the screen voltage at 210 volts when excitation is removed. These tubes may extinguish when excitation is applied and the screen current rises; however, such operation is not objectionable as long as the screen voltage is between 150 and 200 volts—high enough for efficient operation. For phone operation, it is desirable to keep the VR tubes extinguished to prevent shunting of the ac screen voltage. The value of the screen-dropping resistor is chosen to provide approximately 190 volts on the screen under normal operation; this value rises to only 210 volts when the excitation is removed.

The stability of the final amplifier is improved materially by the use of a small mica capacitor connected directly at the socket from grid to ground. This capacitor helps to attenuate the grid harmonics and lessens the tendency toward oscillation by keeping the grid impedance low. A small amount of resistance loading is used across the grid circuit to help flatten the bandpass characteristic and to prevent the 'valley' in the overcoupled-circuit response curve from being too deep.

Pi-Network Tank Circuit

The pi-network tank circuit helps eliminate TVI and is well suited to all-band operation, particularly where bandswitching is desired. The pi network provides considerably more harmonic reduction than the parallel tank circuit without a sacrifice in amplifier efficiency. In regions where the TV signal strength is high, there is no need for additional filtering if reasonable design precautions are taken.

The network chosen for this transmitter was calculated from the curves given by Pappenfus and Klippel.* The only trouble encountered was the result of the initial assumptions. The plate impedance of the 6146, under normal operating conditions, is approximately 2,000 ohms or less—somewhat lower than that of most tetrodes. The pi network capacitances required for matching this rather low plate impedance to 50-ohm coax are fairly high if an operating Q of 15 is chosen for the 3.5-Mc band.

The importance of keeping the Q as high as this is rather dubious, particularly because it has never been adequately demonstrated that a high Q contributes materially to the reduction of higher-order harmonics when stray coupling is usually the source of most of the trouble. With a Q of 7, not low enough to reduce the amplifier efficiency, the network becomes more manageable and the values of the capacitances are reasonable. On the higher-frequency bands, the Q may be increased because the required capacitance is less.

L-Network

The complexity of the switching is not materially increased by the addition of an L network** between the pi and the antenna. The use of an L network offers two added advantages: (1) further reduction of the capacitance required to make the network fit the design curves; (2) additional harmonic attenuation. The pi network steps the impedance down to about 500 ohms, and the L network reduces it from 500 to 50 ohms. A little cut-and-try is necessary to obtain the proper taps on the inductors and the proper values of loading capacitance for the different bands if a Q meter is not available for measurement of these values beforehand. *It is well to note that the values of the loading capacitance given in the charts in the previously mentioned reference are for optimum or full load; the capacitance must be increased somewhat to provide for tuning up and lighter loading.*

A certain amount of compromise in the matter of flexibility of adjustment must be accepted in a multiband rig, because the required capacitance values vary greatly when tuning from 3.5 to 28 Mc especially where a single wide-range capacitor is to be employed. However, constants chosen for the tank provide ease of adjustment without unduly complicating the switching. On 3.5 Mc, it is necessary to switch in additional capacitance to provide proper operation without compromising the high-frequency performance.

In a complex multiband tank circuit, the use of parallel capacitances may cause high-frequency resonances and parasitics, and this case was no exception. Also, lead lengths in a bandswitching arrangement sometimes prove vulnerable to high-frequency resonances. During the bench stage of the development work on this transmitter, several rf burns were obtained from the "cold" end of the shunt capacitors before the exact nature of the parasitic resonance was recognized. However, once the parasitic paths were discovered, the judicious use of a grid-dip meter indicated where corrective measures were needed.

Because of its high power sensitivity, the 6146 cannot be expected to be free from parasitics—particularly since its high-frequency performance is so good. It is necessary, therefore, to use a parasitic choke in the plate lead and to load this choke with resistance to keep its Q low at high frequencies.

The shunt tank capacitor, C_{50}, resonating with the main variable tank capacitor on 3.5 Mc, developed a parasitic which was eleminated by the addition of choke L_{26} to the circuit. The resistance loading (R_{35}) across this small inductance introduces enough high-frequency loss to suppress the parasitic oscillation without affecting the low-frequency performance.

As a TVI precaution, the shunt padding capacitors used for both tuning and loading should be checked to make certain that they do not resonate in any of the TV channels.

(To be continued in the next issue of HAM TIPS.)

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* *"Pi Network Tank Circuits," by E. W. Pappenfus, W0SYF, and K. L. Klippel, W0SQO, CQ, Sept. 1950, pg. 27.*

** *"Further Notes on Pi & L Networks," by E. W. Pappenfus, W0SYF, and K. L. Klippel, W0SQO, CQ, May 1951, pg. 50.*

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