



Ham Tips

PUBLISHED - IN - THE - INTEREST - OF - RADIO - AMATEURS - AND - EXPERIMENTERS

VOLUME IX, No. 1

EDITORIAL OFFICES, RCA, HARRISON, N. J.

JAN.-FEB., 1949

A PRACTICAL METHOD FOR REDUCING HARMONIC RADIATION

USING TUNED FEEDBACK CIRCUITS TO CANCEL TRANSMITTER HARMONICS

By JOHN L. REINARTZ, W3RB
RCA Tube Department

"TIN-CAN" WAVEMETER



Despite its humble origin, this easily built but extremely sensitive absorption type wavemeter is a "must" for tracking down offending harmonic radiation in transmitters.

In the previous article on this subject it was pointed out that the generation of Harmonics in a class C stage is natural and must be expected. In fact, it is this harmonic generation that makes doubler and tripler stages possible. However, if the radiated power capable of causing interference must be kept to less than 0.01 microwatt, even such high order harmonics as the 8th or 16th from fundamental operation at 7 or 3.5 Mc may cause television interference. Even more trouble can be expected from stages operating at 14 and 28 Mc where the harmonic order that can cause interference is much lower and the amplitude much higher. The problem then is —what to do about these harmonic radiations that cause TVI.

SELF-CONTAINED VFO DESIGNED FOR STABILITY ON ALL BANDS

By ANDREW RAU, JR., W3KBZ
RCA Tube Department

Even a confirmed proponent of crystal-controlled operation will concede that under present-day crowded band conditions, a really stable variable-frequency oscillator is indispensable. The completely self-contained VFO described in this article includes a regulated power supply, provision for oscillator keying, band spread on the higher-frequency bands, control circuits for the receiver and transmitter, and coupling by means of coaxial cable to the crystal socket of the transmitter. This method of coupling permits locating the high-power rf section away from the operating position.

A really satisfactory VFO has two basic requirements. The first of these requirements is relative freedom from drift or instability, and the second is the ability to key without chirps or other transient effects. A careful choice of components with due consideration to layout, along with a "workmanlike" mechanical job will go a long way toward meeting the first requirement. The recently publicized Clapp circuit⁽¹⁾ will assist in satisfying the second requirement.

Frequency Drift Considerations

In addition to the effects of component choice, layout, and workmanship, the most troublesome factors contributing to the instability of a self-excited oscillator are the effects of humidity, temperature, and changes in operating conditions such as voltages, currents, etc. The effect of humidity can be minimized by the use of high-quality components of ceramic or other

low-loss material in the rf portions of the circuit. The effects of temperature are most satisfactorily minimized through the use of a frequency-determining coil wound on a ceramic form large enough to give a high "Q" but which will undergo little change of inductance with temperature. In addition, the main tuning capacitor should be of sturdy construction with small plates well spaced in a frame with ceramic end plates and with two bearings. All other capacitors should be silver mica or ceramic types with a low temperature coefficient.

Because fundamentally it is desirable to obtain maximum "Q" in the oscillator tank circuit, it is important to make all rf connections in this circuit as short and direct as possible. Moreover, it is undesirable to depend on a steel chassis to conduct rf tank currents because

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What To Do About It

In Part I, it was pointed out that previous investigators advocated the use of complete shielding along with the installation of parallel-tuned series-inserted traps⁽¹⁾ and other bypassing devices which must also be shielded. The writer, however, has had considerable success with another method of reducing harmonic radiation which does not depend upon shielding for its efficacy. This method involves the use of the tank-coil traps described in Part I but with one additional and important refinement in the method of connecting the traps together and grounding them. These tank-coil traps operate by absorbing the unwanted harmonics and cancelling them out by means of tuned feed-

back circuits. But more of this later. Our first problem is to locate the offending harmonics.

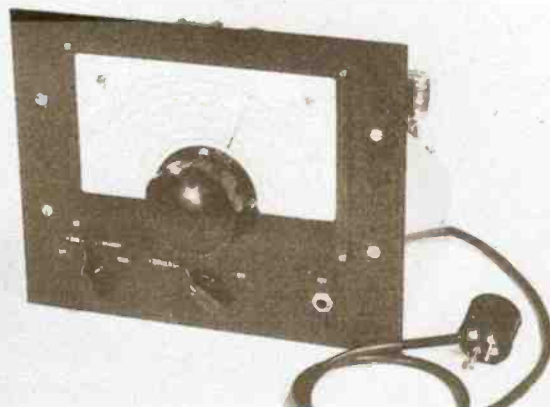
Locating the Harmonic

In order to use this method, we must first locate the offending harmonic and utilize some method of measuring its relative amplitude. For this purpose an old standby, the universally used absorption-type wavemeter, comes into play.

A modified wavemeter that has proved extremely sensitive was devised by the writer. This unit, diagrammed in Figure 1, consists of a resonant circuit (L_1C_1) for the frequencies under discussion, a 4-turn $\frac{1}{4}$ " diameter coil of #20 enameled insulated wire (L_2) in series with the resonant circuit, a 1N34

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STURDY AND STABLE



Completely self-contained, this efficient looking VFO has its own power supply, provision for oscillator keying, band spread on the higher-frequency bands, control circuits for both receiver and transmitter, and coupling by coaxial cable to the transmitter crystal socket.

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crystal and microammeter in series connected across the 4-turn coil, and a capacitor (C_2) connected across the meter. The microammeter is connected to the tuned circuit by means of a flexible two-wire cord of any desired length. This arrangement allows the operator to get much closer to circuits suspected of harmonic radiation than would be the case if the resonant circuit and the meter were in one container. The absorption meter may be built into a small metal can into which the pick-up loop for the particular frequency

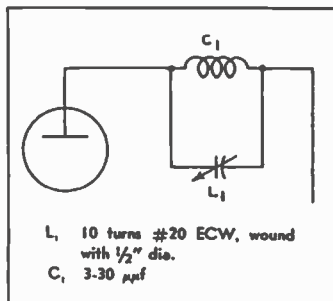


Figure 2. A parallel-tuned trap circuit.

range desired can be plugged. A photograph of the wavemeter is shown on Page 1: When a variable capacitor of 3.5 to 75 μf is used together with a pickup loop 2" long, consisting of a single hairpin turn, the tuning range extends from 50 to 150 megacycles.

The hairpin pickup loop should be threaded with glass or porcelain beads or with some other insulating material so that when the wavemeter is used to probe near high-voltage points, direct contact will be prevented. An additional, but very worthwhile precaution is to connect a flexible grounding wire between the wavemeter can and ground.

Because the 4-turn coil is inside the can, it picks up very little energy from the fundamental frequency when the wavemeter hairpin is held close to a tank circuit.

Preliminary Checking

The next thing to do is to make a preliminary check with the wavemeter to determine which harmonics are prevalent in the transmitter and where they are most prominent. A good place to check is near the plate connection of each tube. Caution must be exercised when high-voltage points are checked in order to prevent any accidental contact.

As the check for harmonics progresses, make a note of the location and relative value of the harmonics for future reference. Don't be surprised if harmonic indications are noted in the heater leads of heater-cathode-type tubes or at that end of a plate-tuning-capacitor frame which is not bypassed for rf ground. In order to cut down the harmonics at these points, connect a bypass

capacitor of 0.001 μf and the proper voltage rating between the plate-tuning-capacitor frame and ground. Between the heater lead and ground use a 0.01 μf capacitor. A further check with the wavemeter at these points will in all probability show a substantial reduction in the harmonic amplitude. Any long lead under a chassis may also show harmonic voltages and should be similarly bypassed at readily accessible points.

Tuned-Plate Traps

After adequate bypassing is accomplished, the first step is to insert parallel-tuned trap circuits in series with the plate leads of each class C stage. See Figure 2. These traps may be made readily with ten turns of #20 enamel coated wire, wound with a 1/2-inch inside diameter and shunted with a 3- to 30- μf trimmer capacitor for tuning. It will be found that the tuning range of this trap extends from 25 to 80 Mc.

Tank-Coil Traps

The next step, which is something new in TVI reduction, is to utilize the previously mentioned tank-coil traps which absorb and cancel through negative feedback the unwanted frequencies. These traps are positioned about 1/4" from the hot end of the plate tank coil at each stage. Each trap (see Figure 3) is made by winding a coil of as many turns as can be made from 18 inches of wire in the same direction and of the same diameter as the tank coil.

Wire comparable in size to that of the tank coil should be used although it is not necessary to use wire larger than #10. The coil is then shunted with a 3- to 50- μf tuning capacitor. The hot end of the coil is connected to the stator plate. This capacitor is mounted adjacent to but not more than 2" to 3" from the coil in such a manner as to be tunable from the front panel by means of an extension shaft. The rotor side of the variable capacitor is then grounded. Similar traps are mounted at the

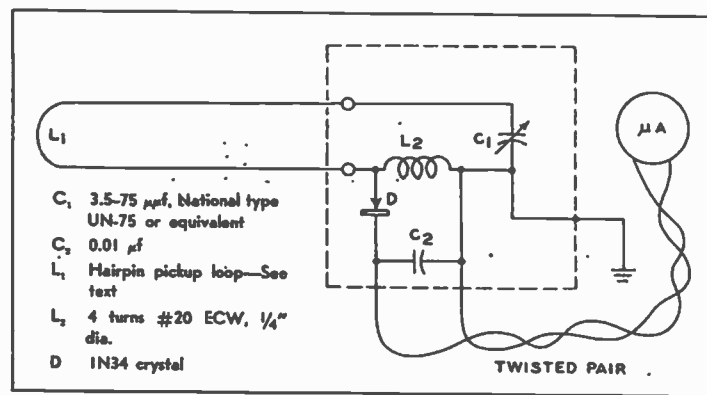


Figure 3. Wavemeter schematic.

hot ends of the other plate tanks and the antenna coil as shown in Figure 4. Each trap is then coupled by means of a 25- μf fixed capacitor to a common line which is grounded at a point approximately half way between any pair of 25- μf fixed capacitors.

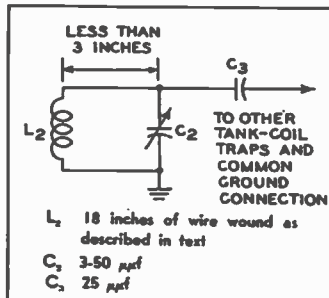


Figure 4. A tank-coil trap circuit.

Connecting the Grounding Wire

A final connection completes the hookup. This connection is made to the trap in the tank circuit of the final and consists of a grounding wire approximately ten inches long connected between the ungrounded side of the variable tuning capacitor and any convenient point on the chassis. Some experimentation may be necessary to locate the optimum grounding

point necessary to produce maximum harmonic attenuation.

In push-pull stages only one tank-coil trap is required. If either a center-tapped antenna tuning unit or a split tank circuit is used, the tank-coil trap may be located at either end.

Shielding Considerations

Although the operation of this system of reducing harmonic interference does not specifically require shielding, it is advantageous to use a metal front panel in addition to the usual metal chassis. The metal front panel minimizes the detuning effects of hand and body capacitances when the several air capacitors are adjusted.

Tune Up

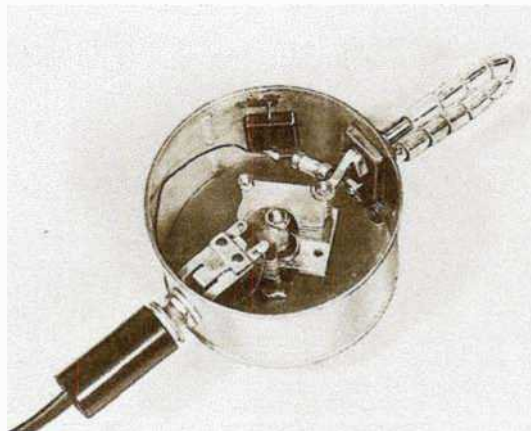
The tune-up procedure is quite simple. The absorption-type wavemeter is tuned to the lowest harmonic causing TVI. It is then brought in close proximity to the tank circuit of the first stage in the equipment and the series-inserted plate trap is tuned to reduce the offending harmonic to a minimum. It will be found that several minimums will be noted as the 3- to 30- μf trimmer capacitor is adjusted from minimum capacitance to maximum capacitance. In the doubler and final stages, however, care must be taken to avoid tuning to the output frequency so that the 3- to 30- μf capacitor will not tend to arc over and burn up. After testing over the entire range with the wavemeter, choose the setting at which all harmonics, even and odd, above and including the offending harmonic are reduced to a minimum. The tank-coil trap is then tuned for still further harmonic reduction. The process is repeated for each stage, in order, ending with the antenna-tuning stage. A further check is made at the antenna feeders to make sure that no harmonic emission is detectable. The final, and most important check, of course, should be made on the nearest television receiver.

Field Tests

In several rigorous field tests, this system of reducing TVI gave excellent results. One test was made

(Continued on Page 3, Column 1)

LOOKING INSIDE



An interior view of the wavemeter shows placement of components. The rotor plates of the variable capacitor may be trimmed in order to make the frequency response of the unit more linear at the high-frequency end.

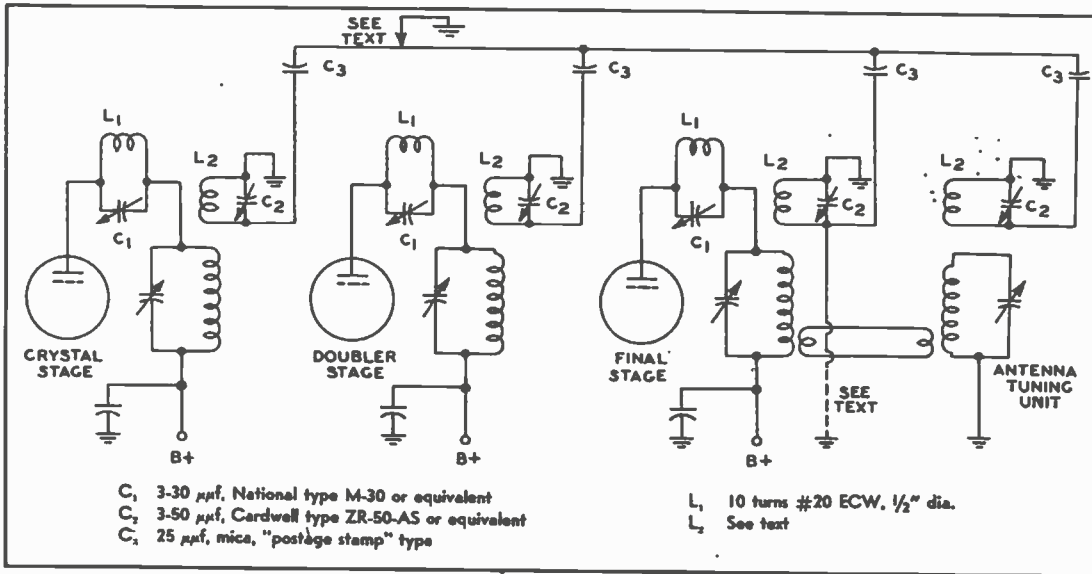


Figure 4. Partial schematic of transmitter showing manner in which harmonic-cancelling traps are placed in circuit.

HARMONIC OUTPUT

(Continued from Page 2, Column 4)

at the writer's home station in Lancaster, Pa. The regular 20-meter folded dipole 45 feet high was located within 50 feet of the television antenna also 45 feet high. The transmitter was operated with 300 watts input and caused no interference on channels 3 and 6 originating in Philadelphia 65 miles away. For these tests the TV screen was viewed at a distance of approximately 40 inches in order to obtain the standard 4-to-1 viewing ratio for a 10-inch kinescope.

For a more strenuous test, the transmitter was then taken to Harrison, N. J., where it was operated in the same room with a commercial television receiver. All 6 channels in the New York area were sampled and were clear of transmitter interference to a degree considered unattainable before the tests began.

In Lancaster, the system was tried and is still in use on a Collins 32V transmitter operating on 10 meters with equally satisfactory results.

Although this system has worked remarkably well in every transmitter the author has modified, it should be recognized that each case of TVI presents special problems and requires experimentation.

(1) Mack Seybold "Curing Interference to Television Reception," *QST*, August 1947 Vol. XXXI, No. 8, pp 19-23.

ECHOES

The High-Fidelity Audio Amplifier described in the September-October 1948 issue of *HAM TIPS* inadvertently listed C12 as a 0.01 uf capacitor. Actually the capacitance should have been shown as 0.1 uf.

VFO UNIT

(Continued from Page 1, Column 2)

the high rf resistance of the chassis will cause a substantial reduction in "Q".

A large portion of the drift due to temperature changes results from expansion, twisting, and warping of the chassis and panel are, however, and the more substantially they are fastened together, the less the frequency drift will be. To appreciate fully the order of stability required, it should be remembered that a shift of only 500 cycles will be 4000 cycles when multiplying from the 3.5-Mc band to 28 Mc. Also, it is not uncommon for receiver oscillators, particularly of the broadcast variety, to drift as much as several thousand cycles.

Frequency drift due to changes in operating conditions is minimized by using a well-regulated power supply.

Circuit Details

Excellent descriptions of the Clapp oscillator circuit are given in the references and need not be repeated here. The complete circuit of the VFO is given in Figure 5, on Page 4. The frequency-determining circuit consists of L_1 , C_1 , C_2 , and the series-parallel combination of C_3 to C_6 , all in series. Because the capacitive reactance of C_1 to C_6 cancels a portion of the inductive reactance of L_1 , a relatively large inductance may be used. This large inductance, plus the fact that the 6AG7 grid No. 1 is effectively tapped across only a portion of the tank circuit, provides a circuit with extremely high "Q". When the 6AG7 is connected as an electron-coupled oscillator, it is possible to use a considerably larger coil for L_1 with a further reduction in the effects of voltage and tube changes on frequency stability. However, if such a circuit is used, the actual

tuning capacitance becomes smaller and the effects of temperature and mechanical changes in the chassis and tank circuit are much greater.

Switch S_1 is used in one position (A) for the 3.5-Mc band. In the other position (B) the higher-frequency bands are spread out when multiplying in later stages to 7 Mc and higher. C_4 is the main tuning capacitor while C_1 and C_2 are the band-spread padders. Considerably greater band spread could be obtained if the 11-meter band were not included. C_2 is the 3.5 Mc band-set capacitor. C_1 and C_2 compensate to some degree for changes in temperature. The oscillator operates with a screen current of about 1.5 ma at 75 volts and a plate current of only 5 ma at 180 volts. Keying of the cathode circuit causes no perceptible change in frequency, and no chirp nor other transient.

The 6AG7 was selected as a class A buffer because, due to its high transconductance, it is capable of about 3 watts output with negligible grid power or voltage requirements.

Across a 10,000-ohm load, about 70 volts are developed at the output connections of this circuit. This voltage is more than sufficient to drive the regular crystal stage of a transmitter.

The buffer amplifier plate and screen currents total about 20 ma with the plate operating at 250 volts. A low-value coupling capacitor (C_{12}) plus the use of dropping resistor R_2 prevents the following stages from affecting the oscillator frequency. In fact, the frequency shift, from full load to no load (complete disconnection of the coaxial output lead) is only one or two cycles. The output circuit, L_2 link-coupled through a coaxial feeder to L_{11} , is low in capacitance and gives nearly uniform output over the entire 3.5-Mc band when C_{11} and C_{17} are stagger tuned.

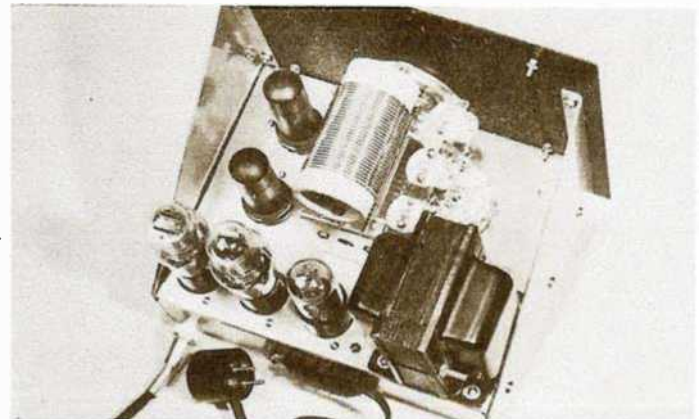
The voltage-regulator tubes largely eliminate the effect of variations in line voltage. A decrease of 20 volts in line voltage causes less than a 10-cycle shift in frequency. The power supply, conventional in design, has a total drain in the order of 50 ma. Because it is often desirable to provide complete control of the rig from the VFO unit, switch S_2 was added to provide switching circuits for the receiver and the power relay of the transmitter final. The standby position of the switch permits checking the oscillator frequency before the final is in operation.

Construction Details

Ample room is provided by a 7" x 9" x 2" chassis, preferably of aluminum, with welded or reinforced corners. If an 8" x 10" panel is used, the VFO will fit several types of small standard cabinets. Home-made side brackets of aluminum rigidly tie the panel and chassis together and, to a large degree, prevent warping and twisting. A National type ACN dial is directly calibrated for each band. A "U"-shaped aluminum bracket supports the main tuning capacitor at the front and rear more rigidly than the brackets

(Continued on Page 4, Column 1)

BEHIND-THE-PANEL VIEW



Well planned design of the VFO provides ample space for mounting components. Band-spread and padder capacitors are fixed to a 4-inch strip of polystyrene shown in center of photograph.

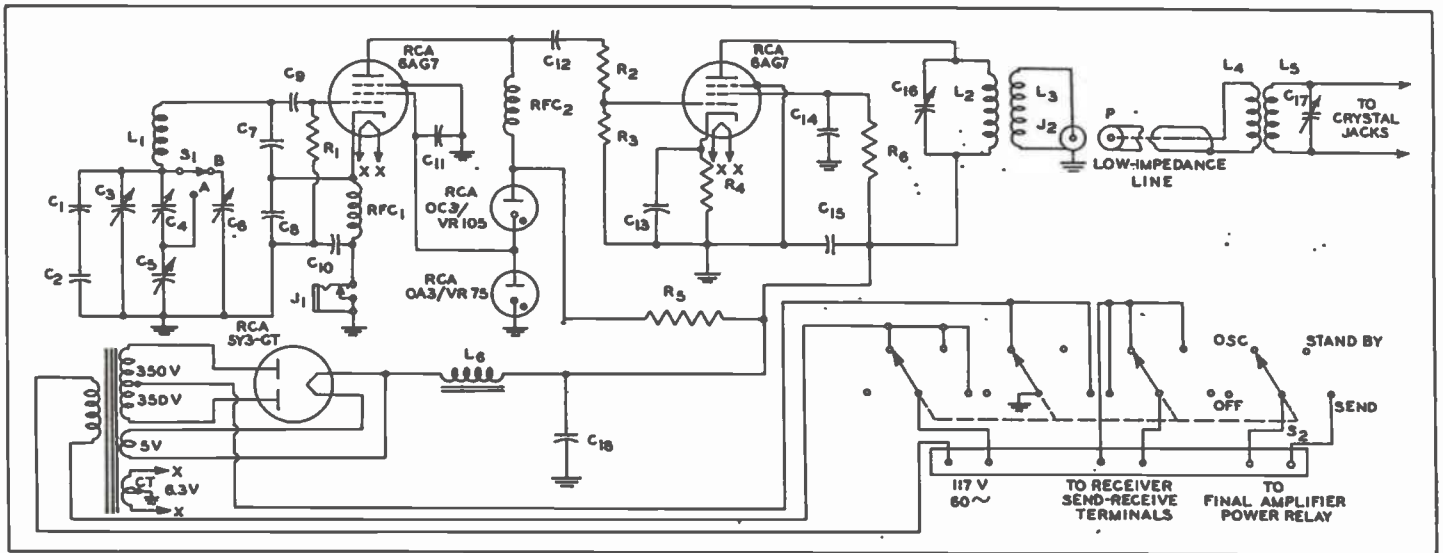


Figure 5. Schematic of variable frequency oscillator.

VFO UNIT

(Continued from Page 3, Column 4)

supplied with the capacitor. In addition, the aluminum bracket provides a support for the coil clear of the chassis and panel thereby reducing the effect of temperature changes. The band-spread and padder capacitors are mounted on a 4-inch strip of polystyrene attached to the side of this bracket. (See photograph on page 3.)

Switch S₁ is mounted face down with the shaft extending through a hole in the top of the chassis. It is controlled from the front panel by means of a flexible shaft. The power supply components are mounted along the rear of the chassis with the filter choke on the underside. The 6AG7 oscillator is directly behind the panel. The two 6AG7 tube sockets are oriented for the shortest possible connections. Except for the usual considerations of providing good mechanical rigidity, short leads, and bringing the rf returns for each stage to a common point, the wiring is simple and not critical. No trouble should be experienced with self oscillation.

L₂ is wound on a medium-sized octal tube base from which the pins

have been removed. The tube base is then fastened to the chassis by means of a screw through the bakelite positioning plug. Capacitor C₁₅ is mounted inside the coil. A three-turn link (L₂) wound on L₂ at the low-voltage end is connected to receptacle J₂. A suitable length of B & W Miniductor (one-inch diameter and having 32 turns per inch) may be substituted for L₂ if desired. A low-impedance transmission line of any reasonable length connects the output jack to L₄ and L₅. Because high "Q" was not particularly desired for L₁, it was random wound on a form together with L₂, its three-turn link, and inserted in a four-pin tube base with the pin spacing altered to fit the standard crystal pin spacing. If room permits, however, the use of a suitable plug-in type coil form will simplify the construction.

The frequency drift, even without temperature compensation, will not be excessive. Some adjustment of the degree of compensation, however, may be desirable and can be easily accomplished by changing the value of capacitor C₁. Any check of the keying characteristics should include listening on one of the higher-frequency bands because

any defects will be considerably accentuated by frequency multiplication.

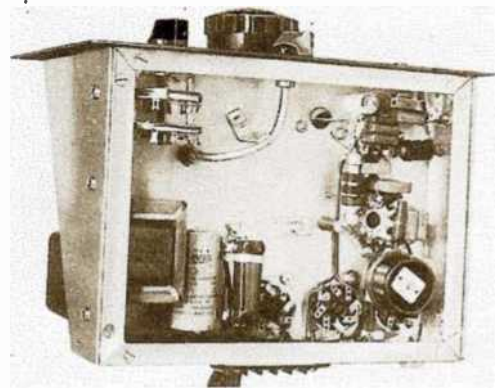
(1) J. K. Clapp, "An Inductance-Capacity Oscillator of Unusual Frequency Stability," *Proc. I. R. E.*, March 1948. "Technical Topics," May and Oct. 1948 *QST*. Nicholas Lefor, "The 'Topics' VFO," Aug. 1948 *QST*.

PARTS LIST

- C1 15 uuf, zero temperature, Centralab style NPO
- C2 100 uuf, negative temperature, Centralab style N750
- C3 6-75 uuf, Hammarlund type APC-75 or equivalent
- C4 7-100 uuf, Hammarlund type APC-100 or equivalent
- C5 10-75 uuf, Bud #CE-2014 or equivalent
- C6 5-50 uuf, Hammarlund type APC-50 or equivalent
- C7, C8 0.001 uf, silver mica
- C9 100 uuf, silver mica
- C10, C11, C13, C14, C15 15 uuf, silver mica
- C12 3-30 uuf, mica
- C16, C17 20 uf, 450 working volts, electrolytic
- C18

- R1, R3 100,000 ohms, 1/2 watt
- R2 27,000 ohms, 1/2 watt
- R4 100 ohms, 1/2 watt
- R6 15,000 ohms, 1 watt
- R5 2,000 ohms, 10 watts
- T1 Transformer, 350-0-350 volts at 90 ma., 5 volt. at 2 amps, 6.3 v at 3.5 amps. Thordarson No. T17R37 or equivalent 28 turns, No. 18 enamel, spaced over 2 3/4", on 1 3/8" dia x 3 1/2" National No. XR13 Ceramic coil form or equivalent
- L1 No. 26 enamel close wound 1 1/2" on 1 3/8" dia. form. B & W Miniductor (Cat. 3016) may be substituted
- L2 3-turn link wound on L₂ at low-voltage end.
- L4 56 turns No. 26 enamel, random wound approx. 3/4" on 1 1/2" dia. form
- L5 3-turn link, wound on L₁
- RFC₁, RFC₂ Choke, 2.5 mh, 125 ma
- L4 Choke, 8-24 henry, 80 ma. Thordarson No. T20CS3 or equivalent
- S1 Switch, 4-position, 1-section Mallory Hamband switch.
- S2 Switch, 2 gang, 4 circuit, 4-point rotary
- J1 Closed circuit jack for key
- J2 Coaxial receptacle
- P Coaxial plug

VFO UNDER-CHASSIS



Aside from the usual considerations of providing mechanical rigidity, short leads, and bringing rf returns for each stage to a common point, the wiring of the VFO is simple and not critical.

HAM TIPS is published by the RCA Tube Department, Harrison, N. J., and is made available to Amateurs and Radio Experimenters through RCA tube and parts distributors.
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