

An Easy-To-Build VFO

By Lewis G. McCoy, W1ICP

A VFO can be substituted in place of crystals and will permit the amateur to change his frequency to any point in the 80 or 40 meter bands. In other words, the VFO can be substituted in place of an 80- or 40-meter crystal.

There are three general rules that should be followed when constructing a VFO.

- First, the mechanical or physical construction must be very rigid, at least in those parts of the circuit that make up the frequency-determining elements. Any component that is not mounted securely, particularly the VFO coil (L_1 in Fig. 1), can vibrate or move, which will cause the oscillator signal to vary in frequency.
- Second, the plate and screen (if the tube has a screen) voltages of the VFO tube should be regulated. Otherwise, an unregulated voltage on the plate of the oscillator could change under changing load conditions and cause the frequency to be unstable.
- Third, if possible, the power supply for the VFO should be mounted on a separate chassis. More often than not, you will get hum vibration from the power transformer, which in turn will cause mechanical vibration of the entire chassis. Any vibration of the frequency-determining elements will cause the oscillator signal to change frequency. In the case of a power transformer it usually vibrates at a 60-cycle rate, and this can cause the oscillator tube elements to move at this same rate, putting a 60-cycle hum on the signal.

Another point that should be followed in constructing a VFO is that all fixed capacitors in the frequency-determining elements should have good temperature-compensation ratings. If the value of a capacitor changes when it becomes hotter or colder, it can make the frequency change in an oscillator. The result is a "drift" in frequency. The unit described here uses silver mica capacitors, which have good temperature stability.

Because of the heat problem, it is always good procedure to mount any heat-producing components, such as tubes, away from frequency-determining elements. The unit described in this article meets all these rules and the result is a very stable VFO.

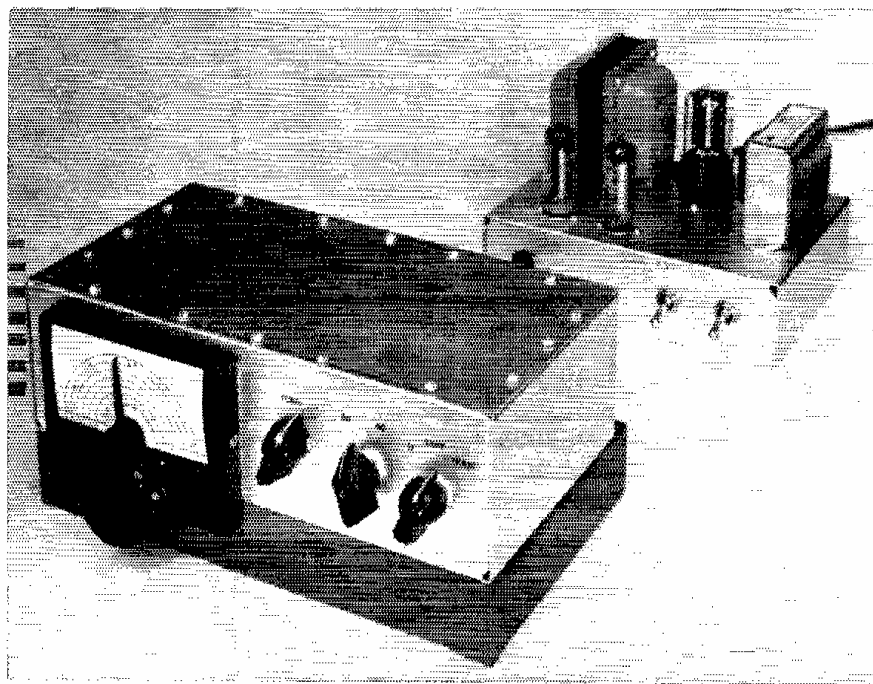
Circuit Information

The circuit of the VFO is shown in Fig 1, and is a updated copy of one described by George Hanchett, W2YM.

It consists of a Colpitts-type oscillator, high C, with basic coverage of the 3.5 to 4.0 MHz frequency range. Practically the entire tuning range of C_1 is required to cover the 80-meter hand. C_3 serves as the band-set capacitor. The tube capacitances are practically swamped out by the use of large (0.001- μ f) silver micas as a capacitive voltage divider from grid to cathode to plate of the oscillator tube, which is one section of a 12AU7. The second half of the 12AU7 is used as a cathode follower to isolate the VFO from succeeding stages.

The output from the cathode follower is used to drive a buffer/multiplier 6AU6. The output of the 6AU6 can be tuned to the 80-meter band, and also to 40 by shorting turns on L_2 with S_2 .

This view shows the completed v.f.o. and power supply. The switch on the right on the power supply chassis is S_3 , and S_4 is on its left. On the v.f.o. C_1 is to the right of the v.f.o. dial, then S_2 and S_1 at the far right.



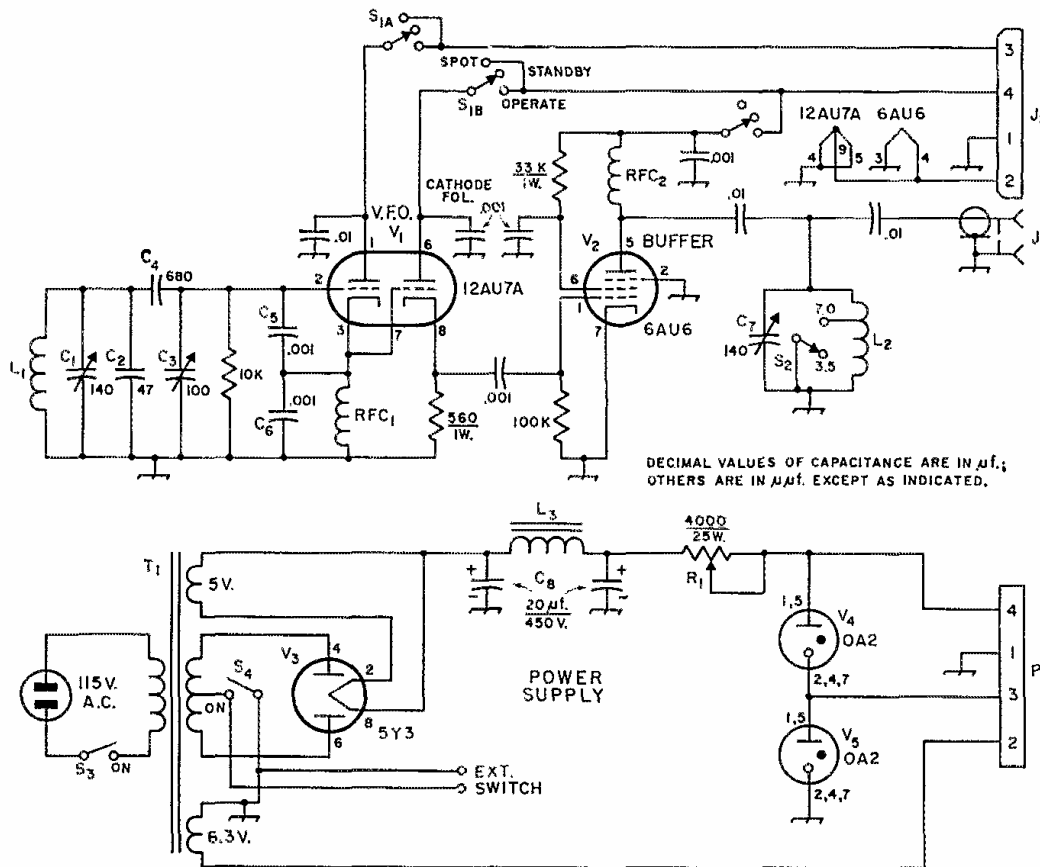


Fig. 1—Circuit diagram of the v.f.o. and power supply. Capacitors marked with polarity are electrolytic, resistances are in ohms, resistors are 1/2 watt unless indicated otherwise.

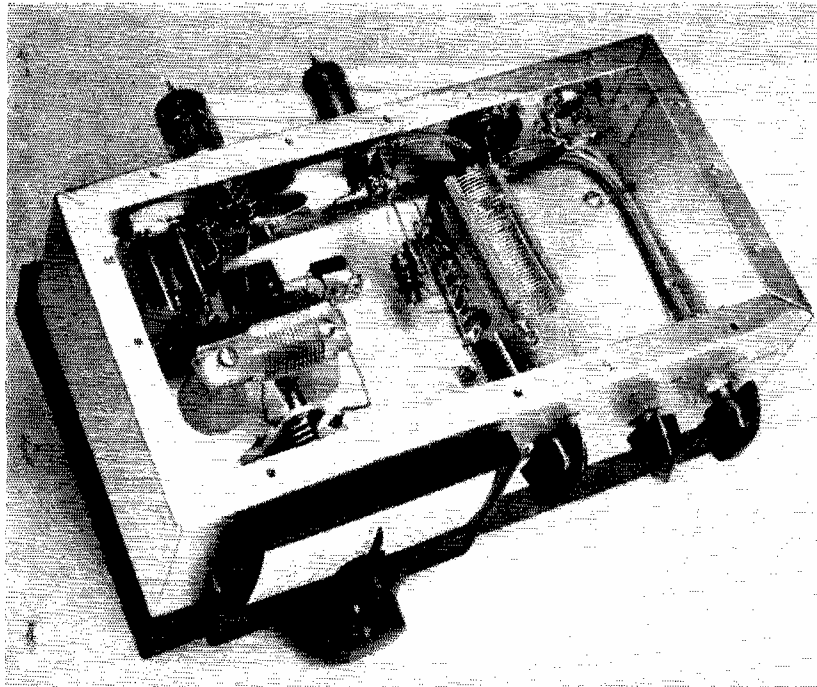
- C₁—140- μ f. variable (Hammarlund MC-140-S).
- C₂—47- μ f. silver mica.
- C₃—100- μ f. air padder (Hammarlund APC-100).
- C₄—680- μ f. silver mica.
- C₅, C₆—1000- μ f. silver mica.
- C₇—140- μ f. variable (Hammarlund (APC-140-B).
- C₈—Dual-section, 20- μ f.-per-section, 450-volt electrolytic.
- J₁—Coax chassis fitting.
- J₂—Octal chassis connector, male.
- L₁—14 turns No. 20, 16 turns per inch, 1-inch diam. (B & W Miniductor 3015).
- L₂—33 turns No. 20, 16 turns per inch, 1-inch diam. (B & W Miniductor 3015).
- L₃—15-hy. 75-ma. filter choke (Stancor C-1002, Knight 62-G-138).
- P₁—Octal cable plug, female.
- R₁—4000-ohm 25-watt, with slider.
- RFC₁, RFC₂—R.f. choke, 750 μ h. (Millen 34300-750).
- S₁—3-pole, 3-position wafer switch (Centralab 2507).
- S₂—Single-pole double-throw switch (Centralab 1460).
- S₃, S₄—Single-pole single-throw toggle switch.
- T₁—Power transformer, 500 volts center tapped, 70 ma., 5 volts, 2 amp.; 6.3 volts, 2.5 amp. (Knight 61-G-464, Triad R-108A).

The switch, S₁ is a three-pole job, one portion of which is used to turn on the plate voltages for the oscillator and cathode follower. This provides enough VFO output for "spotting" your own frequency. In another position the switch puts the VFO unit on standby, and the last, or "operate," position turns on the multiplier.

The power supply consists of T₁, V₃, and a capacitor-input filter, C₈ and L₃. A 0A2 and 0C2 provide the regulated voltages for the oscillator, cathode follower, and multiplier. Regulated

voltage is 225 volts for the multiplier and cathode follower and 75 volts for the plate of the oscillator.

S_4 is used to turn off the voltages of the unit by opening the center tap of the power transformer. In addition, a pair of terminals connected across S_4 permits using an external switch, which may be mounted at a convenient location at the operating position. This same external switch, if DPDT can be used to control the antenna changeover relay if one is used in the station.



Looking down into the chassis, L_1 is mounted on the two isolantite standoffs at the left in this view. The coil towards the right is L_2 . On the back wall at the far left is C_3 . The tubes V_1 and V_2 are mounted on the rear chassis wall.

It is also true that S_1 can be used to put the VFO on standby, but an external switch, as mentioned above, will probably be more convenient.

There is no provision for keying the VFO as all keying should be done at the transmitter, as it was with crystal control. Keying a VFO along with the rest of the transmitter can cause some problems. It would be a simple matter to key the cathode of the VFO, but the first problem you would likely encounter would be clicks on your signal. When you attempt to do shaping of the signal to get rid of the clicks you get chirps, so the easiest way around the problem is not to key the VFO.

It is true that you can key a VFO and get a good clean signal with no clicks or chirps. However, this usually requires elaborate circuitry. Details on this type of keying can be found in the keying chapter of the ARRL Handbook.

Construction Details

A 3 x 5 x 9.5 inch aluminum chassis is used to house the complete VFO unit. In order to obtain mechanical strength, the aluminum chassis is mounted on top of a steel chassis which is 1.5 by 5 by 9.5 inches, and secured with several screws and nuts. This system prevents any flexing of the aluminum chassis. Note from the top view photographs that V_1 and V_2 are mounted on the back side of the chassis. This keeps the heat from the tubes from reaching any of the frequency-determining components mounted inside the chassis.

~The coil L_1 is mounted on two isolantite standoffs, one inch high. Two poly bars, 1/8 inch thick, 1/2 inch wide and 2 inches long, sandwiched the coil between the two bars, which are screwed down on the standoffs. It is important that this procedure be followed as the coil must be held rigidly in place.

~ C_1 is mounted to the base of the chassis with two screws and, in addition, is held to the front of the chassis with the mounting nut that comes with the type capacitor used.

~Just to the rear of the L_1 installation is a terminal strip which is used to mount C_2 , C_4 , C_5 and C_6 .

~ C_3 is mounted on the back wall of the chassis.

~The tank circuit for V_2 is mounted at the right-hand side of the chassis as viewed from the front.

~ C_7 , S_1 , and S_2 are installed on the front of the chassis to the right of the VFO dial. The dial for the VFO is a Millen type 10039.

~An octal plug, J_1 (Amphenol type 86-CP8), is mounted on the back wall of the chassis.

The power supply is mounted on a 2 X 5 X 7-inch aluminum chassis with T_1 , L_3 , V_3 , V_4 and V_5 mounted on top of the chassis. The remaining components are placed below deck. A three-foot length of four-conductor cable terminating in P_1 (Amphenol 78RS8 socket and type 3-24 cap) is used to connect the power supply and VFO together.

Adjustment Procedure

The first adjustment to be made is to find the right value for R_1 . Insert a 0-50 mA meter between R_1 and Pins 1 and 5 of V_4 . The slider on R_1 should be adjusted for a reading of about 30 mA. Be sure to turn the supply off when making adjustments as the voltage can be dangerous.

When R_1 is correctly adjusted, tune your receiver to 3500 KHz and adjust C_3 , to bring the VFO signal to this point. You'll find that nearly complete rotation of the VFO tuning knob is required to cover the 80 meter band. There is enough range in the VFO circuit so that you shouldn't have any problem in setting C_3 . If you find for some reason that the circuit does not quite cover 3.5 to 4.0 MHz, check all component values carefully, particularly the number of turns on L_1 .

The first position of S_1 should give you enough output from the unit for zero-beating. Never change the VFO frequency with the transmitter on the air. Nobody likes to hear signals swishing up and down the band causing unnecessary interference. That's why you have a spotting switch on your VFO.

Connecting the VFO to Your Transmitter

There are some general rules that can be followed for connecting the VFO. You'll need about two feet of coax cable to connect the VFO output (from J_1) to your crystal socket. The length of coax is important because it is part of the tuned plate circuit of the 6AU6 amplifier. Two feet of RG-58U has about 50 pF capacitance, and this amount is across the tuned circuit C_7L_2 .

The circuit will still tune to 80 and 40 with three feet of coax, which is the most you should use. If you use more than three feet there will be too much capacitance across the tuned circuit C_7L_2 and the circuit won't tune to 80 or 40. In this case you would have to remove turns from L_2 , the number depending on how long the coax is. The circuit should be checked with a grid-dip meter and altered accordingly.

Many commercial rigs have two inputs, one for crystal and the other for VFO. In such cases all you need do is connect the VFO to the transmitter's VFO input. When a rig has only crystal input you may have to make a slight modification in the crystal stage in order for the rig to work with the VFO. However, before making any modifications try the VFO and see if you get grid drive to the crystal stage. Also, when connecting the cable to the crystal input the inner conductor of the coax should go to

the terminal on the crystal socket connected to the grid of the oscillator stage. In other words, you may have to reverse the VFO plug in the crystal socket in order to get excitation to the crystal oscillator.

If your transmitter is one designed only for crystal input and won't work with the VFO, you will have to make one slight change in the crystal oscillator stage. Most transmitters of this type use the oscillator circuit shown in Fig. 2A.

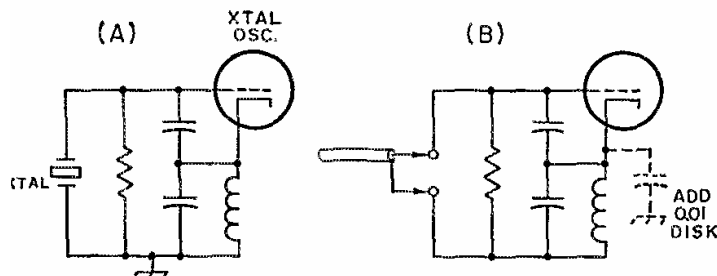


Fig. 2 —Circuit diagram of a typical crystal-oscillator stage at A. At B, the only change required to use the same stage with v.f.o. is the addition of a 0.01-disk ceramic capacitor as shown.

The only modification required to make it work with VFO input is shown at Fig 2B. This consists of adding a 0.01 disk ceramic capacitor between the cathode terminal on the oscillator tube and chassis ground. If you want to operate with either crystal or VFO, it will be necessary to install a switching arrangement to switch the 0.01 μF capacitor in or out of the circuit as needed. Otherwise, you'll have to unsolder the capacitor if you want to use crystals.

The transmitter is keyed in the normal manner and the VFO is put on standby during listening periods. The two terminals on the power supply connected in parallel with S_4 can be connected to a switch at the operating position. If the switch is double pole, it can be the same one that controls your antenna changeover relay. If you are interested in break-in keying, it is suggested that the keying chapter of the *ARRL Handbook* be studied for suggestions.

In using the VFO you have the option of using 80 or 40-meter output. However, when possible, operate the setup so that the

ex-crystal stage is working as a doubler. This will reduce any chances of the crystal stage "taking off", oscillating on its own.

You can check to see if the setup is stable by turning off the VFO, but leaving the transmitter on. If you get output from the final stage then the rig is taking off on its own. The only band where you are likely to run into this trouble is on 80 when the ex-crystal stage operates as a straight-through amplifier. If it does take off, it might be possible to stabilize the circuit by putting a resistor in series with the grid of the ex-crystal stage tube directly at the grid. You might have to try different values of resistors, starting off with a low value, say 25 to 50 ohms.

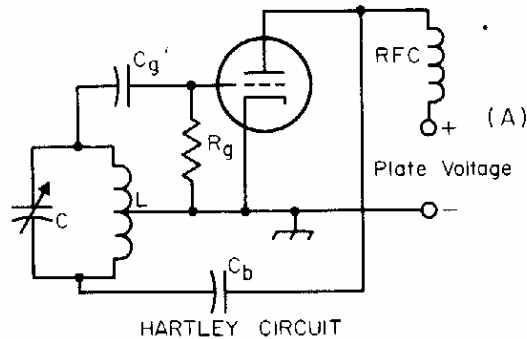
You'll also probably find that you have more drive to the crystal stage than when using a crystal. This can be taken care of by tuning C_7 to give approximately the same amount of final-amplifier grid current as with a crystal.

Larger Schematic and Parts List in separate documents.

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If there is enough positive feedback in an amplifier circuit, self-sustaining oscillations will be set up. When an amplifier is arranged so that this condition exists it is called an oscillator.

Oscillations normally take place at only one frequency, and a desired frequency of oscillation can be obtained by using a resonant circuit tuned to that frequency. For example, in Fig. 3-21A the circuit LC is tuned to the desired frequency of oscillation.



The cathode of the tube is connected to a tap on coil L and the grid and plate are connected to opposite ends of the tuned

circuit. When an RF current flows in the tuned circuit there is a voltage drop across L that increases progressively along the turns. Thus the point at which the tap is connected will be at an intermediate potential with respect to the two ends of the coil. The amplified current in the plate circuit, which flows through the bottom section of L , is in phase with the current already flowing in the circuit and thus in the proper relationship for positive feedback.

The amount of feedback depends on the position of the tap. If the tap is too near the grid end this voltage drop between grid and cathode is too small to give enough feedback to sustain oscillation, and if it is too near the plate end the impedance between the cathode and plate is too small to permit good amplification. Maximum feedback usually is obtained when the tap is somewhere near the center of the coil.

The circuit of Fig. 3-21A is parallel-fed, C_B being the blocking capacitor. The value of C_B is not critical so long as its reactance is low (not more than a few hundred ohms) at the operating frequency.

Capacitor C_g is the grid capacitor. It and R_g (the grid leak) are used for the purpose of obtaining grid bias for the tube. In most oscillator circuits the tube generates its own bias. During the part of the cycle when the grid is positive with respect to the cathode, it attracts electrons. These electrons cannot flow through L back to the cathode because C_g "blocks" direct current. They therefore have to flow or "leak" through R_g to cathode and in doing so cause a voltage drop in R_g that places a negative bias on the grid. The amount of bias so developed is equal to the grid current multiplied by the resistance of R_g (Ohm's Law). The value of grid-leak resistance required depends upon the kind of tube used and the purpose for which the oscillator is intended. Values range all the way from a few thousand to several hundred thousand ohms. The capacitance of C_g should be large enough to have low reactance (a few hundred ohms) at the operating frequency.

The circuit shown at B in Fig. 3-21 uses the voltage drops across two capacitors in series in the tuned circuit to supply the feedback. Other than this, the operation is the same as just described. The feedback can be varied by varying the ratio of the reactance of C_1 and C_2 (that is, by varying the ratio of their capacitances).

There are many oscillator circuits but the basic feature of all of them is that there is positive feedback in the proper amplitude and phase to sustain oscillation.

Oscillator Operating Characteristics

When an oscillator is delivering power to a load, the adjustment for proper feedback will depend on how heavily the oscillator is loaded – that is, how much power is being taken from the circuit. If the feedback is not large enough – grid excitation too small – a small increase in load may tend to throw the circuit out of oscillation. On the other hand, too much feedback will make the grid current excessively high, with the result that the power loss in the grid circuit becomes larger than necessary. Since the oscillator itself supplies this grid power, excessive feedback lowers the over-all efficiency because whatever power is used in the grid circuit is not available as useful output.

One of the most important considerations in oscillator design is frequency stability. The principal factors that cause a change in frequency are

- 1) temperature,
- 2) plate voltage,
- 3) loading,
- 4) mechanical variations of circuit elements.

Temperature changes will cause vacuum-tube elements to expand or contract slightly, thus causing variations in the interelectrode capacitances. Since these are unavoidably part of the tuned circuit, the frequency will change correspondingly. Temperature changes in the coil or the tuning capacitor will alter the inductance or capacitance slightly, again causing a shift in the resonant frequency. These effects are relatively slow in operation, and the frequency change caused by them is called drift.

A change in plate voltage usually will cause the frequency to change a small amount, an effect called dynamic instability. Dynamic instability can be reduced by using a tuned circuit of high effective Q. The energy taken from the circuit to supply grid losses, as well as energy supplied to a load, represent an increase in the effective resistance of the tuned circuit and thus lower its Q. For highest stability, therefore, the coupling between the tuned circuit and the tube and load must be kept as loose as possible. Preferably, the oscillator should not be

required to deliver power to an external circuit, and a high value of grid leak resistance should be used since this helps to raise the tube grid and plate resistances as seen by the tuned circuit. Loose coupling can be effected in a variety of ways – one, for example, is by ‘tapping down” on the tank for the connections to the grid and plate. This is done in the “series-tuned” Colpitts circuit widely used in variable-frequency oscillators for amateur transmitters.

Alternatively, the L/C ratio may be made as small as possible while sustaining stable oscillation (high C) with the grid and plate connected to the ends of the circuit as shown in Fig. 3-21. Using relatively high plate voltage and low plate current also is desirable.

In general, dynamic stability will be at maximum when the feedback is adjusted to the least value that permits reliable oscillation. The use of a tube having a high value of transconductance is desirable, since the higher the transconductance the looser the permissible coupling to the tuned circuit and the smaller the feedback required.

Load variations act in much the same way as plate-voltage variations. A temperature change in the load may also result in drift.

Mechanical variations, usually caused by vibration, will cause changes in inductance and/or capacitance that in turn cause the frequency to “wobble” in step with the vibration.

VARIABLE-FREQUENCY OSCILLATORS

The frequency of a VFO depends entirely on the values of inductance and capacitance in the circuit. Therefore, it is necessary to take careful steps to minimize changes in these values not under the control of the operator. As examples, even the minute changes of dimensions with temperature, particularly those of the coil, may result in a slow but noticeable change in frequency called drift. The effective input capacitance of the oscillator tube, which must be connected across the circuit, changes with variations in electrode voltages. This, in turn, causes a change in the frequency of the oscillator. To make use of the power from the oscillator, a load, usually in the form of an amplifier, must be coupled to the oscillator, and variations in the load may reflect on the frequency. Very slight mechanical movement of the components may result in a shift in frequency, and vibration can cause modulation.

V.F.O. Circuits

The performance of the VFO, as mentioned before, is exceedingly good. With the coil and capacitors used, the tuning range is nearly linear from 3495 to 4005 kilocycles. The frequency-set capacitor, C_3 will shift the oscillator frequency about 35 KHz. The measured frequency drift after about 30 minutes warm up was less than 20 cycles in 2.5 hours.

From Dave WA4QAL

C_2 : Functions to limit the maximum frequency swing of the oscillator. Without that shunting element, when C_1 goes to zero (well, approaches zero), the frequency will shoot up to a very high value.

Plate: The plate is at zero potential for RF via the 0.01 μF bypass capacitor and, ground, by definition, is ground.

C_3 , C_4 , C_5 , and C_6 : You need to factor in their capacitances using the appropriate series/parallel formulas. Just because C_4 is there to decouple the tank from the DC bias of the grid doesn't mean that it and the capacitors beyond it don't affect the resonance of the tank circuit. If you do this, you'll find the oscillator varies between about 2.6 MHz and 4.5 MHz, which easily spans the 80 meter band.

Figure the total capacitance across the coil. Doing some quick and dirty back of the envelope calculations, I came up with a capacitance that varies between 335 and 980 pF (depending upon how the various variable capacitors are adjusted, from 0 pF [1] to their maximum value) [2].

[1] We all know that they won't really go to zero, but I didn't want to have to factor in a minimum capacitance, since this varies with the style of capacitor.

[2] And, ignoring the grid to other electrode capacitance of the tube, which should be only a few pF.

From Ian K3IMW

The frequency-determining components are C_1 through C_6 and L_1 . The tube input capacitance is shunted by C_5+C_6 and can be neglected.

Working from right to left:

C_5 & C_6 are in series: effective capacitance 500pF.

$$C_{5,6} = \frac{0.001 \times 0.001}{0.001 + 0.001} = 500 \text{ pF}$$

C_3 is in parallel with this. Assume C_3 can be varied between 10-100pF.

Then the $C_3C_5C_6$ capacitance is between 510-600pF.

McCoy VFO QST February 1962

$$C_{3,5,6} = 10pF + 500pF = 510pF \text{ and } 100pF + 500pF = 600pF$$

C_4 is in series with the $C_3C_5C_6$ combination. The resulting capacitance varies between 291-319pF. That's a capacitance variation of 28pF.

$$C_{3,5,6+4} = \frac{680pF \times 510pF}{680pF + 510pF} = 291pF \text{ and } \frac{680pF \times 600pF}{680pF + 600pF} = 318.75pF$$

$$C_{\text{VARIATION}} = 319pF - 291pF = 28pF$$

The capacitance of the $C_4C_3C_5C_6$ combination appears in parallel with C_1 and C_2 across L_1 .

Assume C_1 can be varied between 10-140pF.

So C_1 operates as a 'bandset' control and C_3 operates as a 'bandspread' control because the effective change in capacitance across L_1 is 130pF for C_1 , but only 28pF for C_3 .

Imagine C_1 is set to halfway (assuming it has a linear law); then its capacitance will be 75pF. This is shunted by C_2 and the $C_4C_3C_5C_6$ value of between 291-319pF, depending on C_3 setting.

At the low frequency end, the total capacitance will be

$$75 + 47 + 319 = 441pF.$$

At the high frequency end, the total capacitance will be

$$75 + 47 + 291 = 413pF.$$

Calculating the resonant frequency in each case with $L_1 = 3.69\mu H$:

$$f \text{ low} = 3.945\text{MHz}$$

$$f \text{ high} = 4.077\text{MHz}$$

You can repeat these calculations for various values of C_1 between the maximum and minimum capacitance to see what the centre frequency and tuning range of the VFO will be.

C_6 is shunted by a resistance equal to $1/gm$ of the tube. At 3.5MHz, the reactance of C_6 is about 45 ohm. The transconductance, gm , for a 12AU7 is no more than about 3 mmho (3000 μ mho for those of an American persuasion).

$$\text{So } 1/gm = 333 \text{ ohm}$$

This is effectively swamped by the much smaller, 45Ω reactance of C_6 .

However, the change in gm with operating point is more likely to affect the frequency of oscillation than any change in tube capacitances with operating point.

From Jim, N2EY

Another way to look at it is that the plate is grounded for RF but the cathode isn't.

The capacitive voltage divider (the two 1000 pF caps) actually performs two functions:

- First, they create the feedback path, and
- Second, they establish the resonant circuit as being very high C.

End result is that changes in the tube capacitances due to heat, etc., have very little effect on the tank circuit frequency.

10KΩ resistor is the grid leak. C_3 serves to keep the coil L_1 , from being a DC short across this resistor, and it is part of the feedback voltage divider.

Colpitts Oscillator Calculations

Radio and Television Mathematics

Frequency of Oscillation (Colpitts):

$$f = \frac{1}{2\pi\sqrt{L\frac{C_1C_2}{C_1+C_2}}}$$

6.02 An inductor of 28.3 micro henries is used for a Colpitts oscillator. A fixed capacitor of 25 pF is available. What is the value of the other capacitor required to tune the circuit to 7500 kilocycles?

Solution:

1. Frequency of resonance depends upon the values of L and C (total).

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \text{solve for } C = \frac{1}{4\pi^2 L f^2} = \frac{1}{4\pi^2 \times 28.3\mu H \times (7500 KHz)^2} = 15.96 pF$$

2. Since the capacitors are in series and C_{TOTAL} is equal to 15.96 micro microfarads, and C_1 was set as 25 pF.

$$\frac{1}{C_{TOTAL}} = \frac{1}{C_1} + \frac{1}{C_2} \quad \text{solve for } C_2 = \frac{25 \times 15.96}{25 - 15.96} = 44.2 \mu F$$