# DESIGNING and USING VFOs

Perhaps you are tired of being "rock bound" with your QRP transmitter. Certainly, a VFO provides greater operating lattitude when you look for a clear frequency or wish to answer a CQ. A VFO need not be especially stable when it is used in a household environment, where the ambient temperature remains fairly constant over a span of hours. But, portable operation creates a scenario that tests the stability factor of any tunable oscillator. Changes in temperature are often significant from night to day, there are humidity changes and there are breezes to contend with. Special care must go into the design of a VFO that is used in the field. Let's examine some of the fine points of VFO design.

## CHOICE of CRITICAL CAPACITORS

There is a common belief that silver-mica capacitors are stable components for use in the frequency-determining part of a VFO circuit. They are, in fact, suitable for use in many low-frequency tunable oscillators. I do not find them to be of quality at frequencies above 3.5 MHz when frequency stability is a criterion. Some silver micas exhibit positive drift, while others produce negative drift with temperature. Some of these capacitors are relatively stable. Much depends on the brand and the particular production run. I have hand picked silver micas from a batch of several in order to find some that were reasonably temperature stable. It can be a tedious job that requires soldering various capacitors into an operating VFO, then performing a drift run with a frequency counter or stable receiver.

Better results may be expected when using polystyrene capacitors. They have good temperature stability, but exhibit a slight negative drift. This can be used to advantage in VFOs that contain coils with powdered-iron cores or slugs. These cores have a positive drift characteristic, and the polystyrene caps tend to equalize the drift. Furthermore, polystyrene caps are less costly than are silver micas.

I prefer to use disc or dogbone NPO ceramic capacitors in my VFOs. These have a zero temperature coefficient, and produce very little change in capacitance versus temperature variations. Foreign-made NPOs do not seem to be as stable as those made in the USA, although I have had good results with some Japanese NPO units.

RF currents that flow through the VFO capacitors cause internal heating, and this leads to long-term drift. This condition may be greatly minimized by using a number of capacitors in parallel to arrive at a desired net value of capacitance. This provides a larger area for the current flow, and hence reduced internal heating of any one capacitor. For example, if a VFO calls for a fixed-value 100-pF NPO capacitor across the VFO coil (or in the feedback divider), I use four 25-pF NPO units in parallel. Likewise with polystyrene caps.

It is helpful to glue the VFO capacitors in place after they are mounted on the PC board. This helps prevent frequency changes from vibration.

## VFO COILS

The coil used in a VFO is as critical a component as are the capacitors. It needs to be mechanically sound and have sufficient wire diameter to minimize heating from RF currents. The loaded Q of the coil should be as high as practicable. This helps to ensure oscillation and it reduces the noise bandwidth of the VFO output voltage. The latter trait is especially important when designing the local oscillator for a high-performance receiver.

The most ideal VFO coil is one that is air wound or wound with heavy-gauge wire on a ceramic coil form. Ferrite or powdered-iron cores may aid the Q of a small coil, but the core material contributes to long-term drift. If a slug-tuned coil is used, try to arrange the winding so that the desired inductance occurs just as the slug starts to enter the coil winding. This will minimize inductance drift as the core temperature changes. Greater drift will occur when the slug is well into the coil at its required setting. Slug-tuned inductors should be secured after adjustment so that the slug cannot move from heat changes or vibration. A lock nut and star washer may be used on slugs with a threaded metal shaft. Hex-adjust slugs can be held in place by melting a small drop of canning or bee's wax on them. No. 6 powdered-iron (yellow coding) cores are the most stable ones for HF VFO coils. No. 2 (red) cores are not recommended.

Although W7ZOI, W7EL and others have reported good stability from VFOs that have no. 6 toroid cores (T68-6) in them, I have not enjoyed their successes. They anneal the cores by heating them in the oven, and this seems to make them more stable. But, once the toroid is wound the wire on it can move from stress or vibration, and this changes the inductance. The net result is drift. I have had better results with No. 6 toroid cores after I coated them with three layers of polystyrene Q Dope (1). This keeps the winding firmly in place. I also like to coat my other coils with Q Dope for the same reason. This also helps to prevent frequency drift from changes in humidity. In other words, I use Q Dope for slug-tuned coils, and those I wind on low-loss coil forms.

Avoid using slug-tuned forms that are made from phenolic. This is poor insulation and it expands or contracts with temperature changes. Ceramic or steatite is the best coil-form material for VFOs.

## VFO VARIABLE CAPACITORS AND TRIMMERS

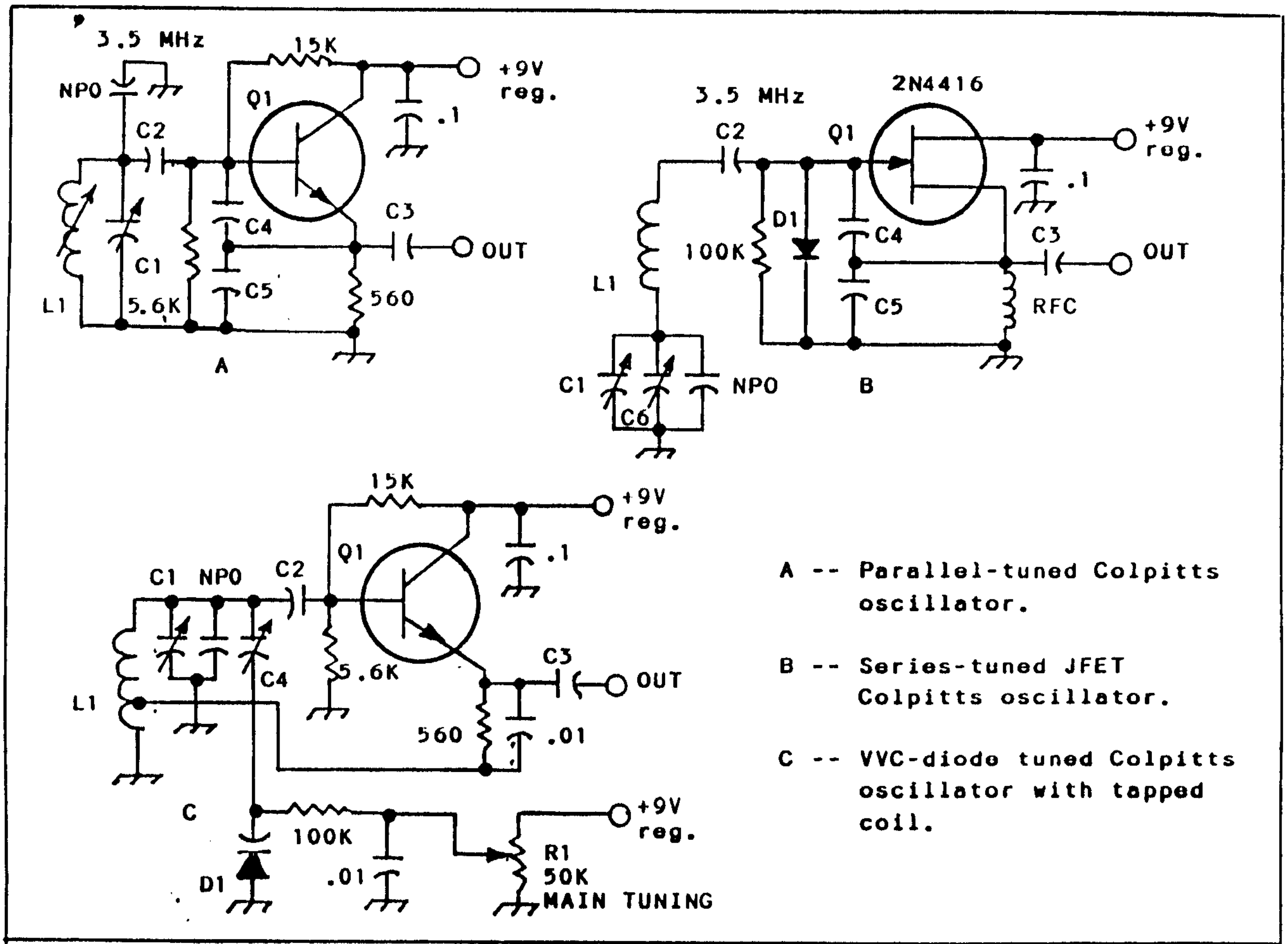
It is important that you use variable capacitors and trimmers that provide good mechanical stability. The main tuning capacitor should be a double-bearing type (rotor bearing at both ends), and it should turn easily. Avoid using VFO capacitors that have aluminum plates. This metal is more temperature-sensitive than is plated brass or steel.

Trimmers and padders should be, if possible, small air variables. These are the most temperature and mechanically stable. Mica compression trimmers are the worst kind you can use in a VFO, and cheap plastic trimmers aren't much better. If you can't locate air-variable trimmers, try to find some NPO ceramic trimmers. These units are reasonably stable, once they have been set and have time to "seat in." I have also used glass piston trimmers in VFOs. The stability was quite good.

A smooth-operating vernier drive is mandatory for good VFO operation. Make certain your drive assembly is not sloppy, lest you experience backlash.

## VARACTOR-TUNED VFOs

Fig 1 shows three types of VFO circuits. The one at C is tuned by a VVC (voltage variable capacitance) diode, or varactor. These diodes eliminate the need for a mechanical tuning capacitor. This reduces the cost and bulk of a VFO. But, what is the tradeoff in performance? Varactors, like all other semiconductors, have PN junctions. When operating voltage and RF currents are applied to the junctions, they change capacitance as a result of internal heating. This is true also of the junction in the VFO transistor. Normally, the change in capacitance is fairly rapid (short-term drift), but it can amount to a shift as great as 2 kHz during the first five minutes of operation at, say, 7 MHz. VVC diodes are quite acceptable as electronic tuning elements in many circuits. They are worth considering when one contemplates the cost of a quality air variable capacitor! VVC diodes are excellent also for use in compact gear. As reverse voltage is applied to the VVC diode through a potentiometer (positive voltage applied to the diode cathode) the internal capacitance changes in a nonlinear manner, and this tunes the VFO. The potentiometer serves as the MAIN TUNING control for the VFO.



A -- Parallel-tuned Colpitts oscillator.

B -- Series-tuned JFET Colpitts oscillator.

C -- VVC-diode tuned Colpitts oscillator with tapped coil.

*Fig 1 -- Examples of VFOs that represent the most common circuits used by amateurs. Circuit A has a slug-tuned coil (L1). C1 is the main-tuning control. The oscillator at B shows how a JFET may be used in a VFO. Series or parallel tuning may be used (see text). Circuit C illustrates how a VVC diode may be used in place of a mechanical tuning capacitor. R1 serves as the main-tuning control. C2, C3, C4 and C5 are NPO or polystyrene caps in each of the above circuits.*

Perhaps, the circuit of Fig 1A is the most common one is use by amateurs. It is easy to make operate and it is quite stable. The objective here is to make C2 as small in value as practicable, consistent with reliable oscillation of Q1. The lighter the coupling between L1 and Q1 the better the stability and the higher the tuned-circuit Q. Capacitance values as low as a few pF have been used successfully by some designers when the active device was an FET. You will need to experiment with the value of C2. In all three examples it should be an NPO capacitor.

No trimmer capacitor is used at Fig 1A. This is because a slug-tuned coil (L1) is indicated. The coil is adjusted to provide calibration of the readout. C4 and C5 comprise the feedback network in examples A and B. Normally, these are of equal value and of fairly high capacitance. I use an Xc of 45 in my VFOs. This provides a value of 1000 pF for C4 and C5. This large value of C helps to minimize the effects of the smaller internal C of the transistor, which changes as the device warms up.

The output capacitor, C3, in all of the Fig 1 circuits should be small in value to minimize the effects of load pulling from the subsequent stages of the VFO. I use an Xc of 455 at this circuit point, which equates to 100 pF at 3.5 MHz. Output in each example is taken from a low-impedance point in the circuit, which means that the output RF voltage is very low at those terminals -- usually less that 3V peak-to-peak.

Fig 1B shows a JFET oscillator with series tuning. D1 limits the device transconductance on positive sine-wave swings. This stabilizes the bias and prevents large changes in junction capacitance during the sine-wave cycle. This aids stability. Series-tuned VFOs are often used at 7 MHz and higher because the value of inductance for L1 (circuit A) may be very small with so much shunt C present. A VFO coil with only a few turns can cause drift when only minor changes in inductance occur (heating and vibration). Series-tuned VFOs require substantially more coil inductance for the same VFO frequency, and this reduces the potential for drift from small changes in inductance. If a JFET is used in a VFO it should have a high pinchoff-voltage rating. The 2N4416 is excellent in this regard, and is superior to the common MPF102. The higher pinchoff voltage results in greater RF output from the oscillator. RFC in Fig 1B has an XL of 22,000 ohms. Therefore, the choke value is 500 uH at 7 MHz. This may be solved by simple formula: L(uH) = XL/6.28 X f(MHz). In a like manner you can derive capacitance values versus XC via C(uF) = 1/6.26 X f(MHz) X XC.

A varactor-tuned VFO is illustrated in Fig 1C. This diode and its associated components may be applied also to the VFOs at A and B of Fig 1. L1 at C is tapped 1/4 the total coil turns, starting at the grounded end of L1. This ratio ensures the proper feedback voltage for the oscillator. D1 is selected for high Q at the chosen operating frequency. The best range of operating voltage for a VVC diode is +1-1/2 to 9 volts, regulated. Below +1.5 volts there is little change in junction capacitance, which leaves a portion of the tuning dial without frequency change. A fixed-value resistor may be inserted between the low end of R1 and ground to prevent the diode voltage from being less than 1.5V. VVC diodes, like transistors, have PN juntions that heat and cause drift, as mentioned earlier. The long-term drift is acceptable when using tuning diodes. Various ranges of capacitance are available from VVC diodes. I like to use diodes that change approximately 25 pF from 1.5 to 9 V.

## OTHER CAUSES of VFO DRIFT

The stage that follows a VFO should have a constant input impedance. Small changes in VFO loads introduce reactance shifts, and this leads to drift. I like to use a source-follower JFET buffer or a Class A bipolar-transistor buffer to ensure a nonchanging load. Examples of buffers are given in Fig 2. The voltage gain of a source-follower (Fig 2A) is 0.9, which means that you will get slightly less output voltage than is applied at the FET gate. But the high input impedance of the JFET (determined by the value of the gate resistor) offers good VFO isolation and provides a constant load. RFC1 of Fig 2A is chosen to be broadly resonant with the usual 10-15 pF of stray circuit capacitance at the operating frequency. This provides a slight peak in output voltage at the operating frequency. A 270-ohm resistor may be used in place of RFC1 at a sacrifice in source output voltage.

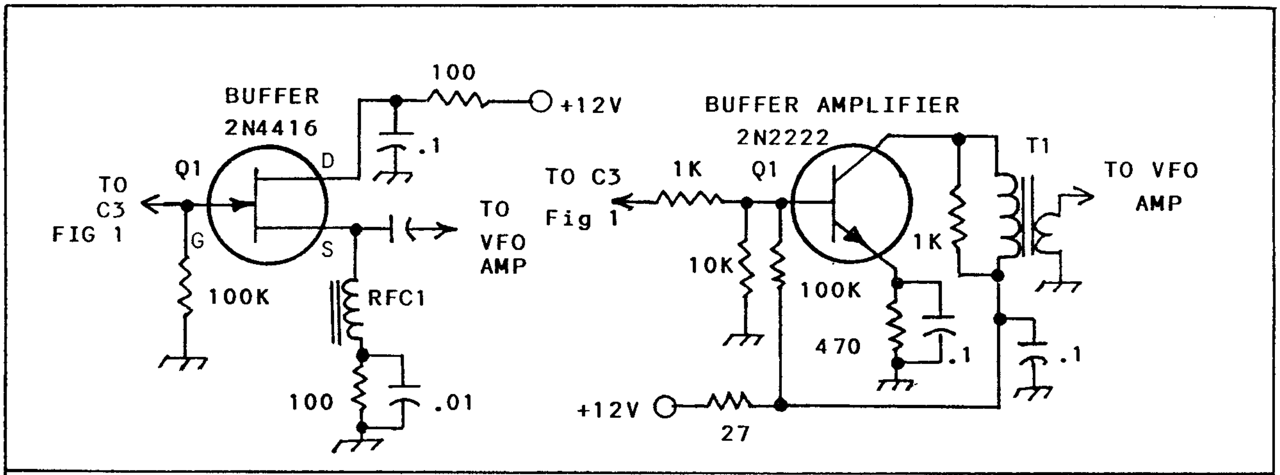


*Fig 2 -- Examples of buffer stages that can follow a VFO. These stages provide isolation between the oscillator and the VFO amplifier to minimize frequency changes that result from load changes. Although a 2N4416 is listed at A, an MPF102 will perform satisfactorily. RFC1 is chosen to provide resonance at the operating frequency in combination with the stray circuit capacitance. An XL of 1895 may be used for RFC1. Circuit B operates Class A. T1 is wound to match 1000 ohms to 600 ohms, assuming the VFO amplifier is a also a Class A amplifier (desirable). Use 12 turns of no. 26 wire on an Amidon FT-37-43 toroid. The secondary has 9 turns of no. 26 wire for a 600-ohm load, such as that of a Class A bipolar amplifier. For a 50-ohm load use a 3-turn secondary.*

The buffer stages in Fig 2 may be not require an additional amplifier provided the they deliver sufficient output for the transmitter or receiver stage with which they interface. In a typical situation there is one more stage that is used to provide additional gain and load isolation.

Avoid double-sided PC boards in VFOs. The ground plane side and the etched foils form low-Q capacitors with the epoxy insulation. These capacitors are unstable electrically and physically. Drift can be expected from this type of VFO construction.

The composite VFO or module needs to be enclosed in its own shield compartment for best stability. If not, stray RF and abrupt temperature changes can affect the frequency stability.

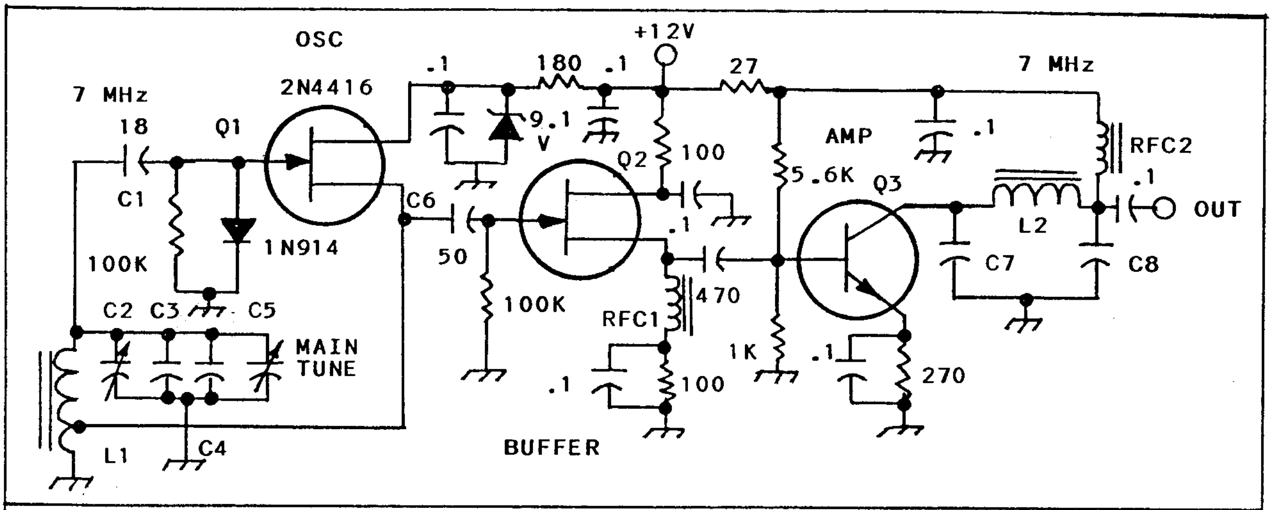


*Fig 3 -- Example of a buffered and amplified 40-M VFO. This circuit may be used as a basis for VFOs that cover other frequency ranges, such as 160M, 80M, 30M and 5 MHz. NPO or polystyrene capacitors are used at C1, C3, C4 and C6. Trimmer C2 should be a ceramic NPO unit for best stability. C2 is a 25 pF trimmer. C3 and C4 are 25 pF NPO disc ceramic. C5 is a 15-pF double-bearing air variable. The L1 nominal inductance is 6.7 uH. An air-wound coil is best. A slug-tuned high-Q coil may also be used. A T68-6 toroid core, if used, requires 37 turns of no. 24 enam. wire. Coat with three layers of polystyrene Q Dope. L2 is 3.2 uH. Use 25 turns of no. 26 enam. wire on an Amidon T50-2 toroid. C7 is 180 pF and C8 is 360 pF. Q2 is an MPF102 and Q3 is a 2N2222 or 2N3904. RFC1 and 2 are miniature 50-uH RF chokes.*

## A VFO FOUNDATION CIRCUIT

Fig 3 shows the circuit of what might be considered a "universal" VFO. Scaling the circuit to other frequencies may be done by converting the specified parts values (tuned circuits and RF chokes) to XL and XC, then calculating the actual values for the new frequencies. The circuit of Fig 3 covers all of the 40-meter band. Increase the value of C3 and C4, then decrease the value of C5 if you wish to cover a smaller part of the band. The output impedance of the Q3 amplifier is 50 ohms. Power output is on the order of 15 to 25 mW, depending upon the transistors used.

The tap on L1 is placed 25% up from the grounded end of the coil. If you use the toroid coil you may locate the tap 9 turns above the grounded end of L1. A 9-turn link may be substituted for the tap. Wind the link over the grounded end of L1 if this is done.

## Summary

If you study and follow the guidelines in this application note and you will have excellent results when building homemade VFOs. Experimentation will give you additional pleasure. The component values aren't sacred. Use the next closest component value if you don't have the specified part.