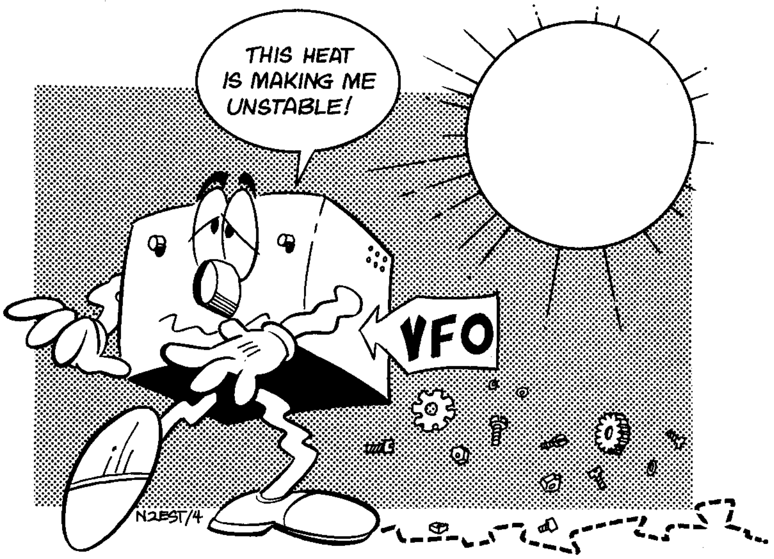
• *Beginner's Bench*

The Principles and Building of SSB Gear



Part 4: As we approach the wrap-up of this series, let's discuss VFOs and examine a practical circuit for use with our SSB transmitter. Emphasis is on stability and purity of the VFO signal.

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Drift, hum, low output and unwanted harmonic energy are the unwelcome bedfellows of some homemade VFOs. The cures are not casual, even though solid-state circuits are the way of life today! Some of us concluded that the passing of vacuum tubes for low-power applications would erase the usual shortcomings of home-built VFOs, but such is not the case. In effect, we have traded one cause of poor performance for another, and some of the maladies in both styles of VFO—tube or transistor—are caused by the same operating characteristics. In general terms, the solid-state VFO is easier to tame when problems arise, but certain design procedures are necessary. Let's examine the general problem before we get into the meat of this installment.

Frequency Instability—the Causes

Heat-caused drift is perhaps the most common cause of frequency instability in an oscillator. The greater the change in VFO temperature, the more pronounced the drift problem. Changes in operating temperature can take place in the general area of the VFO assembly (ambient temperature changes) or within the components used in the circuit. Both forms of temperature shift contribute to the overall drift picture. These difficulties pertain not only to tunable oscillators, but also to crystal-controlled oscillators. The higher the operating frequency, the more pronounced the drift with any oscillator.

Ambient-temperature changes are caused by equipment warmup over time (power supplies and other stages in a transmitter or receiver) and by variations in room temperature where the equipment is being used. Circuits designed for critical operating conditions may be equipped with temperature ovens that maintain a nearly constant ambient temperature, irrespective of variations in air temperature in and around the VFO unit. Some amateurs build homemade ovens that use small incandescent lamps or resistors as heating elements; dc voltage is applied to the resistors to cause them to dissipate power and generate heat. Several of these resistors may be coupled thermally to the inner wall of the VFO or crystal-oscillator shield compartment. Heater power is supplied around the clock to stabilize the operating temperature.

Heating within the VFO components —particularly the fixed-value capacitors —is caused by RF energy flowing through these parts. Even a small amount of RF current can change the value of a capacitor. Changes in ambient temperature also affect these capacitors. Additional drift may result from transistor-junction heating when power is first applied. Changes in junction temperature create shifts in the internal capacitance and resistance of a semiconductor. This is not true of vacuum tubes. Fortunately, most transistors used in oscillators do not generate sufficient case or package heat to significantly affect the VFO ambient temperature, whereas tubes contribute markedly to increased ambient temperature. This represents one of the trade-offs we mentioned earlier.

Reducing Component-Heating Drift

The combined drift from ambient-temperature excursions and component heating may have a long cycle—an hour or greater. This is known as *long-term drift. Short-term drift* results from changes within the components at turn-on time; the drift period is generally 10 minutes or less. Learning to identify the nature of the drift problem, respective to elapsed time, helps to solve the cause of the malady. A frequency counter or stable receiver (both completely warmed up) is useful for this experiment.

Short-term drift can be minimized by keeping the operating voltage (and current) of the oscillator as low as possible, consistent with reliable oscillation. The lower the oscillator power, the better our chance to reduce component heating. Oscillator-chain power output can be increased inexpensively *after* the VFO stage by adding small amplifiers.

Another way to restrict drift from component heating is to use parallel capacitors in place of a single capacitor in critical parts of a circuit. Fig. 1 illustrates this principle. The greater the number of parallel capacitors (up to a reasonable limit), the better the current distribution among them; hence the lower the internal heat in any one capacitor.

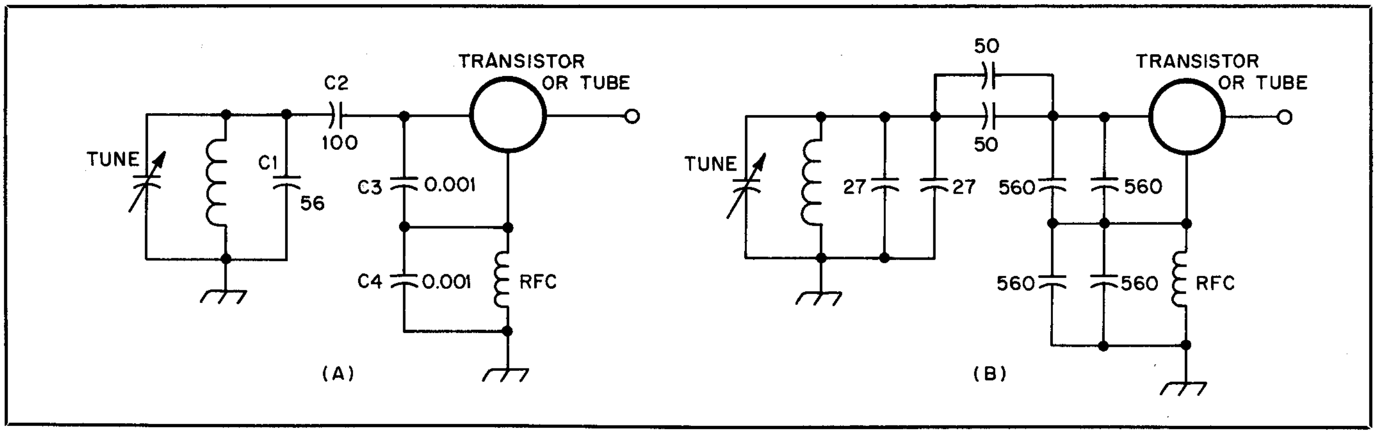

Fig. 1—Example A shows a common method for using capacitors in the critical section of a VFO. The circuit at B illustrates the use of additional capacitors in parallel to achieve the aproximate values given at A. The additional capacitors provide a greater path for the RF currents; this reduces internal heating and resultant changes in capacitance.

Modern VFO circuits are generally built on PC boards. This practice contributes to drift problems. Double-sided PC board (copper on both sides) is the worst material we can use; single-sided material can be a problem, too, if the layout is not planned properly. Why do PC boards cause drift? We must recognize that PC-board foils act as the plates of a capacitor, and the phenolic or glass-epoxy insulating substance becomes the dielectric for the capacitor. These unwanted capacitors become part of the VFO circuit; because the board insulating material for capacitors is of poor quality, the capacitance value will change with heat. Therefore, when using a PC board for your VFO, make certain that the copper foils in the frequency-determining part of the circuit are far apart (¼ inch or greater). Only glass-epoxy or Teflon® (expensive!) PC board is recommended.

Other Instability

Minute changes in VFO operating voltage can cause frequency jumping. Zener-diode regulators help in this situation, but are not ideal. The true regulating voltage of a Zener diode is not constant. As operating conditions vary, the Zener diode may allow small voltage changes about its nominal value. Such voltage variations will cause shifts in operating frequency. I have bought surplus or bargain-price Zener diodes that provided no regulation at all! It is wise to check them for performance prior to soldering them into your circuit. A variable dc power supply and a suitable series resistor will tell the story while monitoring the voltage across the Zener diode with a VOM. A stiff regulated power supply should be used to power the VFO and related circuitry.

Frequency jumping can have various mechanical causes, such as loose bearings in a variable capacitor. Trimmer capacitors may be prone to changes in value with vibration, owing to loose movable sections. Loose slugs in VFO coils are still another source of abrupt changes in frequency. Frequently, this problem can be cured by melting a drop of bee's wax on the end of the slug. This cure has been used for loose VFO-coil slugs in the HW-8 and HW-9 QRP rigs.

While on the subject of coil slugs or cores, the ferrite or powdered-iron material is a cause of drift in most circuits. This pertains to toroids as well as slugs. Since the permeability changes with heat, ferrite is the worst of the two materials. No. 6 material (yellow color code) is perhaps the most stable of the HF core substances when using powdered iron. For example, we might use a T68-6 toroid as the foundation for a VFO inductor. Magnetic cores of this type create a positive drift (increased inductance) characteristic. This often requires the use of negative-coefficient capacitors to compensate for the positive drift. Polystrene capacitors may be used successfully in such a situation to achieve drift balance. Silver-mica capacitors, on the other hand, are unpredictable. Some may have negative drift, while others from the same batch may show positive trait. I avoid using them in VFOs. Zero-temperature coefficient (NP0) ceramic capacitors represent the best starting point in VFO design.

VFO Load Changes

Variation in operating parameters *after* the VFO will cause abrupt changes in frequency. A wise designer includes at least two isolation stages (buffers) after the oscillator. This minimizes load changes being reflected back to the oscillator. These changes are caused by variation in transistor operating conditions during the RF sine-wave excursion. Changes occur in transistor capacitance and resistance with dc-level alterations, and these variations are "seen" by the VFO as changes in reactance. However, the most significant load-shift effect is observed when the termination at the output of the VFO chain is changed, such as when switching from transmit to receive in a transceiver, or when

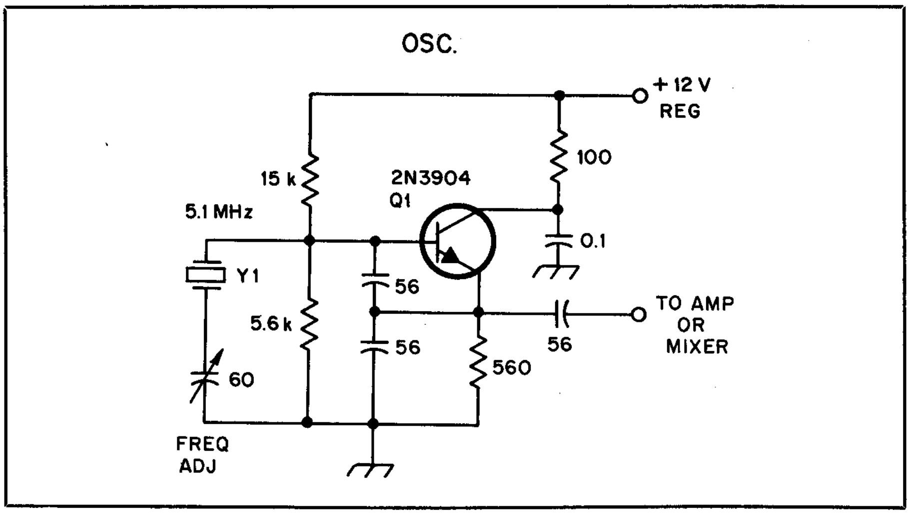

Fig 2—Suggested circuit for a crystal-controlled LO for the SSB transmitter. This oscillator may contain several switched crystals to provide channelized operation. A buffer amplifier may be added, if desired.

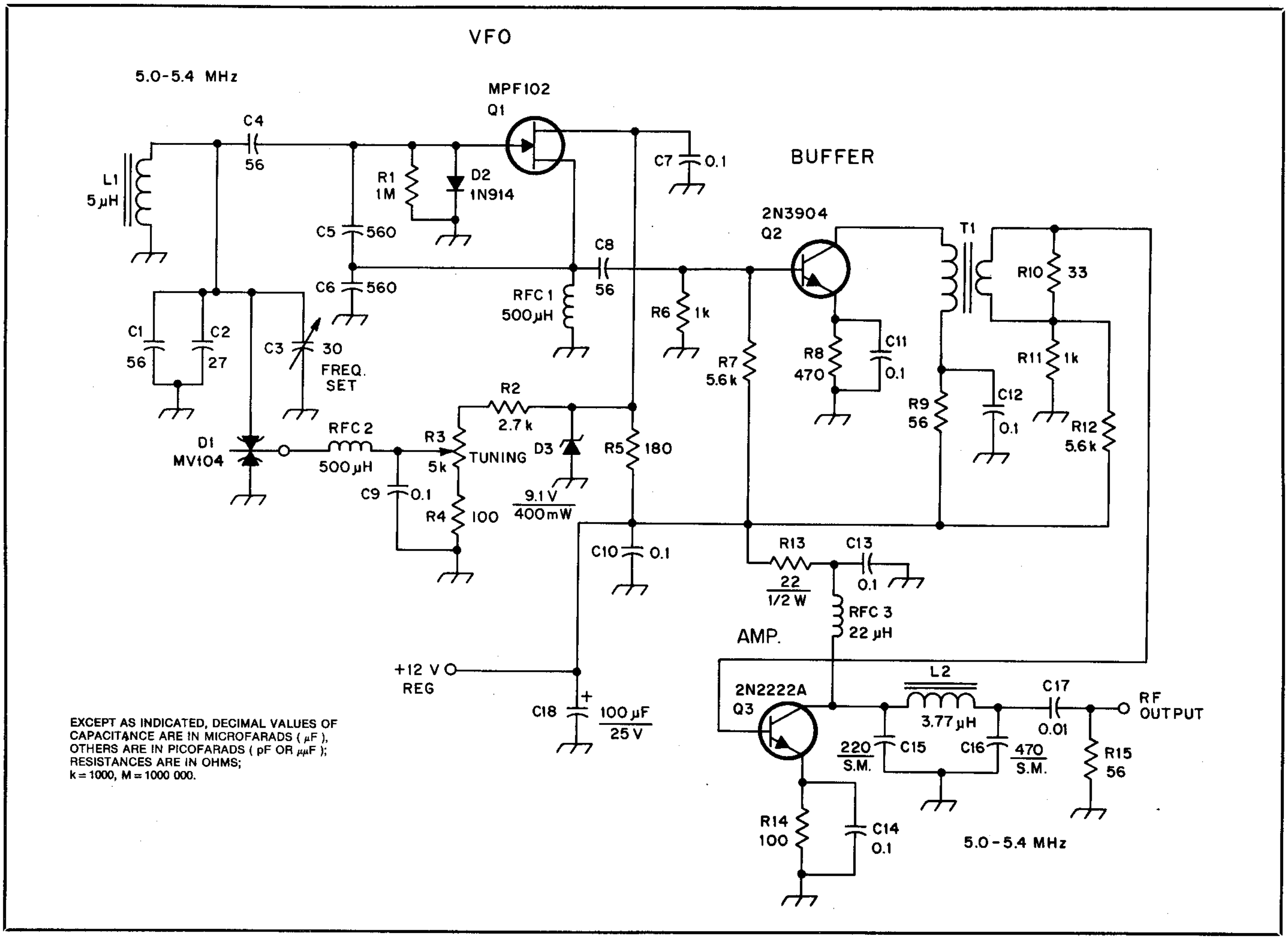

Fig. 3—Schematic diagram of a practical 5-MHz VFO. Fixed-value capacitors are disc ceramic unless otherwise indicated. Polarized capacitors are tantalum or electrolytic. Fixed-value resistors are carbon composition and are ¼- or ½-W unless otherwise noted. Numbered components not appearing in the parts list are numbered for layout purposes only.

C1, C2, C4, C5, C6 and C8—NP0 disc or dog-bone ceramic.
C3—NP0 ceramic trimmer preferred. Plastic Radio Shack trimmer may be suitable.
D1—Tuning diode, Motorola MV104 or equiv. Separate varactor diodes may be used if hooked in series as shown.
D2—Small-signal, high-speed silicon diode.
D3—Zener-diode regulator.
L1—Toroidal inductor, 32 turns of no. 24 enam. wire on an Amidon Assoc. T68-6 core. See text.
L2—Toroidal inductor, 3.76 µH. Use 30 turns of no. 30 enam. wire on a T-37-2 Amidon toroid.
Q1—VHF JFET, Motorola MPF102. 2N4416 suitable also.
R3—Carbon control, linear taper (see text).
RFC1, RFC2—Miniature 500-µH choke (Mouser Electronics or equiv.).
RFC3—Same as above, but 22 µH.
T1—Primary has 15 turns of no. 30 enam. wire on an Amidon FT37-43 toroid (ferrite, 850 µ). Secondary has 4 turns of no. 30 wire.

keying the main transmitter stages in a CW rig. The usual effect is a chirp on the signal, or a difference in VFO frequency between the transmit and receive modes. Light coupling between the VFO and all subsequent stages, plus two or more buffer stages, will minimize this problem. Abrupt frequency changes may result also from stray RF (from late stages in a transmitter) migrating into the VFO circuit. Supply-line decoupling and VFO shielding are mandatory if this ailment is to be avoided.

A Practical VFO

Our SSB transmitter requires a mixer-injection voltage at a frequency of 5.0 to 5.25 MHz. We may use a crystal-controlled oscillator (Fig. 2) for channelized operation, or we can build the circuit of Fig. 3 for coverage of the 75-meter phone band. If you're a whiz with synthesizer design, you may prefer to go that route for your local oscillator (LO).

Fig. 3 shows a three-stage LO that employs voltage-variable capacitor (VVC) diode tuning (D1). This eliminates the bulk and high cost of an air-variable capacitor. I should mention, however, that by adding one more semiconductor junction (D1), the potential for drift is increased. If this trade-off does not appeal to you, simply replace the tuning-diode circuit with an air variable. Once the Motorola MV104 reaches operating temperature, stability will be acceptable. R3 is a panel-mounted control used for tuning the VFO. A quality "pot" should be used, such as an Allen-Bradley carbon-composition, 1/2-W unit. It will be of better mechanical format than most low-cost controls, and should last much longer before becoming noisy and intermittent. A vernier drive can be used to operate the control, thereby making the tuning smoother.

A JFET (Q1) serves as the oscillator. D2 helps to stabilize the transistor by limiting positive sine-wave peaks and stabilizing the bias. Output from Q1 is supplied to a class-A buffer, Q2. It operates as a broadband amplifier by means of T1, which is untuned.

Output amplifier Q3 is also a class-A stage. A low-pass, single-section filter is used at the output of Q3 to remove some of the harmonic currents generated within the system. The filter output impedance is 50 ohms. The injection level to the mixer (U1, Fig. 5, of Part 3, Nov. 1985 *QST*, p. 19) is 600-mV P-P. Depending upon the gain of your VFO transistors, it may be necessary to change the value of the blocking capacitor to pin 8 of the MC1496 mixer. If so, select a smaller value that will allow 600 mV of injection. A scope or RF probe and VTVM can be used to measure the LO injection level.

Practical Considerations

If you lay out your own PC board, keep the conductors short and direct. Q1, Q2 and Q3 should be placed in a straight line to minimize unwanted input-output coupling, which can cause self-oscillation in the amplifiers.

Place a shield box around the VFO assembly. Double-sided PC board can be used to form a low-cost box. Add a lid to the enclosure to keep air currents from reaching sensitive components.

Wind toroidal inductor L1 of Fig. 3 tightly, then coat it twice with Q Dope® or polyurethane varnish. This will keep the coil turns in place to aid stability of the VFO. A dab of flexible cement (Silastic or RTV compound), such as bathtub caulking, can be used to keep the toroid in place on the PC board.

VFO Setup

A frequency counter or calibrated receiver may be used to monitor the VFO output frequency while establishing the tuning range. A 56-ohm resistor can be used as a dummy load across the output of the VFO final amplifier (Q3 of Fig. 3). Attach the frequency-counter test cable across the resistor. If you use a receiver during the calibration period, attach a short length of hookup wire to the ungrounded end of the 56-ohm dummy load, then place the wire near the antenna lead to the receiver. Adjust the main-tuning control (R3) to provide the lowest VFO frequency. Next, adjust trimmer C3 to obtain a frequency of 5.0 MHz. This VFO will cover more frequency than is required (approximately 5.0 to 5.4 MHz) with the constants specified in Fig. 3. The tuning range can be reduced by restricting the voltage change across D1. This can be done by increasing the values at R2 and R4. Some experimentation will be necessary to do this.

Circuit boards or parts kits for this project are available.[1] You may have a pet circuit to try in place of this one, so feel free to use it. The design shown in Fig. 3 can be used for other projects, such as receiver local oscillators and signal generators. You will find additional design information on VFOs in the *ARRL Handbook* and the League's *Solid State Design for the Radio Amateur*. Basic theory and practical-design information concerning the use of toroids and other magnetic cores is available in book form.[2]

Notes

[1] A & A Engineering, 7970 Orchid Dr., Buena Park, CA 90620, tel. 714-521-4160. PC boards and parts kits are available.

[2] D. DeMaw, *Ferromagnetic Core Design & Application Handbook*, Prentice-Hall no. 0-13-314088-1. Available from Amidon Assoc., Inc., 12033 Otsego St., N. Hollywood, CA 91607.