BASIC QRP TRANSMITTER DESIGN

There are many pitfalls that trap an inexperienced builder of QRP transmitting gear. There is little similarity between the design steps for transistor rigs versus vacuum-tube transmitters. Yet, many amateurs with tube experience try to apply those design techniques when using transistors. The results can be disasterous in terms of harmonic radiation, instability and miserable circuit efficiency. This application note is written to help you avoid some of the more common problems associated with QRP transmitter design. I have also included some considerations that pertain to the design philosophy of this equipment. Additional data may be found is the **W1FB QRP Notebook** (1).

VFO OR CRYSTAL CONTROL, PROS AND CONS

There is nothing other than a frequency synthesizer that can beat the frequency stability of crystal control. This is an important consideration for portable work, where the ambient temperature ramps up and down from day to night. Some VFOs are reasonably stable if careful design is executed, but most simple units (minimum parts and stages) can be frightful when operating afield. I prefer crystal or VXO (variable crystal oscillator) control for all of my portable QRP gear. It is reliable and stable.

A VXO is shown in Fig 1. It will shift the frequency of a 3.5-MHz AT-cut, HC-6/U plated crystal 3 kHz. At 7-MHz this type of crystal can be moved 8 kHz, 12 kHz on 30 meters and 15 kHz on 20 meters. These are typical shifts if the oscillator circuit has minimum stray capacitance.

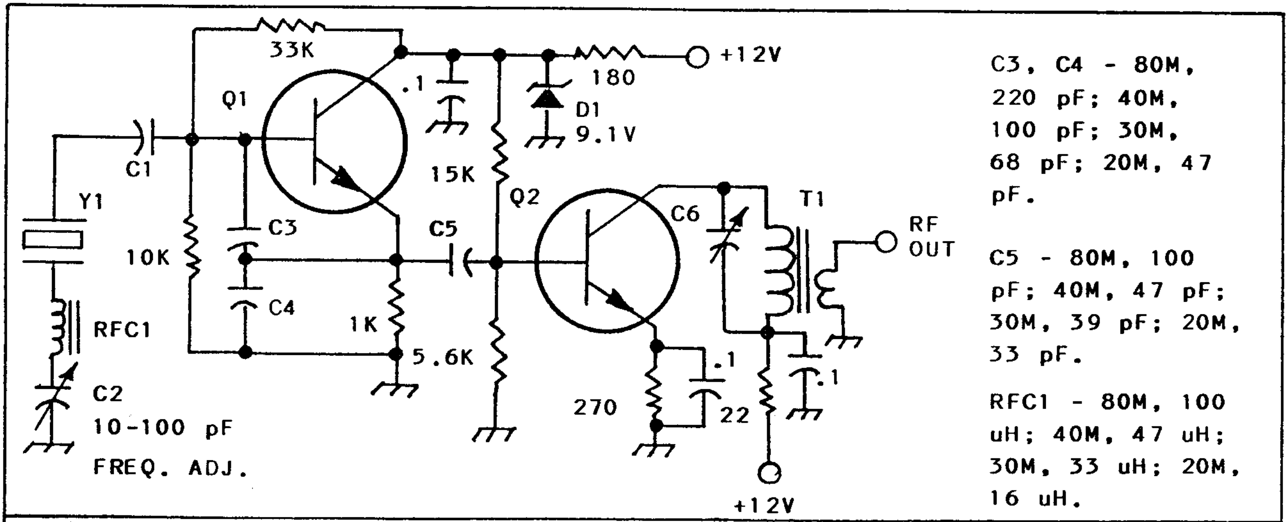

Fig 1 -- Schematic diagram of a universal VXO with key parts values. Q1 and Q2 may be 2N2222A, 2N2222, 2N4400 or 2N3904.

Fig 1 shows the circuit of a universal VXO. C1 is used to minimize the effects of parallel capacitors C3 and C4. Without C1 there would be a restriction to the upper frequency range of Y1. The crystal should be capable of being pulled slightly above its marked frequency in a VXO circuit. C1 aids this objective. Choose a value that will permit reliable oscillator starting, but will not restrict the upper shift range of the crystal when C2 is at minimum capacitance. A typical value at 40 meters is 100 pF for C1. C6 and T1 are chosen to provide resonance at the crystal frequency. A 100-pF trimmer is suitable at C6 from 40 through 20 meters. Use a 200-pF trimmer for 80 meters. The secondary winding of T1 is set in accordance with the primary turns to provide a match to the next stage of the transmitter. You may consider the Q2 collector impedance to be on the order of 500 ohms. For a 50-ohm load the transformer turns ratio will be 3.16:1, which yields a 10:1 impedance ratio.

Some VXOs tend to jump frequency and perform in a "flakey" manner. In this situation it may be helpful to place a 22K ohm resistor in parallel with RFC1. Do not use the resistor unless necessary. Stability is enhanced by the presence of D1, a 9.1-V Zener regulator. It regulates the Q1 voltage along with the bias voltage to Q2. The buffer amplifier, Q2, operates Class A to minimize harmonic output. If you need to broaden the bandwidth of T1, simply bridge a 3.3K ohm resistor across the primary winding. Y1 has a load capacitance of 30 pF.

Do not use long leads from Y1 to the related circuit. Long leads can introduce stray inductance that will spoil the oscillator performance. Keep all leads short in the interest of efficiency and stability.

TRANSMITTER GAIN DISTRIBUTION

One of the most ignored facets of transmitter design is gain distribution. In essence, this concerns the driving power of the various stages. Too little power results in low overall transmitter output power. Too much driving power applied to any stage causes excessive current drain, device overheating and possible transistor failure. You should build your transmitter stage by stage, starting with the oscillator. Terminate the stage being checked with a resistor of the appropriate value. Monitor the RF output across the resistor with a scope or VTVM with an RF probe. Adjust the drive level to the stage until no further increase in output power is noted. This may be done by experimenting with coupling-capacitor values if that form of coupling is used. If an RF transformer is used between stages, experiment with the secondary turns. If you apply more drive than is needed to produce maximum RF output power, the stage is being driven beyond saturation and the collector current will be excessive. This ruins the stage efficiency. An overdriven amplifier may show an efficiency of only 25%. When the drive is reduced below the saturation level, the efficiency may rise to, say, 60% without any reduction in output power. Harmonics will be much lower in amplitude when a stage is not driven excessively.

Another problem is too little driving power to the various stages. Hams are tempted to skimp on circuitry in the interest of simplifying a circuit and saving money. This is foolhardy, since transistors and small parts cost so little these days. Don't be a miser. Include more gain than you think is required, then reduce the stage gain as outlined previously. A QRP rig need not be tiny to qualify under that title. Add a stage if it is needed.

Other causes for low gain are the transistor characteristics, wrong biasing and defective coupling between stages. Choose a transistor that has an upper frequency characteristic that is 5 to 10 times the proposed operating frequency. It should have a fairly high dB-gain or beta rating if you expect it to provide gain. The upper frequency limit is expressed as **fT**, the frequency at which the device gain is unity, or 1. It is not vital that you use transistors that are earmarked for RF service. Most high-speed switching transistors work very well for high-frequency RF purposes, and some perform nicely at VHF. Such devices as the Motorola MPS-U02 and MPS-U05 are excellent for RF power service, even though they were designed for Hi-Fi audio work. Fig 2 shows a typical lineup for a 15-meter CW QRP transmitter.

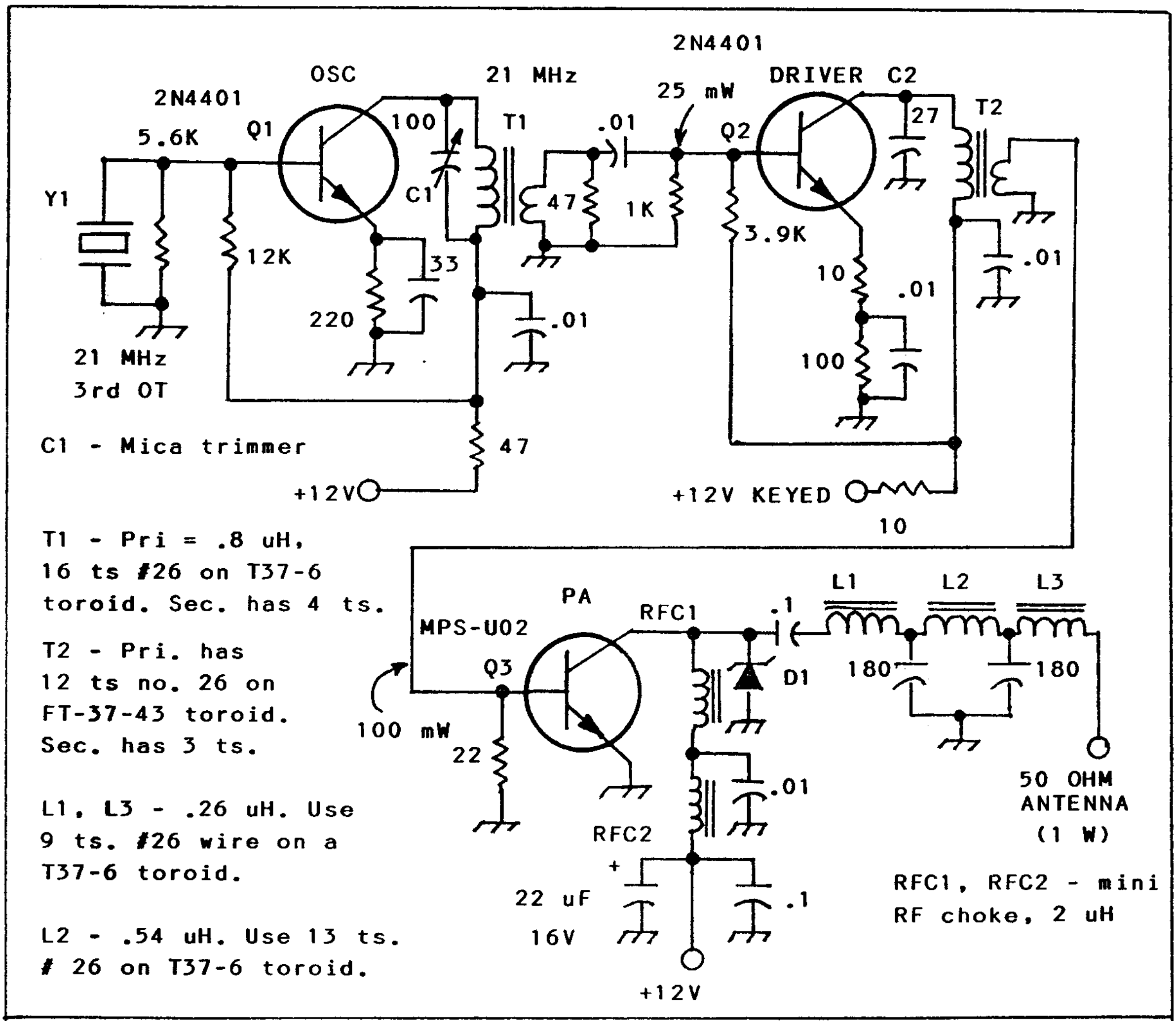

Fig 2 -- Schematic diagram of a proven 15-meter, 1-W QRP CW transmitter. Careful gain distribution and harmonic filtering have been applied. The PA efficiency is 61% and harmonics are 40 dB or greater below peak carrier value. D1 is a 33-V, 400-mW Zener diode for SWR protection of Q3. Output filter cutoff freq. is 23 MHz (low pass). Q2 operates Class A and Q3 is Class C.

The stability of the circuit in Fig 2 is excellent. No self-oscillation is present. The keyed note is chirp free, owing to the oscillator not being keyed. A Class A driver is used because a linear amplifier produces fewer key clicks when it is keyed. Q2 operates as a broadband amplifier with degenerative feedback. Q3 operates Class C and has a 5-element low-pass harmonic filter at the output. Y1 is a 3rd overtone crystal in an HC-6/U holder. Two RF chokes are used in the +12-V line to Q3. This provides suitable RF decoupling to prevent unwanted migration of the PA energy to Q1 and Q2. Were the stray RF to reach those stages there could be chirp and self-oscillation.

Although an MPS-U02 audio transistor is used for Q3, a more costly 2N3553 makes a good substitute. In either event, the PA transistor needs a heat sink to protect it.

The 47-ohm resistor across the T1 secondary helps to provide a constant load for Q1 when Q2 is keyed. This resistor cured a slight chirp problem that existed. The 22-ohm resistor across the T2 secondary stabilizes Q3.

C2 is used to bypass VHF harmonic currents that were present at the collector of Q2. This ensures a cleaner signal to Q3. D1 protects Q3 when a high SWR condition prevails. This diode also prevents spikes on the +12V line from damaging Q3.

The backwave from the transmitter in Fig 2 (measured across a 50-ohm load at the Q3 filter output) with the key open is 46 dB below peak carrier value. Total key-down current drain for this transmitter is 180 mA at 12.5V. Q1 draws 14 mA, Q2 draws 26 mA and Q3 draws 140 mA. The circuit may be used on 10 meters by modifying T1 and the Q3 output filter accordingly. No other changes are required. **The ARRL Handbook** contains filter tables that can be used for determining the 10-meter values for L1, L2, L3 and the two filter capacitors.

BATTLING INSTABILITY

Self-oscillations are a common problem in homemade solid-state transmitters. The principal cause of this malady is poor layout. Excessive gain is the second most common cause. Avoid long component leads. It is vital that we keep capacitor, resistor and transistor leads short and direct. Try to mount the components so that they are snug against the PC board. Long leads introduce stray inductance that can cause not only VHF self-oscillation, but spurious oscillation at or near the operating frequency. Under some conditions we may experience low-frequency oscillation, and it can even occur at audio frequency. The latter problem may develop when RF chokes have a high value of inductance, or when broadband transformers are used. It is important to include a 22-uF or greater bypass capacitor on the +12-V bus to discourage LF oscillations. Low-Q RF chokes are desirable also. The choke Q may be lowered by slipping one or two 850-mu ferrite beads over one pigtail of an RF choke. A 100-ohm resistor may be placed in parallel with a choke to lower the Q.

Supply-line decoupling (see Fig 2) at each stage is essential toward preventing self-oscillations. This requires a resistor and a bypass capacitor in the supply line to each stage. These RC networks help to prevent unwanted RF feedback from stage to stage. The series resistor should not be so large as to cause a significant drop in operating voltage. The greater the current taken by the stage the lower the value of the series resistor. If the stage draws a large amount of current you may use an RF choke in place of a resistor, as with Q3 of Fig 2.

Circuit layout is critical also. Keep the input and output circuits of each stage separated from one another. In a like manner, keep all stages in a straight line rather than folding the output stage back toward the previous or first stages of the circuit.

Double-sided PC boards help to discourage self-oscillations, especially at VHF. The component side of the board has a ground plane that is joined to the ground foils on the etched side of the board. The copper conductors, plus the epoxy insulation between them, form small bypass capacitors that are effective at VHF and the upper end of the HF range. They do not significantly disturb circuit performance because most of the circuit operates at low impedance, where small values of capacitive reactance aren't harmful.

Impedance matching between stages is important in the interest of circuit stability. A gross mismatch robs power and encourages self-oscillation because the SWR allows power to be reflected back to the input of a stage, or other stages. This is the scenario for a tuned base-tuned collector oscillator. Amateurs who attempt to use vacuum-tube circuitry with transistors often run into this dreadful problem.

THE ALL-IMPORTANT OUTPUT CIRCUIT

Unlike vacuum tubes, transistors generate large harmonic currents. It is not uncommon to find the 2nd and 3rd harmonics only 10 dB below the fundamental frequency at the collector of an RF power amplifier stage. These harmonic currents not only cause TVI and RFI, but they may fall into a commercial band and lead to a citation. A driver stage that is rich in harmonic energy can ruin the efficiency of the following stage, since part of the driving energy is useless. Furthermore, the harmonic energy can mix with the fundamental signal in a transistor and generate additional spurious frequencies.

It is prudent to use a reasonable amount of filtering between the driver and the PA when using Class C drivers. This permits the PA to operate cleanly and with greater efficiency. Even a simple pi-network between a driver and a PA can greatly impede the flow of harmonic currents.

Fig 3 shows the right and wrong way to structure the output of an RF power amplifier. The simple tuned circuit at A is used all too often. Likewise with the circuit at B. These networks do not offer much harmonic attenuation. A clean transmitter should have all spurious energy at least 40 dB below peak carrier value. Fig 3C shows the correct way to launder the output signal. A 5-element filter is the minimum we should use to ensure an acceptable output signal.

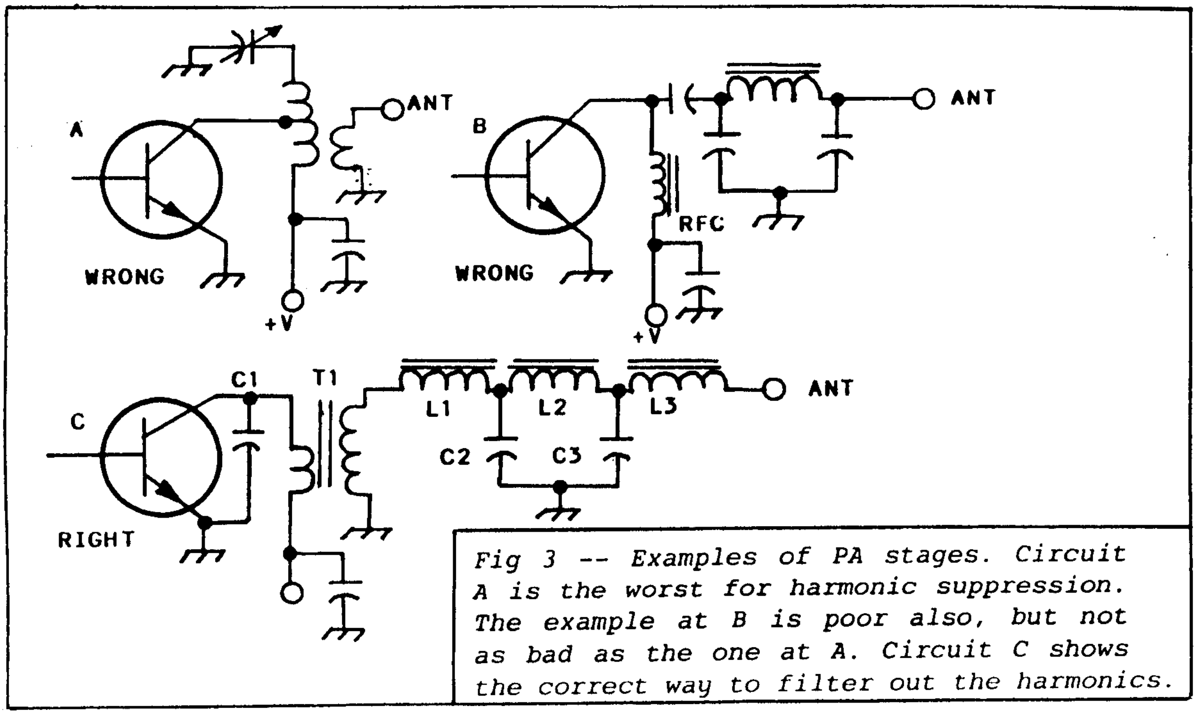

Fig 3 -- Examples of PA stages. Circuit A is the worst for harmonic suppression. The example at B is poor also, but not as bad as the one at A. Circuit C shows the correct way to filter out the harmonics.

Circuit A shows the collector tapped on the coil to obtain an impedance match. Harmonics are seldom down more than 15 dB from the fundamental signal and VHF harmonics are very high. The pi network at B offers very little harmonic rejection. The 2nd and 3rd harmonics are seldom more than 20 dB below the fundamental signal. A better arrangement is shown at C of Fig 3. T1 is a broadband matching transformer. It transforms the collector impedance ($Z = Vce^2/2Po$, where Vce is the collector to emitter voltage and Po is the output power in W) to 50 ohms, which makes it convenient to use a 50-ohm filter. C1 has an Xc that is four times or greater the collector impedance. It bypasses VHF harmonics. Thus, for a 15-ohm collector impedance at 7 MHz we would use 360 pF or less. C2, C3, L1, L2 and L3 comprise a low-pass filter. The cutoff frequency is approximately 1 MHz higher than the highest operating frequency. Therefore, Fco for a 40-M transmitter is 8 MHz. Component values for this and other filters may be obtained from the normalized tables in the transmitting chapter of **The ARRL Handbook**. The filter coils are wound on powdered-iron toroids.

SUMMARIZATION

This report covers the most common of the problems we amateurs encounter when designing and building solid-state QRP transmitters. The rules apply at all power levels, and a little care in circuit planning can go a long way toward clean, trouble-free operation. A skimpy circuit that operates poorly is not worth the effort. A few extra parts cost very little, and they can lead to a successful design.