NOTES ON VXO QRP TRANSMITTER DESIGN

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Introduction

I've been experimenting a bit with building very simple HF equipment that is still practical to operate. Variable crystal oscillator (VXO)-based transmitters can be a good route to building a minimal-parts station which can still get lots of QSOs. This article describes some of the design issues that need to be tackled in getting such equipment to work and presents a (mostly) optimized QRP design for the 14 MHz band. It does not address the basics of transmitter design; these are covered in other places (such as [1]).

Requirements

Several features are necessary to make a small CW transmitter actually useful and enjoyable to use on the air. They are:

- at least a few kHz of frequency tunability. Crystal control is simple, and nearly foolproof to build, but it is very difficult to get many QSOs as you never seem to be exactly on the frequency someone else is listening on, unless you have a huge crystal collection, which will need large multipole switches, or a lot of plugging and unplugging. A VFO is nice too, and really not too hard to build, but it adds complexity to the design as a number of buffer stages are normally required, as well as good shielding and voltage regulation. A VXO seems a good compromise.

- at least about a watt output; QSOs can certainly be had with milliwatts, but they are a much more of a challenge.

- an accurate spotting capability. The frequency must not shift significantly between the "spot" and "transmit" states. The nearly ubiquitous modern transceiver that is used by most of the stations you will want to work leads to a need to be right on frequency. The other station likely has a IF bandwidth of 500 Hz and will only use the RIT to better centre a signal heard initially within this bandwidth. A 100 Watt station can usually be heard some distance down the skirts of the filter, but a QRP signal is rarely very strong and so must be within +/-250 Hz of the other station's transmit frequency to have a high probability of being heard.

- spotting signal at the correct level. My experience is that the spotting signal is usually too loud. If the QRP transmitter is to be used with a simple receiver this can be quite important. If the receiver has no AGC, then it can be very hard on the ears, or will require the volume control to be turned down first, which slows down the process. If the receiver is the even simpler regenerative type, then it will tend to pull in frequency and lock (zero-beat) onto a strong signal, destroying the spotting accuracy.

A Transmitter Design for 20m

Figure 1 shows the schematic of a simple VXO CW transmitter for the 20m band. Some component values are given in Table 1. This design takes into account the requirements from the previous section, which are often ignored in the design of very simple transmitters. The following text discusses the unique design aspects of each stage and why the particular approach was taken.

VXO

This circuit is a combination of ideas from three sources. The basic oscillator, and the keying arrangement were adapted from the Universal QRP Transmitter [1], since that design worked well. Oscillator keying is often avoided, but I find that with modern crystals and good design it sounds fine. I have had chirp problems with some older FT-243 case crystals. In fact, even a VFO can be keyed successfuly, if attention is paid to minimizing sources of thermal drift. DC power is always applied to the oscillator so the spotting signal is enabled by just pressing the key.

Next, it was converted to VXO operation by adding the parts to the left of the crystal selection switch S1. The typical VXO has just an inductor and variable capacitor in series from the crystal to ground. This has the effect of putting a variable inductor in series with the crystal, pulling its resonant frequency downwards. While this works well, the tuning tends to be very non-linear with the rotation of the variable capacitor, which can make spotting a bit difficult, as the tuning rate is too fast for accurate frequency setting at one end of the range. The network used here, described by W3MT [2], does an impedance transformation which makes the variable capacitor appear (to the circuit) to be a variable inductor, with an inductance proportional to the capacitance of the variable capacitor. This results in much more linear tuning and has the added bonus of requiring a smaller inductor. In this case the circuit constants are such that the frequency range of linear tuning is exceeded somewhat, but it is still better than the usual circuit. With five crystals (surplus 42 MHz 3rd overtone units) I was able to get continuous coverage of 14.000 to 14.070 kHz, with some overlap. The tuning range for each crystal was about 20 kHz. With these particular crystals the truly linear tuning range was around 10 kHz. In fact, with fairly small changes in the tuning network values, it was found that a single crystal could be pulled over the entire 70 kHz range. However, the further from the crystal self-resonance the more non-linear the tuning and the less stable the oscillator becomes, so I thought it best to retain the crystal switching arrangement.

I used silver-mica or polystyrene capacitors for all the frequency determining elements to avoid temperature-related drift, but it probably isn't all that critical as the oscillator is much more stable than a VFO due to the crystal Q. It is likely that ceramic NP0 types would be fine. The Q of the inductor in the pulling network is critical. I started with a small molded choke, but the output power of the VXO dropped markedly as it was tuned down from the nominal crystal frequency. This power variation was much reduced when a toroid was substituted. The VXO circuit is quite sensitive to layout and stray capacitances and inductances. It will work quite reliably but the tuning range will vary. To get the desired range with a given layout and crystal it may be necessary to tweak the values in the pulling network. The strays will tend to increase with a larger number of crystals and the accompanying multipole switch.

The third noteworthy aspect is the RC output coupling from the collector, taken from G3MY's "Pippin" transmitter circuit [3]. For some reason, most designers seem to prefer taking the output from a Colpitts oscillator from the emitter. There may be some deficiencies in waveform at the collector; I have had some trouble with efficiency of the following stages in similar circuits, but this one is OK. Someone with a high frequency oscilloscope, or good simulation software, can perhaps check this out. However, untuned collector output provides significant isolation, so changes in load impedance do not affect the oscillator frequency as much. This is key to meeting the spotting frequency accuracy requirement. The collector load resistance would ideally be lower, perhaps 100 ohms, to get best isolation from pulling due to load variations. However, to get enough output voltage to drive the following stages it was necessary to use 1 kilohm. A four stage (or three stage with lower power output) transmitter could avoid this tradeoff and could achieve better spotting accuracy. As it is, the frequency shift between spot and transmit is under 100 Hz with the particular crystals that I used, and is much better for frequencies near the crystal's nominal (un-pulled) frequency.

The spottting signal level is minimized by keeping the emitter resistance as high as possible (oscillator power as low as possible) consistent with having sufficient output to drive the following stages. The oscillator draws about 5 mA with a 12.5V supply voltage. Again, a four stage circuit could relax this tradeoff and permit lower oscillator power without reducing the transmitter output.

Finally, for the sake of simplicity, I used no voltage regulation. With a good stiff voltage source, this is good enough. I have been using this transmitter with a well charged 4Ah sealed lead-acid battery. However, with a nearly flat battery, or a lightweight, low capacity battery as might be used for backpack-portable operating, there might be some difficulty with chirp, drift or degraded spotting accuracy.

Driver Amplifier

The driver amplifier is necessary because the VXO, operating at a power level low enough to produce the right spotting signal level, has insufficient output to drive the power amplifier. This circuit is not too special but a few features are worth noting. First is the unconventional use of a PNP transistor. This may be of no significance; it just happened as a result of the way this design evolved. However, if there is indeed something strange about the oscillator output waveform, it may play a role in providing the correct drive waveform to the final amplifier. This stage operates in class AB; a little collector current flows when there is no RF drive, but it increases to about 21 mA (with 12.5 V supply) when the oscillator is keyed. The broadband output coupling transformer also just happened; I switched from tuned output to untuned during a long process of trying to improve the final power amplifier stability. I don't know if the PA stability was improved but it still worked, so I never switched back, and eliminated the need for a trimmer capacitor. DC power is applied to the driver only in transmit, so that the spot signal level can be minimized. This means however that the load on the VXO does change between spot and transmit, so the spotting accuracy is dependent on the VXO's insensitivity to load changes.

Power Amplifier

This is quite a conventional Class C circuit, except for a few minor aspects. It is probably perfectly good to substitute your favourite circuit. The transistor I used was a 2SC2092. This was selected because a store in Toronto had them at a reasonable price. I haven't found a data sheet yet but if the NTE235 replacement device really is a good match, then it is a CB transmitter output device capable of 4 watts output at 27 MHz. Since it is designed for AM service it has a high collector-emitter breakdown voltage rating (75V for the NTE235), which makes it much more robust, and eliminates the need for a protective zener diode across the output as is found in many circuits. The 5A peak current rating helps too. I have had it oscillating (and drawing up to 600 mA) many times while investigating the PA stability (enough times to destroy lots of 2N4427s !) and it shows no sign of damage.

The small resistor in series with the collector was intended as a safety measure to reduce current in case of such oscillations, and may provide a bit of decoupling from the previous stages as well. It reduces overall efficiency a little, so I may try taking it out. The input coupling contains a 4.7 ohm series resistance, where most designs would connect the transistor base directly to the transformer. This was added while investigating the stability and appeared provide some improvement. The output network is designed to provide a small impedance transformation, so the transistor sees a little more than 50 ohms load. I started with only a single pi section, but there was so much harmonic output that I couldn't get proper SWR readings, due to reflections of harmonic power from the antenna tuner back into the SWR meter. Also, the output capacitance of the transistor has been considered in selecting the value of the 150 pF capacitor, something which isn't often done in amateur designs. However, the values have not been tweaked experimentally too much; some further improvement in efficiency and/or output power is likely possible. The three capacitors in the output network (150,330,220 pF are silver mica types). The most unusual aspect of this circuit is the 5 ohm resistor in series with the output. This was by far the most effective solution I found to PA instability. It greatly reduced the tendency to oscillate at certain antenna tuner settings so I considered the resulting small loss of output power (about 10%) to be worthwhile.

I didn't quite meet the power output specs; I get about 900 mW out with a collector current of about 140 mA at a 12.5V supply. There just isn't enough gain avalable from the driver and PA to do much better while keeping the spotting signal level down. Perhaps a real RF transistor in the driver stage would be better. Oh well, at least I can get a higher multiplier in some QRP contests ! Using the measured collector voltage and adding in the power dissipated in the 5 ohm resistor (about 90mW), the collector efficiency of the PA transistor is (to the best of my ability to measure it) about 65-70%, which is pretty typical for a small class C stage.

Construction and Packaging

I built this transmitter in a home made PC-board case, with sheet aluminum cover, and have used it with a simple homebrew superhet receiver with no AGC. The spotting level is low enough to be reasonably comfortable when using headphones. I found when I rebuilt the open dead-bug construction breadboard into the case, and especially when the cover was added, that the frequency shift between spot and transmit increased to about 400 Hz at the low end of the tuning range for a particular crystal. I was able to reduce it to about 100 Hz with some shielding around the oscillator components to prevent feedback from the fields around the power amplifier components. I think a good part of the remaining shift is due to the drop in the voltage applied to the oscillator when the PA is turned on and draws current.

Construction of the circuit is mostly "dead-bug" or "ugly-construction" style on the inside of the case, but neatly done, with a few PC board pads (as in so-called "Manhattan-style" construction) in critical spots either glued down or held in place by components connected to ground. The TO-220 case PA transistor is mounted face (marked) side down (metal side up) with the emitter bent down and soldered to the ground plane as close to the body as possible. This mounting arrangement prevents the metal tab (connected to the collector) from accidentally contacting ground. No heatsink was used on Q3 since it dissipates only about half a watt. Inductor L1 must be firmly fixed in place to prevent mechanically-induced frequency instability; I used a nylon screw and nylon washers to mount it to, but spaced away from, the case.

The circuit would fit in a much smaller case; the size (3.5" wide x 3.5" deep x 2" high) is largely determined by the size of the knobs, and the choice of "dead-bug" construction to allow changes to be made easily.

Miscellaneous

The MUTE function is set up for a receiver which requires an open circuit for normal operation and a short to ground to mute it. No sidetone function is provided in the transmitter because the MUTE condition of the receiver is a low gain state where the transmitter signal can be heard as a sidetone.

The capacitors of 0.0047 to 0.02 microfarads could probably all be 0.01s. They reflect primarily what was available in my junkbox. The only exception was the 0.005 microfarad bypass on the MUTE line, which was kept on the low side to avoid slow receiver recovery as my homebrew receiver will operate normally only once it has charged the capacitor through a 1 Megohm resistance.

The oscillator keying is designed for use with a straight key or relay output keyer. Some keyers have output switching devices with a saturation voltage significantly higher than zero, which may result in reduced VXO, and transmitter, output power.

References

[1] Wes Hayward, W7ZOI and Doug DeMaw, W1FB, Solid State Design for the Radio Amateur, ARRL, Newington CT, 1977

[2] Frank W. Noble, W3MT, "Phantom Coil VXO", *ham radio magazine*, Greenvile, NH, January 1982, pp.66-71.

[3] http://www.qsl.net/g3pto/pippin.htm (originally described in SPRAT Issue No. 60, Autumn 1989)

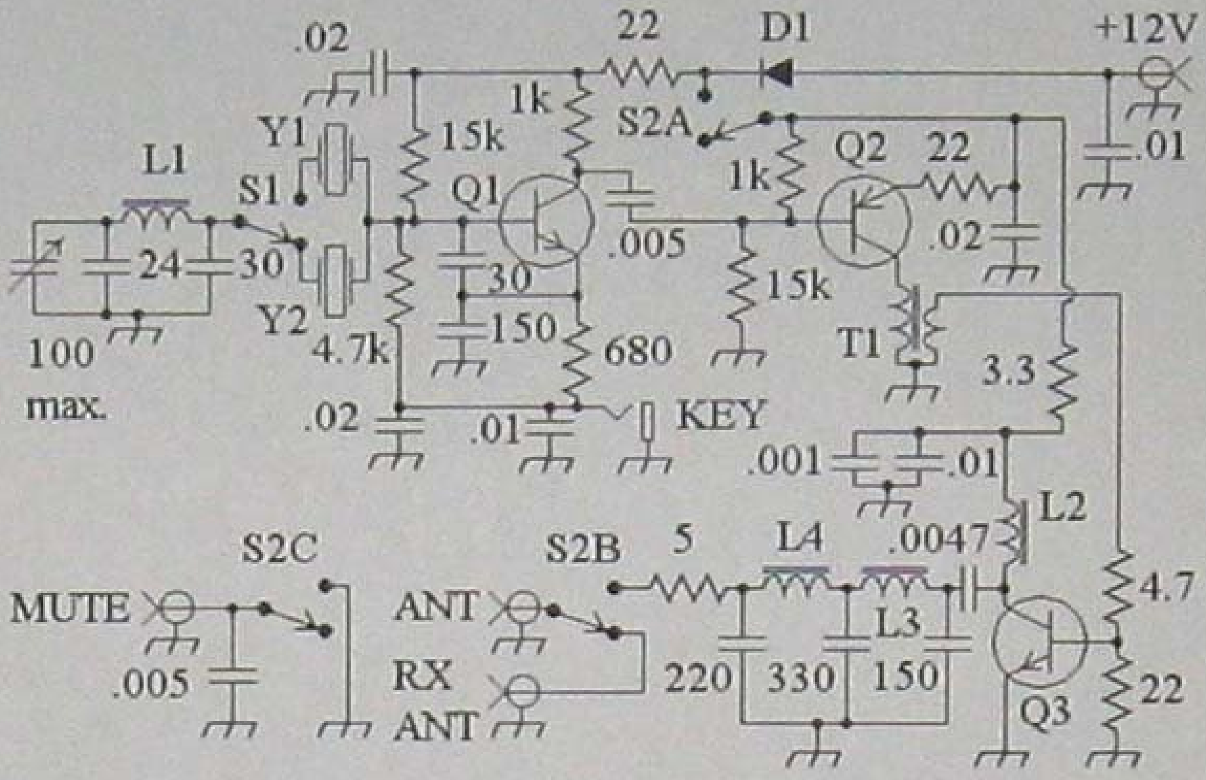

Figure 1: Schematic of 20m VXO transmitter. Capacitor values are in microfarads if less than 1, picofarads if more than 1. S1 may have enough poles to select any number of crystals; however, see text. The transmit/receive switch S2 is shown in the receive position.

Table 1: Component Values not Shown in Schematic

D1	1N4001	Q1	2N3904
L1	27 turns #30 enam.on T50-2 toroid	Q2	2N3906
L2	8 turns #22 insul.on FT37-43 toroid	Q3	2SC2092
L3	13 turns #22 enam.on T37-2 toroid	T1	Primary 12 turns #30 enam., Secondary 2 turns #24 insul., on FT37-43 toroid
L4	12 turns #22 enam.on T37-2 toroid