A 222 MHz transverter for the Yaesu FT-817

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When the Yaesu FT-817 was introduced last year, it seemed like an ideal IF rig for portable microwave transverters. I couldn't resist! After playing with my new toy for a while, I said, "the only thing missing is 222 MHz." After the mountains closed for winter, I started thinking about fixing this deficiency.

An ideal accessory should have the same features that make the FT-817 so attractive: good performance in a small, light package requiring only modest power. An ideal location for a transverter would be inside the battery compartment, but the FT-817 uses AA-cells rather than the C-cells found in older generations of portable transceivers, so there just isn't enough space. However, I was able to pack the 222 MHz transverter shown in Figure 1 in a small case that sits on top of the transceiver. It provides performance similar to all the other bands, and even bandswitches automatically with the radio.

Description

One of my projects the previous winter was a "Miniverter[1]" - a bare-bones printed-circuit transverter for 144 MHz. My intent was to install these inside small 10-meter transceivers to make microwave IF rigs. Then I was seduced by the FT-817 — but the Miniverter became the start of a 222 MHz transverter.

A minimal transverter like the Miniverter consists of a mixer, also called a "frequency changer," a local oscillator (LO) to mix with the RF and IF frequencies to produce the sum or difference frequencies, filters to select the desired output frequency, and amplifiers. The local oscillator is usually the hardest part: mixers, helical filters, and MMIC amplifiers are inexpensive and readily available.

The local oscillator must stable and have low phase noise, so a crystal oscillator is the most obvious solution. Good crystals have become more expensive and harder to find, except for frequencies used in computers —

those are cheap and produced in high volumes. I looked through the Digi-Key catalog (www.digikey.com) for DIP-packaged oscillators and found one usable for 222 MHz: 66 MHz, times three, is a perfect LO for a 12 meter (24 MHz) IF.

The next problem is multiplying the frequency times three. A frequency tripler is usually touchy and inefficient. After some thought, I realized it is also unnecessary; the packaged oscillators have a square-wave output, and a square wave has lots of third-harmonic content. Separating out the third harmonic and amplifying it with an MMIC will probably produce more output than using the same MMIC as a frequency tripler.

Since the frequencies are widely spaced, a simple diplexer is sufficient to separate out the third harmonic frequency, 198 MHz, from the fundamental crystal frequency, 66 MHz. I sketched out a simple circuit, built a dead-bug style breadboard, and fiddled with values for best results. The final circuit is shown in the schematic, Figure 2. The packaged oscillator is intended to drive logic, equivalent to a load of several hundred ohms, while an MMIC amplifier input is closer to 50 ohms, so a series resistor, R20, provides a better load for the oscillator. A series resonant circuit, L5 and C3, is a short circuit at 66 MHz, so the fundamental output is dissipated in R20. At the same time, L5 and C3 form an inductive combination at 198 MHz: in combination with C4, the result is an impedance step-down transformer which also forms a high-pass filter. At the output of the MMIC amplifier, A5, an output of several milliwatts at 198 MHz is available, with other frequencies at least 10 dB down. After the helical filter, FL1, and another amplifier, A6, an LO level of perhaps +12 dBm is supplied to the mixer. All the other oscillator harmonics are at least 60 dB down, as shown in Figure 3.

The packaged oscillators don't have any provision for frequency adjustment, but they are cheap. I placed two orders for four pieces, and each group had two that came within 1 KHz of 198.000 MHz. They do seem to be quite stable, settling down after a short warmup and staying put, which is what really counts.

RF circuit

The 222 MHz output from the mixer passes through a three-resonator helical filter, FL2, to eliminate the other mixing products; the receive path passes through the same filter to eliminate out-of-band signals. A 3-dB pad made up of chip resistors between mixer and filter allows each to work into a reasonable impedance match, which makes the performance of each much more predictable.

Transmit circuit

In transmit, the clean signal coming out of the helical filter is amplified by two MMIC stages to get the power level high enough, +13 dBm, to drive a power amplifier module, A7. I chose a 5 watt Class-AB module for linear operation, the Mitsubishi M67723 (www.rfparts.com) , as a good complement to the FT-817 — a higher power module requires much more current and heat-sinking, increasing size and weight.

Finally, the output passes through a low-pass filter to reduce harmonic content. The design is right out of the tables in the ARRL Handbook[2], and works just like the book — see the measured response in Figure 4. The Handbook suggests that some amplifiers are less stable with capacitor-input filter, so I took the hint and used the inductor-input topology.

Receive circuit

I chose to use an MMIC front end for simplicity rather than a GaAsfet for ultimate noise figure. The noise figure is still better than most transceivers. A tuned circuit at the front end provides reasonable rejection but not enough for an RF-polluted mountaintop — real filters are required for these locations.

The receive gain, with two MMIC stages, is just high enough to overcome losses in the mixer and IF switch. More important is the dynamic range; the second-stage MMIC and the high-level mixer were chosen so that the dynamic range is limited by the FT-817 and not the transverter.

IF interface

The IF interface is tailored to match the FT-817, which has two output jacks, selectable by band. I prefer to connect the transverter to the rear jack and use the front jack for other VHF and UHF bands. A band-selection voltage is available on the rear accessory jack of the FT-817; this voltage is used by connected to the transverter so that it will only transmit when tuned to the IF band, 12 meters.

On the web, I found a nice band-detect circuit by K6XX (www.k6xx.com) Since only one band, 12 meters, is needed, I reduced it to a simple comparator, an LM393 dual-comparator IC, U4. (Actually, all bands below 10 meters are detected — this is intended for VHF+ operation.) The other half of the comparator is used for the PTT line from the accessory jack, with diodes to provide the AND logic for band selection.

The comparator output drives a relay, which is the simplest way of switching voltages between transmit circuits and receive circuits. The voltages also activate PIN diode switching for the IF. The FT-817 is operated at the lowest standard power output level, 1/2 watt, but further power reduction is necessary before driving the mixer. At the 1/2 watt level, ordinary 1/4 watt resistors are adequate for an input attenuator: in this case, R1-5 make up a 13 dB attenuator for both transmit and receive. Further power reduction for transmit is provided by a variable attenuator consisting of R6, R7, and R8; R7 adjusts the maximum drive power. On receive, the variable attenuator is bypassed by the PIN diodes. A simple low-pass pi filter, C1, L2, and C2, keeps LO and RF frequencies out of the transceiver.

Voltage regulators

The FT-817 will operate with a rather low battery voltage, so the transverter has internal voltage regulation to allow operation over a wide range of voltage. Most of the circuit is supplied from an 8-volt three-terminal regulator IC, U2: the regulator needs 3 volts headroom, so operation is guaranteed down to 11 volts. At 11 volts, a "12 volt" battery is nearly dead.

The oscillator is powered from a 5-volt regulator, U1, running off the 8-volt regulator, so that the oscillator is doubly regulated for additional stability. A separate 5-volt regulator, U3, provides stable bias for the power amplifier: if it were not separately regulated, the change in current on transmit would change the oscillator frequency slightly. Three-terminal regulators are small and cheap enough to use duplicates and avoid problems.

Printed-circuit board

If you are only making one of something, a printed circuit board isn't necessary. A hand-cut board or dead-bug construction will do just fine — but making more than one gets awfully tedious. I'd prefer to spend the time doing a good printed-circuit layout to make assembly easy. Finally, if you are making something neat, others will want to copy it — every FT-817 owner I know wishes that Yaesu had included 222 MHz.

One of the things I experimented with in building the Miniverter was a printed-circuit service from ExpressPCB. They provide free PCB layout software (download from www.expresspcb.com) that is quite easy to learn and use. When the PCB layout is complete the layout, the data is uploaded to their website. For $59, four days later you receive three finished printed circuit boards — not a bad deal. The boards are high quality double-sided boards with plated-through holes and tinned finish for easy soldering; you can't make these in the basement.

One of the ExpressPCB limits is that the board size is exactly 3.8 x 2.5 inches — or the price is much higher. A board this size, in a metal box with room for a comfortable fit, seems appropriate for the FT-817. Clearly, I had to fit the transverter in this board area. I sketched a block diagram, marked the board outline on a sheet of paper and shuffled the large components around. There wasn't a whole lot of room left over. The small components would have to be chip components on the bottom side — an approach that worked well for the Miniverter, where I managed to fit two transverters in the same standard board outline that barely fits one transverter for 222 MHz.

Looking at the top view of the board in Figure 5, the main helical filter, FL2, is placed as a barrier between the RF side of the board and the IF and LO sections. The isolation helps to reduce "birdies." The lower-frequency side is crammed fairly tight to preserve as much space as possible on the higher-frequency side, since most of the gain is at 222 MHz. High gain with tight spacing is a recipe for instability.

The other key to stable, predictable performance is adequate bypassing. The schematic diagram includes not only plenty of capacitors, but also different values at different frequencies — the values are chosen for operation just below the self-resonant frequency of each capacitor. The exact values are not critical, but shouldn't be changed too much. The power amplifier, A7, is bypassed for a wide frequency range, shown in the detail photo in Figure 6, since bipolar transistor amplifiers are prone to oscillate at low frequencies. Chip capacitors are small enough to use freely, and inexpensive enough, perhaps a nickel each in small quantities, to use by the dozen.

To aid in keeping track of the different values of bypass capacitors, all the capacitors of the same value have consecutive reference designators (for example, C21 through C37 are all 330 pf).

Construction

All of the essential components are mounted on the printed circuit board. The two that require heat sinking, A7 and U2, attach along one edge so that they may be bolted to the box (a dab of heat-sink compound doesn't hurt). Figure 5 is a photograph of the complete assembly. The die-cast aluminum box I used has some raised text and mold marks on the bottom, so the surface isn't flat enough. There are two ways to fit the board in — one of them avoids the raised text. However, the power amplifier module, A7, needs a flat mounting surface, and it lands on one of the mold marks. I flattened the area by scraping off the raised metal with a deburring tool, then wrapping some sandpaper around a small flat block and sanding the area flat. The die-cast metal is soft enough that it isn't a big job.

The top of the printed circuit board can be seen in Figure 5. Component placement diagrams from the ExpressPCB software are shown in Figure 7 for the topside and Figure 8 for the bottom side. Figure 9 is a photograph of the bottom side assembly with all the chip components. Look closely: there are a lot of chip components – a total of 77 resistors and capacitors by my count. Most of them are the 0805 size, slightly smaller than the 1206 size used by Down East Microwave in many of their transverters, but large enough for me to assemble without a microscope. If you are not comfortable working with chip components and surface-mount soldering, this could be a difficult project. However, surface-mount soldering is not really difficult, and can be learned with a bit of practice. A temperature-controlled soldering iron with a fine tip is important (I prefer about 700ºF), and thin "low-residue" solder eliminates the need for flux removal. My technique is to put a small amount of solder on one pad, then hold the component in place with tweezers while reheating that pad to attach one end of the component. Then I solder the other end of the component to the other pad, and finally touch up the first end if necessary. Where pads and components are close together, a little planning can allow soldering the second end of one component while starting the first end of another.

An alternative technique uses soldering tweezers to heat both ends of a component simultaneously. I haven't really tried this, but some folks like it. MCM Electronics has some soldering tweezers on sale in their latest flyer. I've also heard of folks using two soldering irons the same way.

Since the chip components are inexpensive, buy a few spares. If you mess one up or reheat it too many times, simply remove it, clean up the pads, and try again.

Additional closeup photos of the assembly might help with construction: the LO section in Figure 10, the receive section in Figure 11, and the IF and switching area in Figure 12. A back view of the transverter with the cover open is shown in Figure 13. Digital cameras sure make this easy!

A parts list spreadsheet is shown in Figure 14, with Digi-Key part numbers where appropriate. This is a do-it-yourself kit.

The local oscillator should be assembled first and aligned, along with the voltage regulators U1 and U2 (heat sinking is not necessary for just the LO), but not the mixer. The key adjustment is to retune FL1 to 198 MHz, since standard Toko filters are only available for 187 or 192 MHz. A coax connector is temporarily attached near the mixer pins to measure the LO output, and the two tuning screws on top of FL1 are adjusted for maximum output. Turning the screws *clockwise* increases the frequency; at least two full revolutions of each screw will be required to reach 198 MHz.

After the LO is aligned, the rest of the board may be assembled. I like to test the board before final assembly into the box, looking for transmit output (>+10 dBm) at the A7 input pin connection, and applying a signal generator to the antenna connection for receive testing to peak C5. A printed-circuit mount SMA connector will slip on both of the above test points without soldering. Also, see that R7 will vary the transmit output but not the receive.

Try to test everything possible before final assembly, while both sides of the board are still accessible. The band detect input should operate and turn on the yellow LED when the input voltage is below about 2.9 volts, and not at higher voltage. Grounding the PTT input should only activate the relay when the yellow LED is on. Finally, trim all the component leads on the bottom side and go over everything one last time checking for shorts.

The printed circuit board is mounted to the box with six 4-40 screws through the big holes in the board. The board must be spaced high enough to provide clearance for bottom-side components, but low enough so that the power amplifier leads are short. A flat washer and a hex nut seem to be the right combination; the washer is against the box. Then the board is held down with more hex nuts; at least two locations need small-pattern nuts to clear the components.

Adjustment

After assembly into the box, the transmit attenuator must be adjusted. Hook up the FT-817 and a dummy load, and make sure the all the switching works right – using the mike button in CW mode will switch to transmit with no output power. Turn R7 fully counterclockwise, then adjust the FT-817 for low power (0.5 watts) at 24.9 MHz CW. Key the transverter and turn up R7 for maximum output; probably greater than 6 or 7 watts. Adjust R7 for 5 watts out and linearity will be good. Another adjustment is to peak FL2 at this frequency, so that the bandpass will cover the whole band. Then readjust R7 for 5 watts output again. Finally, C5 may be adjusted while receiving a weak signal, or adjusted for best noise figure if possible.

Performance

The transmitter output is set for 5 watts, to match the other bands on the FT-817. The output spectrum, shown in Figure 15, is pretty clean — the LO is 45 dB down, and other spurs are lower. The second harmonic is 50 dB down and higher harmonics are more than 70 dB down. At this power output, total current for the radio plus transverter is around 2 amps, which is reasonable for battery operation, and close to the current for the FT-817 alone at 5 watts output on other bands. On receive, the transverter draws about ¼ amp. While I haven't measured the noise figure, weak-signal sensitivity seems very close to a Down East Microwave transverter with GaAsFET front end.

Frequency stability is excellent after warmup. There is no frequency adjustment, it is where it is and stays there. Audio reports on sideband are good.

Of course, if you want this transverter to cover the whole 222 MHz band, the FT-817 must be modified to transmit on all frequencies. See www.mods.dk for details.

Comparison

I believe that there is only one transverter available today for 222 MHz with good performance, from Down East Microwave (www.downeastmicrowave.com) — a high-performance unit. I built a kit for my home station and am very pleased with it. I also borrowed some ideas to incorporate in this transverter, but elected to make some tradeoffs. Here is a quick comparison:

- Power – the DEMI unit output power is 25 watts or more, and needs a hefty heat sink as a result. I chose to keep the power to 5 watts, and the metal box with no heat sink only warms up slightly. Current drain is also much lower.
- Filtering – the DEMI unit has an additional helical filter before the power amplifier to further reduce spurs. Probably more important at the higher power level. It didn't fit on the smaller board. I also reduced the output low-pass filter from 4 sections to 3, losing a few dB of harmonic reduction.
- Receiver – the DEMI unit has a GaAsFET front end, so the noise figure is a couple of dB lower. Making a stable GaAsFET amplifier with self-biasing can be tricky, so I went for a simple, reliable MAR-6. Good enough for a low-power station.
- IF interface – the DEMI unit devotes a lot of board space to a universal IF interface so that it can be used with any radio ever made. This one is tailored to the FT-817. To use it with another rig (say, inside an Elecraft K2), modify the board design.
- Local oscillator – the DEMI unit uses a relatively expensive crystal, with a trimmer to set it right on frequency (until it ages), and a heater to reduce temperature sensitivity. I used a cheap computer oscillator for simplicity and compactness. If this is the only transverter with a 12-

meter IF, just put the frequency that hits 222.100 MHz in a memory and you'll always be right on.

Conclusion

This transverter adds the missing link to the FT-817, adding 222 MHz with performance comparable to other bands. Now a backpacker or rover can have all the VHF and UHF bands and still travel light.

Alternatives

While this transverter is intended for the FT-817, it could certainly be used with other QRP transceivers. For example, it would probably fit inside an Elecraft K2 (www.elecraft.com). The choice of IF frequencies is limited by available oscillator frequencies; custom oscillators are prohibitively expensive, and programmable ones have egregious phase noise. However, there is one other choice worth considering: a 65 MHz oscillator, rather than 66 MHz, would put the IF at 27 to 30 MHz. A CB transceiver could be used for SSB at the low end of the 222 MHz band, or a ten-meter transceiver would cover the 223-224.7 MHz segment for FM use. Full-band coverage would still require something like the FT-817, modified to transmit on all frequencies.

If more power is required, an external amplifier is the easiest way. A solid-state brick is fine for FM and CW; some of them are almost linear and can be used for SSB. Tube amplifiers provide higher power with better linearity – mine easily drove a surplus AM-6155 (www.fairradio.com) amplifier to 400 watts output – but are far from small and light. The FT-817 transverter was designed for portable and rover operation. For a serious high-power station, the DEMI transverter with a full-size transceiver is probably a better choice.

References

1. P. Wade, W1GHZ, "2-meter Miniverter," *N.E.W.S. Letter*, North East Weak Signal Group, March 2001, pp. 5-6.
2. *The ARRL Handbook for Radio Amateurs*, ARRL, 1992, p 2-40.