2m Weak Signal Sources

Rick Campbell KK7B and Daniel Schaeffer
Portland State University

This paper describes a set of signal sources at power levels from -30dBm to +12dBm in the 144 MHz amateur radio band. All are legal for direct connection to an antenna under FCC part 97, with appropriate provisions for ID. They are used in Portland State University classes and student projects involving ultra-low power and ultra-low data rate communications and wireless instrumentation experiments, typically over distances from tens of meters to several km. Some students acquire amateur radio licenses, and those who earn call signs control transmitters. Students are also encouraged to study and modify the circuits.

An original VHFs Signal Source board was designed in 2008, with a production circuit board layout in 2009. That has been a reference circuit in the 2014 ARRL Handbook, was available as a kit from Kanga US, from 2009 through 2011, and has been used in several Portland State University courses in 2009 and 2010, and since 2012. It remains an excellent design, but several of the components are at end-of-life, and in 2019 there is a need for reduced size and reduced power options for ultra-low-power communications.

The Express PCB pallet below has 5 different designs for VHF signal sources and a frequency multiplier, with early experiments performed on the 144 MHz band using 144.045 MHz crystals from Bomar. The crystals are available in the Electronics Prototyping Lab store at Portland State University. In the upper left of the pallet is the VHFsx board, with the VHFs high-stability crystal oscillator followed by a xN multiplier and double tuned circuit. In the middle of the top row is a xN multiplier for experiments. In the upper right is an overtone oscillator board, based on a design used in the RCX1 6m converter previously available from Kanga.

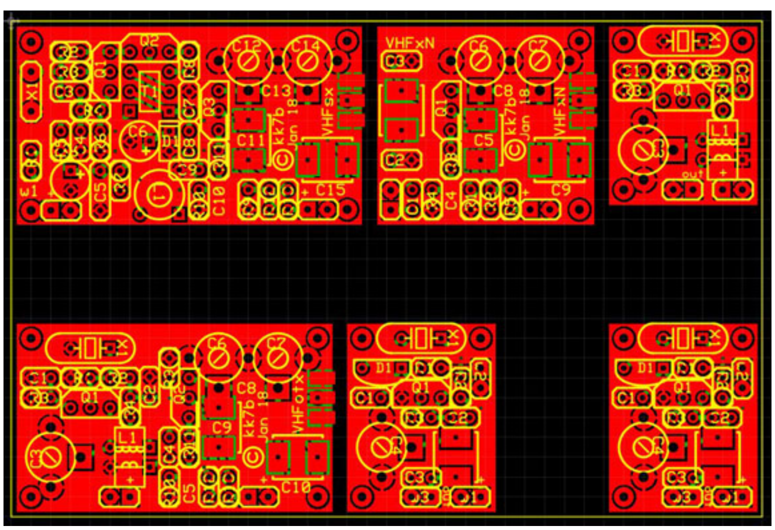


Figure 1 ExpressPCB pallet of boards in this paper

In the lower left is the overtone oscillator followed by an xN multiplier. On the lower center and right are two micro-power signal sources consisting of a Pierce oscillator with 24.045 MHz crystal and varactor diode in series from collector to base. A high-Q single tuned circuit is lightly coupled to the collector to pick off the 6th harmonic.

The simple Pierce Oscillator uT transmitter was conceived as an ultra-low power slow data transmitter for line-of-sight paths. The slow data may be as simple as OOK or FSK ID using morse code. The Pierce oscillator has an output waveform rich in harmonics, and the lightly coupled high-Q single tuned circuit on the output passes the 6th harmonic on to the load while presenting the fundamental and all the other harmonics with reactive terminations. FCC Part 97 governing transmitters in the Amateur Radio VHF bands requires that undesired outputs of ultra-low-power transmitters be reduced to less than -30dBm. Output power in this simple circuit is dependent of power supply voltage, varactor voltage, and output circuit tuning. All interact to some extent.

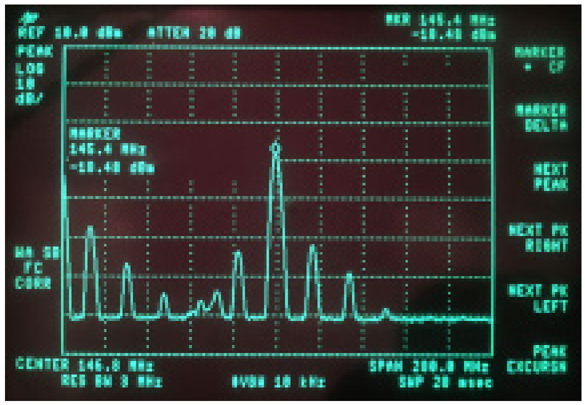


Figure 2 Typical uT output spectrum

The uT (microT) was conceived as the simplest 2m transmitter that may be legally connected to an antenna and used for real communications under FCC part 97. Figure 2 is a typical uT output spectrum at a supply voltage of 6v and a varactor voltage near 5v, with output frequency 144.318 MHz. The desired output is at -18dBm, with x5 and x7 harmonics at 120 MHz and 168 MHz respectively at less than -42dBm out. The most significant undesired output is the fundamental 24 MHz frequency, at -37dBm. The extra structure between the 96 MHz and 120 MHz outputs at -65dBm is bleedthrough into the measurement from the FM broadcast band.

An ongoing issue with VHF circuits designed for classroom use is the rapid migration of parts from leaded packages to surface mount, and the insidious change in component performance as old stock components are depleted and new components become available with the same part number, but built by different companies in different fabrication facilities. This problem is severe when the transistor in a fundamental Pierce oscillator at 24 MHz must have an internal die with device parasitics that encourage a particular wave shape rich in 6th harmonic.

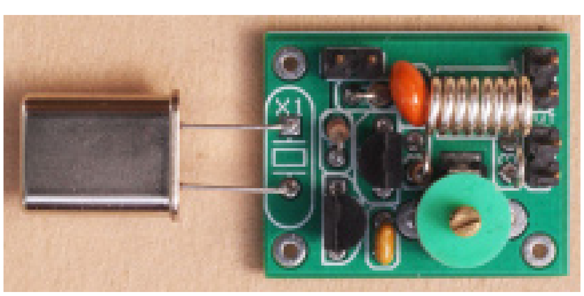


Figure 3 uT micropower 2m signal source

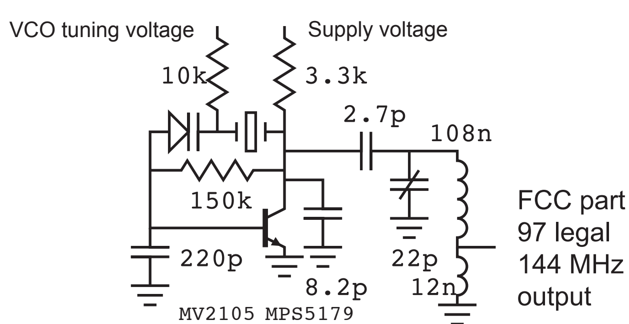


Figure 4 uT schematic

The uT works remarkably well for its intended application, but more impressive performance in a number of signficant specs is available by increasing the VHF signal source parts count. A separate isolated crystal oscillator followed by a carefully designed xN multiplier and double tuned circuit permits each function to be optimized for stability, load independence, dc voltage tolerance, and repeatability. The frequency multiplier stage may be tailored for different xN by adjusting the base drive network, emitter resistor, and optional emitter degeneration resistor.

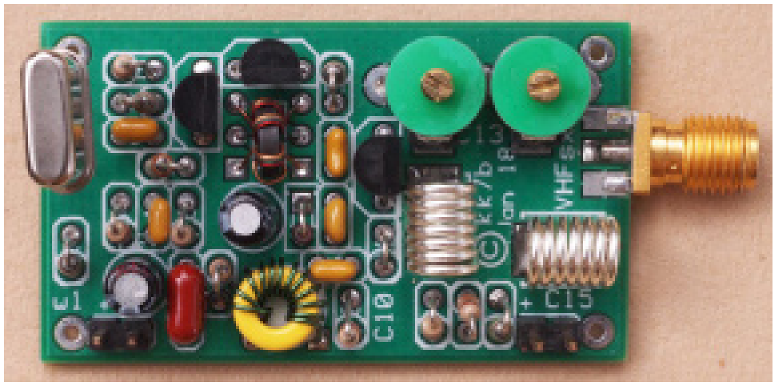


Figure 5 VHFsx Stable Oscillator-Multiplier

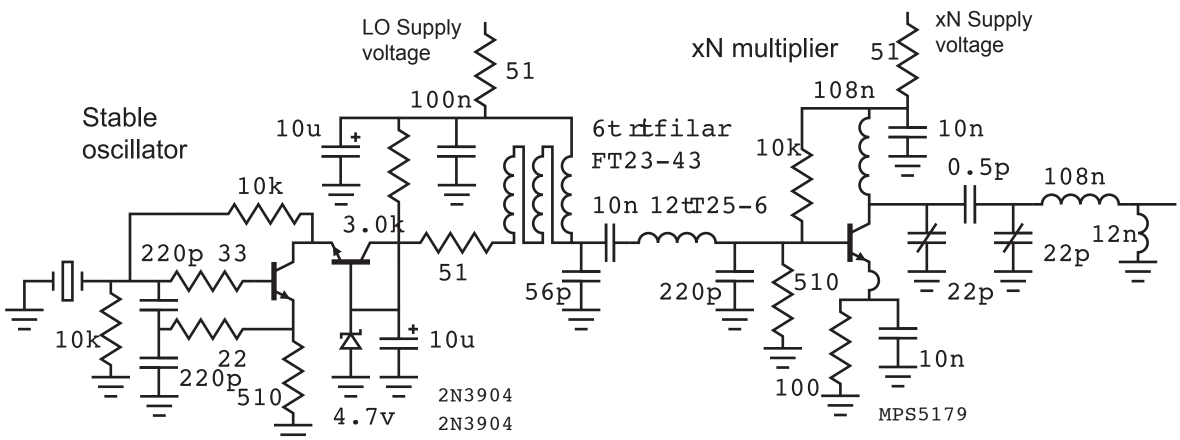


Figure 6 VHFsx Schematic

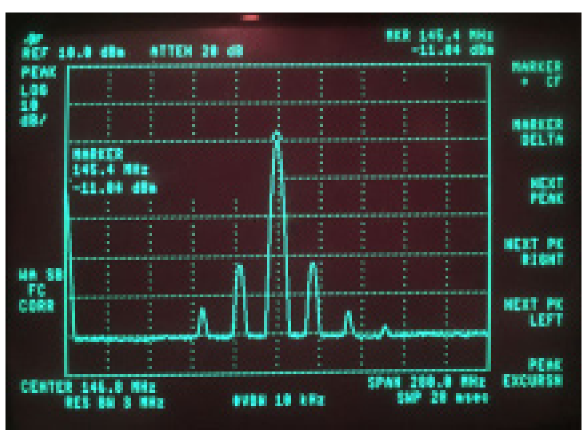


Figure 7 VHFsx spectrum with 6v on the LO and 6v on the x6 stage

The VHFsx circuit tolerates variation of supply voltages. The oscillator 4.7v zener diode in the base of the second transistor has a 3.0k series resistor, which results in a zener current of about 1 mA at 9 volts supply. For optimum frequency stability the oscillator portion of the VHFsx, or the oscillator and frequency multiplier, may be run from a 9v three terminal regulator. Note that the close-in noise floor of the oscillator with a battery supply is cleaner than when using a three terminal regulator, since the regulator output includes some very low level noise. This may be suppressed with an electrolytic capacitor and decoupling resistor on the output of the regulator.

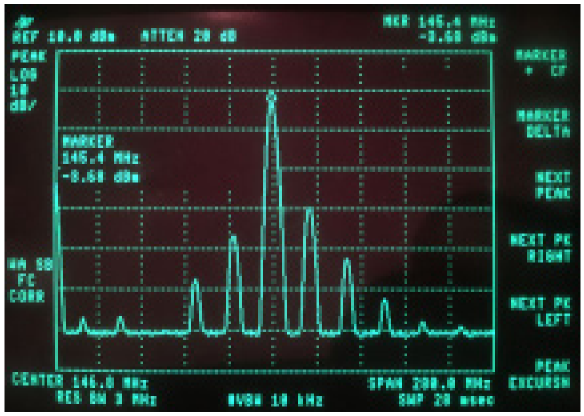


Figure 8 VHFsx with 12v on x6 multiplier

The spectrum in Figure 8 shows output of the VHFsx circuit with 9v on the oscillator and 12v on the xN multiplier. This provides more output power, but also higher spurious outputs at 24 MHz x4, x5, x7 and x8. If a following amplifier is used to obtain +7dBm for a diode ring mixer, it is recommended that the amplifier include a double tuned circuit on the output. The resulting schematic is then identical to the original 2008 VHFs described in the 2014 ARRL Handbook.

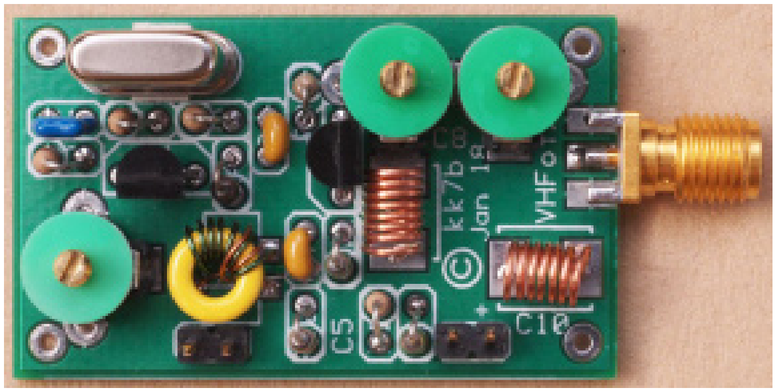
The VHFsx oscillator circuit has independent regulation of active device operating conditions, and resistors to help remove active device parasitics from the crystal frequency determining environment. The circuit is tolerant of variable reactance elements in series with the crystal, and frequency swings of 100 kHz or more at 144 MHz are possible with little change in output power or frequency stability.

Remarkable frequency stability may be obtained by thermally isolating the crystal in a foam packing bead, and maintaining constant temperature. The circuit is capable of part in 10^9 frequency stability over periods of several minutes.

The xN frequency multiplier in the VHFsx circuit has been used for every multiple from 2 to 7 in our experiements. The small wire lead inductor in the emitter, visible in the photo just above the C10 text, may be a low value resistor for resistive emitter degeneration and increased base drive impedance in some applications. The 100 ohm frequency multiplier emitter resistor, and the low-pass base drive network are also changed depending on the desired harmonic and available transistors. For an example of the emitter components used in a x2 multiplier, see Figure 10 on the next page. Generally speaking, sine wave drive, low impedance reactive base termination at harmonics, and experiments with different emitter resistor combinations have been found to be good practice in bipolar transistor frequency multipliers.

In applications where ultimate frequency stability and the ability to vary the output frequency are not needed, a classic and clean way to generate signals in the medium VHF range is to operate crystals on mechanical overtones. The 24.045 MHz crystal oscillates nicely on its third overtone at 72 MHz. Following the single transistor 72 MHz overtone oscillator with a simple x2 frequency multiplier results in a clean spectrum and +12dBm output power at 144.395 MHz.

24.045 MHz
20pF parallel
Bomar crystal
operated on its
3rd overtone



144.395 MHz
output

Figure 9 VHFotx overtone oscillator with x2 multiplier

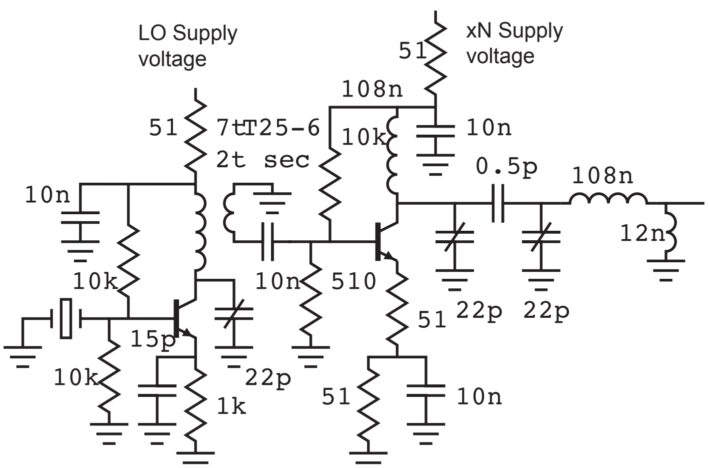


Figure 10 VHFotx schematic

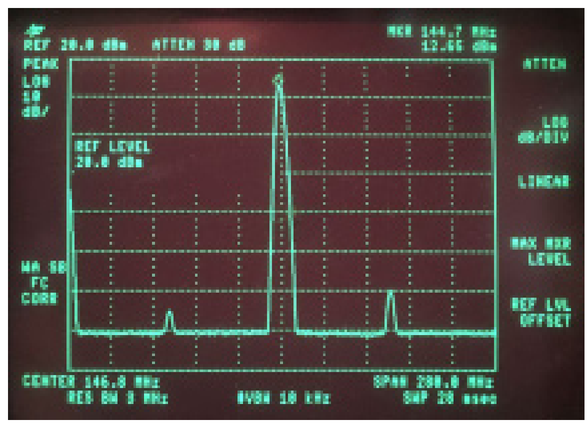


Figure 11 VHFotx output spectrum

The spectrum is remarkably clean for a simple circuit with relatively few components, but there are several issues. Overtone oscillators are notoriously resistant to varying the oscillation frequency by changing series reactance, and operating conditions may suffer when the crystal is “bent” to a desired frequency. Standard practice is to tune the overtone oscillator for reliable operation and compensate for errors in the output frequency elsewhere in the system. There is little isolation between the two stages of the overtone oscillator-frequency multiplier, and tuning of the two stages should be done while examining the output on a spectrum analyzer. The circuit is stable and reliable once tuned, but there are operating conditions at various settings of the x2 frequency multiplier load capacitors that exhibit independent oscillation and even frequency division in that stage.

Reference: Campbell, VHF Signal Sources, in 2014 Handbook for Radio Communications, ARRL, pp. 13.19 to 13.24