All Things Digital

Amateur Radio for the 21st Century

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BUILD A 10 MHZ EXTERNAL REFERENCE DEVICE—PART 2

Special thanks to Brian Grant, VE3GEN, in providing the initial information for this project and explaining a few things to me. Later, I obtained more details from Clint Turner, KA7OEI, and Douglas Hunter, VK4ADC.

CALIBRATION, CALIBRATION, CALIBRATION

Part 1 covered the operation and building of a 10 MHz oven controlled crystal oscillator (OCXO) reference signal device, and this part continues on with its calibration. Most operate very close to their stated frequencies once they have warmed up and reached electronic thermal equilibrium. They are extremely stable, and will not deviate in frequency because of their internal compensation control circuitry unless connected to multiple external loads (a distribution amplifier is required for this). With reference to Table 1 (next page) of the three tested OCXOs, the worst case uncorrected parts-per-million (ppm) error and frequency error in hertz (Hz) was -0.9 ppm and -9 Hz (at 10 MHz) so this one definitely needed in-circuit recalibration; there are two ways we can do this:

1. Use a very stable and accurate radio frequency (RF) signal generator, or a rubidium/cesium clock, or a GPS disciplined oscillator (GPSDO) to calibrate an RF frequency counter (having at least 1 Hz accuracy) and then adjust the OCXO device RF output frequency to exactly 10 MHz using the counter or…

2. Use the 10 MHz WWV time reference signal received by a frequency stable and accurate high frequency (HF) receiver or transceiver, and feed its audio output to a computer/soundcard running digital signal processing (DSP) software to determine an audio frequency (AF) reference signal (AF out) then substitute the OCXO device for WWV, and adjust its RF output to produce the same AF out.

10 MHz OCXO Comparison Table (Ambient Air Temperature 20 °C)

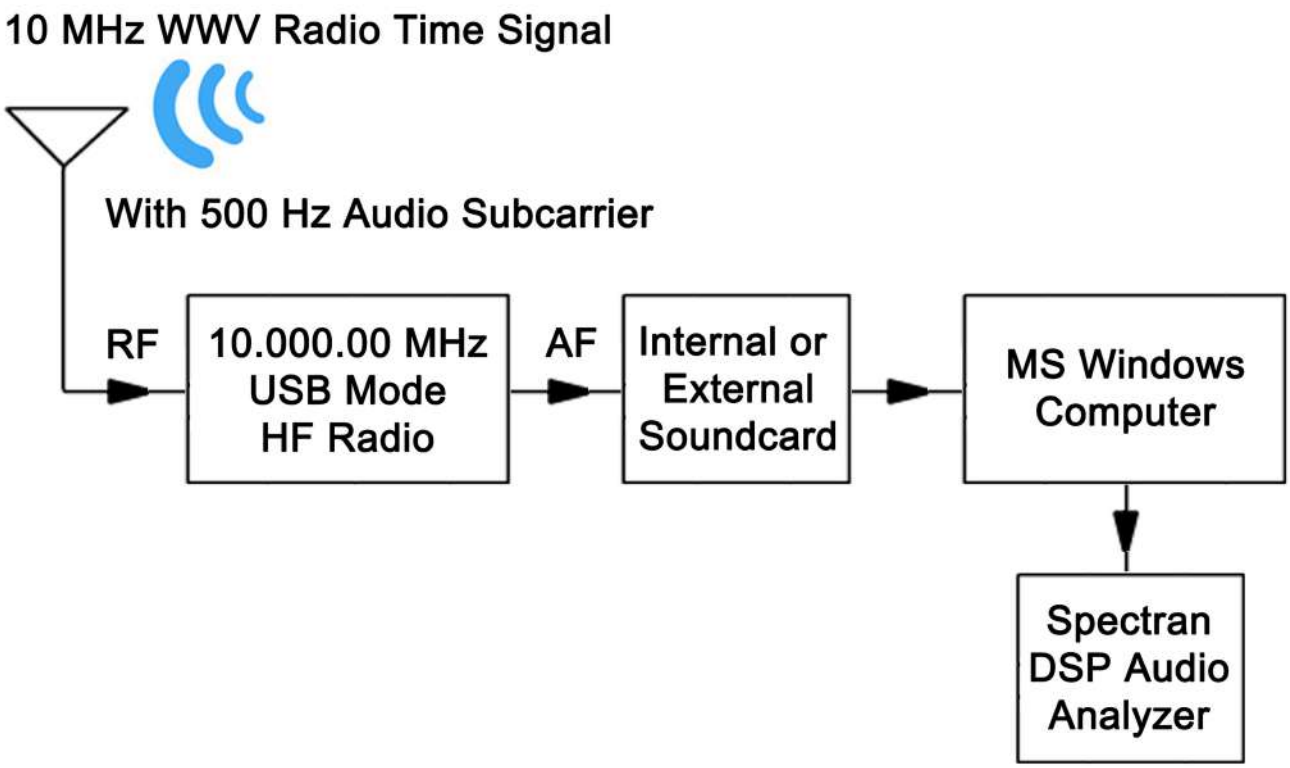
	VDC	I Oven (max) Heat (ma)	I Oven (min) Ready (ma)	Time Oven Ready	OCXO Case Temp ° C	Δ Freq. High (Hz)	Δ Freq. Low (Hz)	Time Freq. Stable	RF Out (mW/dBm)
OFC/McCoy	12	430	80	3m	28	1	-255	3m	9/9.5
ISOTEMP	12	750	200	10m	38	260	-9	15m	6/7.8
GPS Disciplined Clock	12	1300	380	18m	31	3	-250	11m	23/13.6

Notes

1. ISOTEMP frequency starts out high, drops down with an undershoot then climbs back up to near 0 Hz error.
2. ISOTEMP internal frequency adjust used to bring it to 0 Hz error (instead of external VR1 adjust).
3. OFC/McCoy frequency starts out low then very rapidly climbs up and stabilizes.
4. OFC/McCoy has no internal frequency adjust, external VR1 adjust used to bring it to 0 Hz error.
5. GPS disciplined clock requires 3 dB in-line attenuator to bring signal below 10 dBm.
6. GPS disciplined clock OCXO inside GPS aluminum housing & actual temperature likely a few degrees higher.
7. GPS disciplined clock starts out low, rises up with an overshoot then self-corrects to 0 Hz error.

A. OCXO case temperatures measured with Clear Temp IRT0421 IR thermometer.
B. RF power output (all sine wave) measured with calibrated OHR WM-2 QRP wattmeter.
C. Frequency measured at 1-minute intervals with Ramsey CT-2000 counter (calibrated with GPS disciplined clock).
D. Voltage & current measured at 1-minute intervals with inline "Watts-Up" MCU meter.

Most Amateurs probably don't have the equipment required for method one so I'll just cover the second method because most of us have HF radios, computers/soundcards, and can download the free DSP software if not already installed. *Note: Parts-per-million error is just a simple percentage error (1 ppm = 0.000001 percent) and is constant. On the other hand, frequency error changes with frequency because it's derived by multiplying ppm error and frequency. I.E. 1 ppm error at 10 MHz produces a 10 Hz [dial] error (0.000001 x 10000000) but 1 ppm error at 30 MHz produces a 30 Hz [dial] error. Back in the day, Amateurs used WWV and internal or external oscillators to correct their analog tuning dial reading, but it's a lost art and why you see many digital mode operators slightly (or a lot) off frequency..*

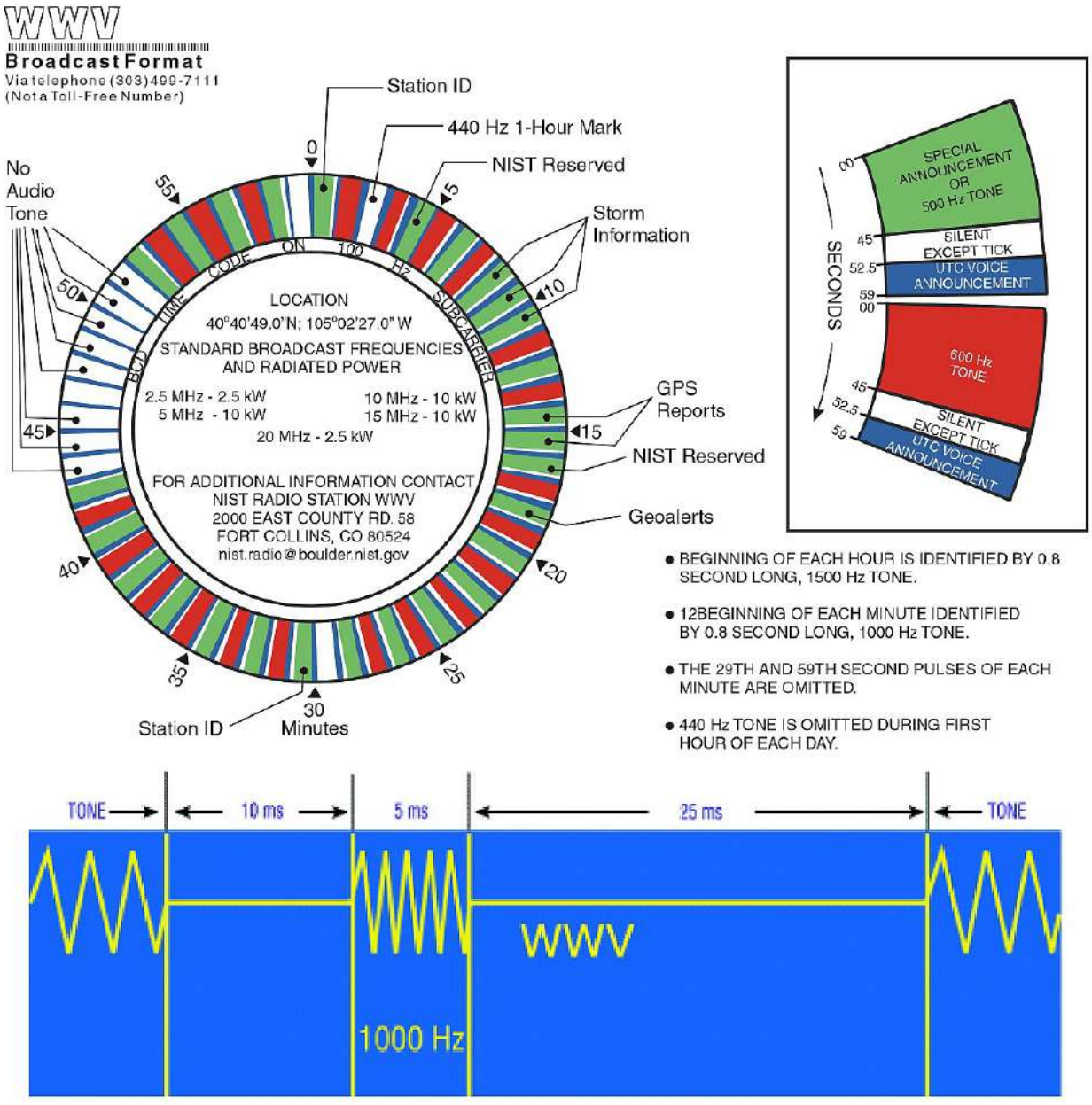


Step 1: Radio plus Soundcard Calibration (see above)

Note: I use Spectran, but if you use a different DSP audio program (Argo, Spectrum Lab, etc.) you may have to [slightly] modify these steps.

a. Connect an audio patch cord between the test radio's audio/speaker output to your computer soundcard's input (microphone or line).
b. Setup the *Spectran* soundcard input and control settings, then slide the frequency scale to the 500 to 600 Hz audio range. *Note: The Spectran manual covers setup and operation in detail, but I will mention the noticeable processing delay before any audio input changes are reacted to and displayed (varies with computer "horsepower").*
c. Connect your radio to a suitable HF antenna, switch it to upper sideband (USB) mode, ensure all radio controls are in their "neutral" or "disabled" positions (i.e. no IF shift, RIT zeroed, etc.) and tune your radio dial to exactly 10 MHz (WWV).
d. Adjust the radio's audio output and soundcard's audio input levels so *Spectran's* audio level indicator is "in the green" (see above). *Note: Before going on, let your radio warm up for at least 60 minutes to ensure it has reached electronic thermal equilibrium.*

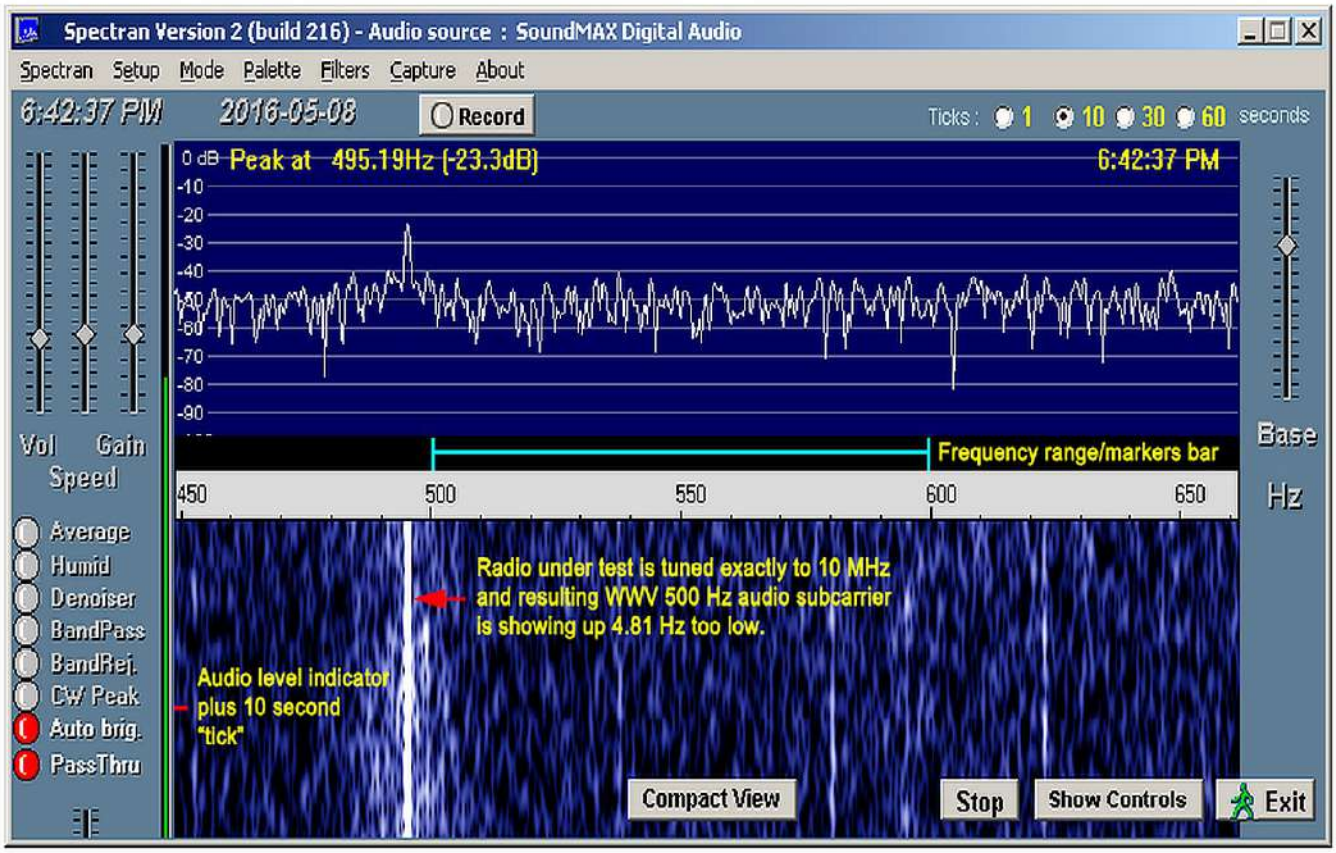
If there are no ppm and frequency errors (radio plus soundcard) you'll see WWV's two audio subcarriers "falling" down *Spectran's* waterfall, alternating each minute at exactly 500 Hz then 600 Hz. You can use either signal, but I prefer 500 Hz.



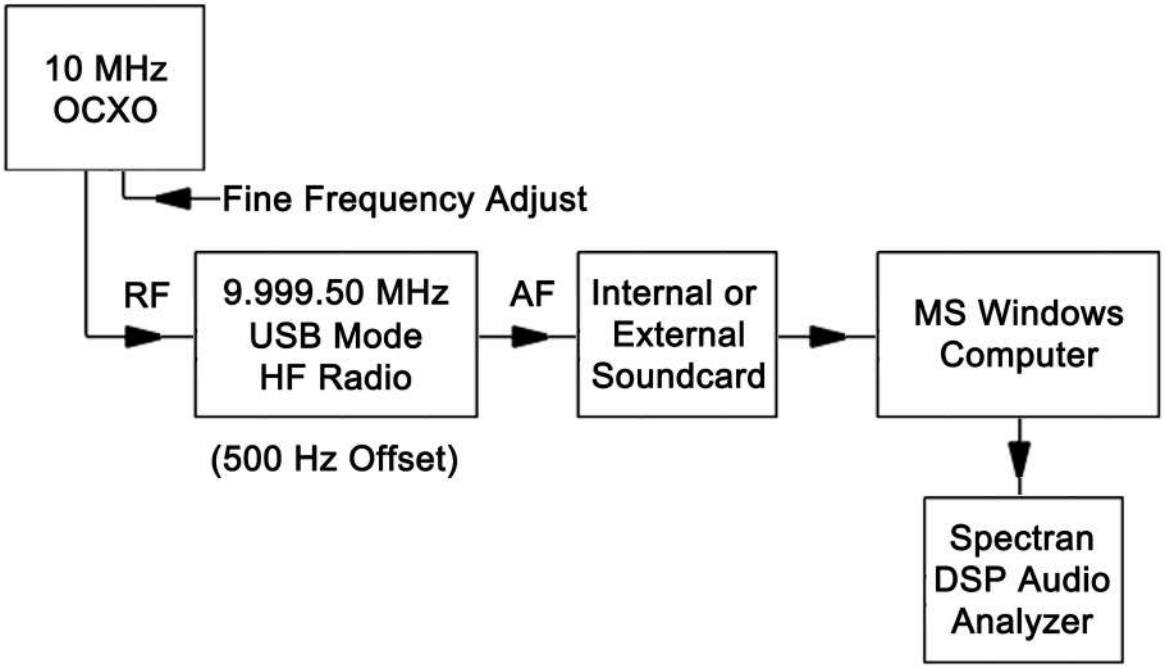
The WWV radio time signal format with its various audio subcarriers (see above) and the most important (for us) are the 500 Hz and 600 Hz "minute markers", which alternate between even and odd minutes (there are a few exceptions).

Note: WWV's 100 Hz binary coded decimal (BCD) audio subcarrier contains digitally encoded date/time data (transmitted continuously) and you can try using it, but I've found that many radios, soundcards, and/or soundcard interfaces have poor low frequency audio response.

In the Spectran waterfall image (below) WWV's 500 Hz audio subcarrier is indicating 495.19 Hz which means that the combined ppm and frequency errors of my radio/soundcard combination shifted it by 4.81 Hz, which means 495.19 Hz is my AF out reference or calibration signal to use for the next step (instead of 500 Hz). *Spectran's* frequency readout will "dance" back-and-forth by fractions of a hertz mainly due to soundcard "sampling jitter" caused by sound card oscillator clock timing errors, but large variations indicates a serious problem you need to find and fix before going on.



Note: Your radio/soundcard pair won't produce the same AF error out as mine—it may be higher, lower, or spot on 500 Hz.

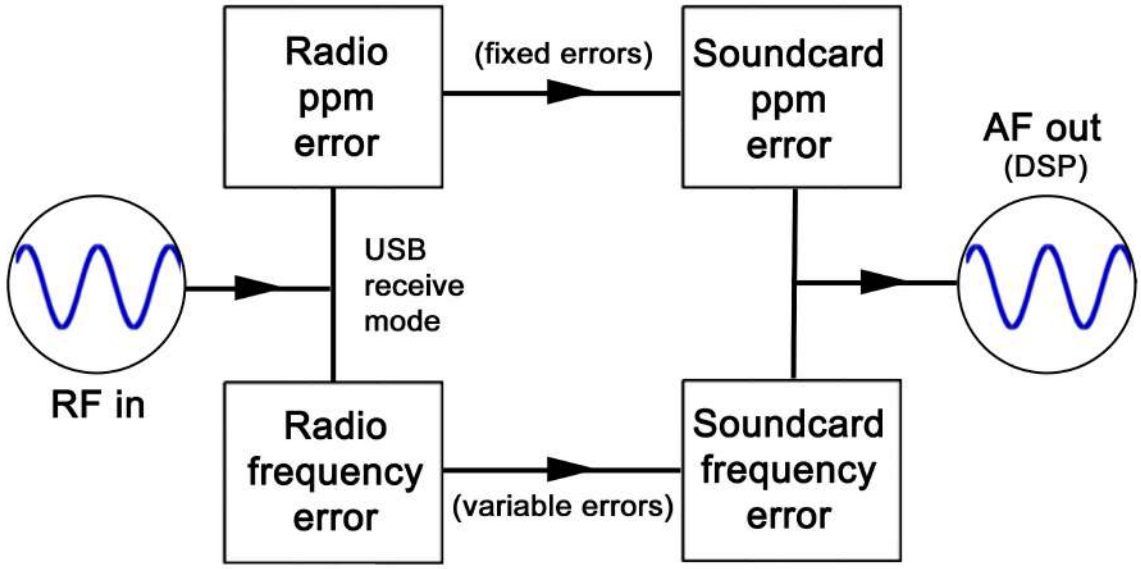


Step 2: OCXO Device Calibration (see above)

Note: In the step 2, the OCXO device replaces WWV, but it only transmits a 10 MHz continuous wave (CW) radio signal so we create the audio subcarrier effect by offsetting the radio's receive frequency to heterodyne or "beat" with the incoming signal (direct conversion method). By tuning your radio 500 Hz lower (USB mode) the beat note equals 500 Hz— plus or minus any radio/soundcard combined ppm and frequency errors.

a. Use the same setup as describe in step 1, except the HF antenna is disconnected and the OCXO device's RF output is connected to the radio's antenna jack. Most receivers can only accept low-level, direct input RF signals at or below 10 decibels per milliwatt (dBm) so a 3 or 6 dB inline attenuator may be required, or just sit the OCXO device near the radio with a short piece of wire connected to the OCXO's RF output (an ersatz "transmitter" antenna).
b. Tune on the OCXO circuit, and let it reach oven ready and thermal equilibrium. Set your radio to USB mode and tune the dial frequency 500 Hz lower than 10 MHz.

c. My AF error reference signal is 495.19 Hz (obtained from step 1) so while viewing the *Spectran* waterfall display, the OCXO circuit's fine frequency tuning (VR1) potentiometer is adjusted (in small increments) until the resulting AF out is as close as possible to 495.19 Hz. When the OCXO's output is set to exactly 10 MHz it must and will produce the same AF out result as did the WWV signal because the radio/soundcard ppm and frequency errors remain the same for both steps (see below). *Note: Remember to wait for Spectran to "react" to any changes— make a slight turn of VR1 (left or right)—then stop, wait and watch.*



1. Use known RF input to produce an AF output (the product of any combined radio/soundcard errors at a specific RF frequency).
2. Replace known RF input with RF device to calibrate. Adjust its RF output to produce the same AF output as in step 1.

Note: Tune radio 500 Hz lower in frequency if RF in has no 500 Hz audio subcarrier (à la WWV).

We've just calibrated our 10 MHz OCXO reference device, and can now use it to calibrate other electronics (WWV is no longer needed). You can verify an oscilloscope's frequency and waveform accuracy, or recalibrate/check a frequency counter, or calibrate other OCXO devices, etc. Most electronic circuitry has some kind of user accessible calibration control you can "tweak", but be very careful when you do it!

VARIATION ON A THEME

Kits and Parts sold a frequency and reference standard kit, which is no longer available, but and the schematic and parts list are posted on their website. It uses a 5-volt, 20 MHz TCXO with divide-by-two digital circuitry to produce RF reference signals at 2.5, 5, 10, and 20 MHz. It's an excellent tool for creating a radio dial calibration card because every radio has a dial error that varies with frequency, unless its ppm error is exactly zero (highly unlikely for inexpensive consumer electronics). Five volt TCXOs usually (unless stated otherwise) output a square wave because they are mainly used in transistor-transistor-logic (TTL) digital/binary circuits, but many external RF devices can only accept a sine wave (or a close approximation to one). A square wave is composed of the fundamental frequency sine wave plus its odd multiples or "harmonics"—to infinity and beyond—so adding an appropriate low pass filter (LPF) allows only the fundamental frequency sine wave to "pass", and sharply attenuates the harmonics. This produces a very good looking sine wave with some signal attenuation.

MY FINAL

And that's a wrap on this project. I do hope you'll try building it for yourself because it's a very useful tool to have for personal or club use (share with others).–73

REFERENCES AND RESOURCES

KA7OEI OCXO design
http://tinyurl.com/jl5a7ad

Kits and Parts Frequency standard/reference kit
http://tinyurl.com/jenlk2x

KP4MD 10 MHz LPF (YouTube video)
http://tinyurl.com/gruwpzy

VA3ROM (All Things Digital)
http://tinyurl.com/og2acxq

VE2ZAZ (GPS clock)
http://tinyurl.com/ju3vdhz

WWV
http://tinyurl.com/o83mtmt
http://tinyurl.com/cqcnosd