All Things Digital

Amateur Radio for the 21st Century

024

Robert C. Mazur, VA3ROM

E: va3rom@gmail.com

W: http://www.va3rom.com

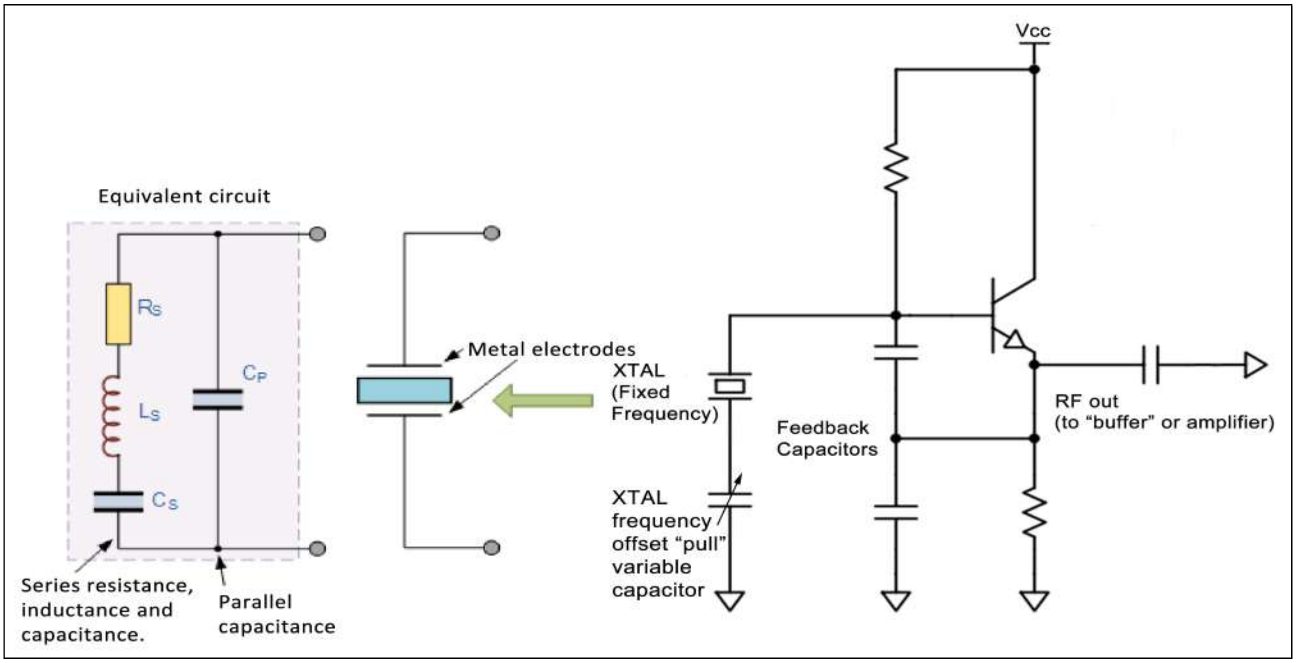
First published in the May-June 2016 issue of The Canadian Amateur

BUILD A 10 MHZ EXTERNAL REFERENCE DEVICE—PART 1

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.

INTRODUCTION

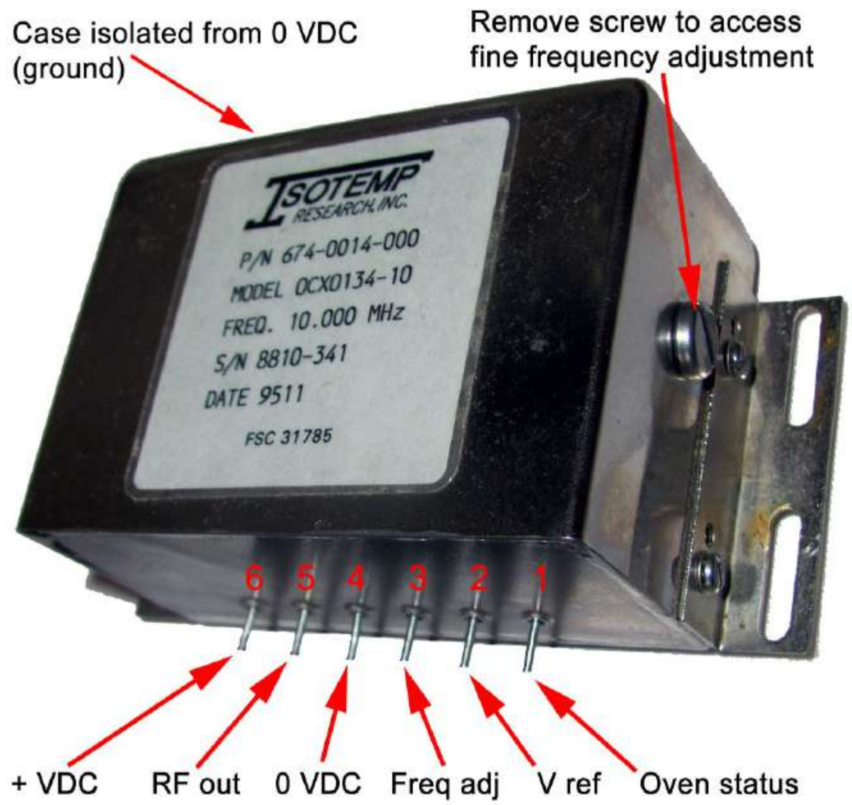
Many newer transceivers, such as the FLEX software defined radio (SDR) series, have a 10 MHz reference signal input port (see above) whereby the radio control software synchronizes the hardware to this signal, increasing frequency accuracy/stability to better than +/- 1 hertz (Hz). But even if you don’t have radio equipment with this capability, our radio shacks are usually full of electronics that will, sooner or later, require realignment/recalibration: transmitters, receivers, frequency counters, oscilloscopes, etc.



THE RF OSCILLATOR
At the "heart" of most electronics is the radio frequency (RF) oscillator, which is just an amplifier with a controlled [positive] feedback loop (see above). Early [vacuum tube] oscillators used capacitors and inductors to control frequency/feedback making them prone to drift and instability because their component qualities/tolerances varied widely. The later addition of quartz crystal control, and then the transistor made most problems a thing of the past, and also reduced size, weight, voltage, current, heat, and noise. The quality and cut of a quartz crystal or "rock" determines its base operating frequency and how much frequency error/deviation it will have in the circuit—usually measured in +/- parts-per-million (ppm). This ranges from around 10 to well over 100 ppm (typically +/- 25 ppm) but a simple technique called [frequency] "pulling" (manual or automatic) allows us to compensate—for a while. Other oscillator issues include: power supply (PS) regulation, RF interference (RFI), and/or changes in the surrounding (ambient) air temperature. Today's electronic components are usually of high quality with tight tolerances; it's easy to build well-regulated power supplies using ubiquitous 3-terminal positive/negative voltage regulators, and enclosing electronics inside aluminum housings makes them less prone to outside air temperature and RFI effects.

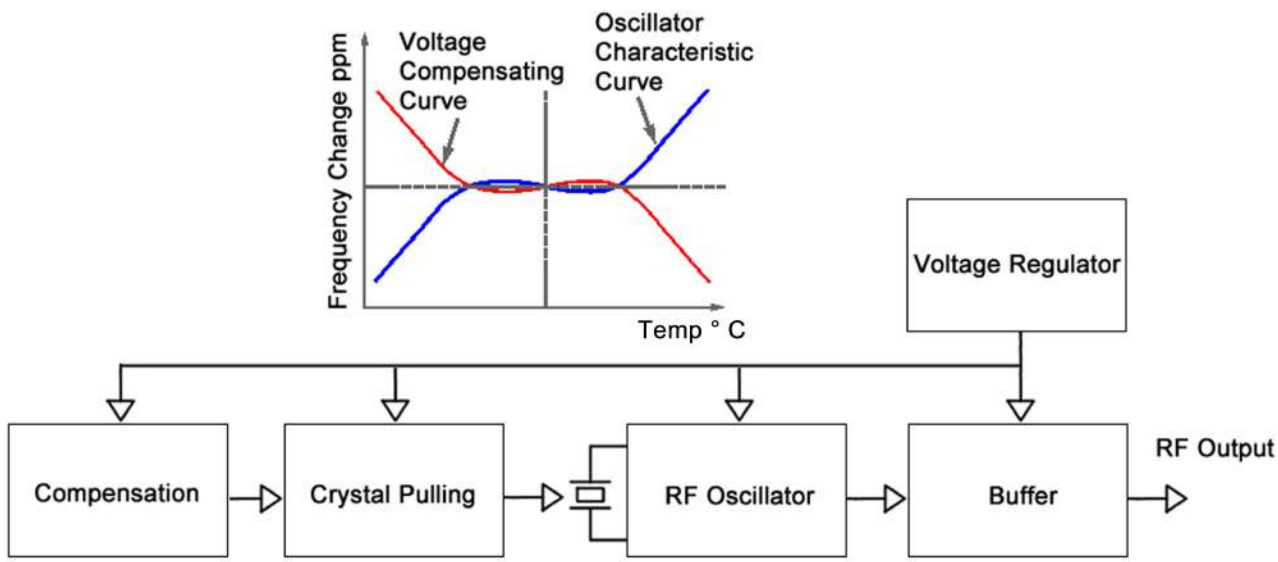
TEMPERATURE AND OVEN CONTROLLED CRYSTAL OSCILLATORS

Most modern higher-end radios have temperature controlled crystal oscillators (TCXOs) with a typical frequency error of +/- 3 ppm ; while this seems really good, it means that a 10 MHz WWV reference time signal can deviate +/- 30 Hz from what your radio dial indicates, and while this was okay in the "ancient" analog world of the last century, it's not in today's digital world where even 5 Hz is considered "extreme" frequency error, especially with very slow data rate, narrow bandwidth modes such as: Slowfeld, QRSS Morse, WSPR, PSK31, FT8, JT65, et al.



Today's high-end (high-price) radios use an oven controlled crystal oscillator (OCXO) and the entire TCXO circuitry is housed inside a small, thermally insulated "oven" (see above) heated to and maintained at a constant internal temperature (75 degrees Celsius is commonly used but this can vary). Frequency errors are dramatically reduced and now measured in parts-per-billion (ppb); for a +/- 3 ppb error the 10 MHz WWV time signal frequency error is now only +/- 0.03 Hz.

BLOCK DIAGRAM: HOW THE OCXO WORKS INTERNALLY



GPS DISCIPLINED CLOCK/OSCILLATOR (GPSDO)

The ultimate for hobbyists (see below) combines a 10 MHz OCXO synchronized with the Global Navigation Satellite System (GNSS) more commonly called the Global Positioning System (GPS) and its accuracy is 200 times that of the OCXO! The GPSDO (or disciplined clock [DC]) also provides a separate secondary signal of a one [square wave] pulse per second (1-pps) often used for digital timing circuits; there's [usually] a standard serial (RS-232) output port providing direct access to the raw GPS serial data to extract the date, time, position, speed, direction and altitude, plus the 1-pps signal.

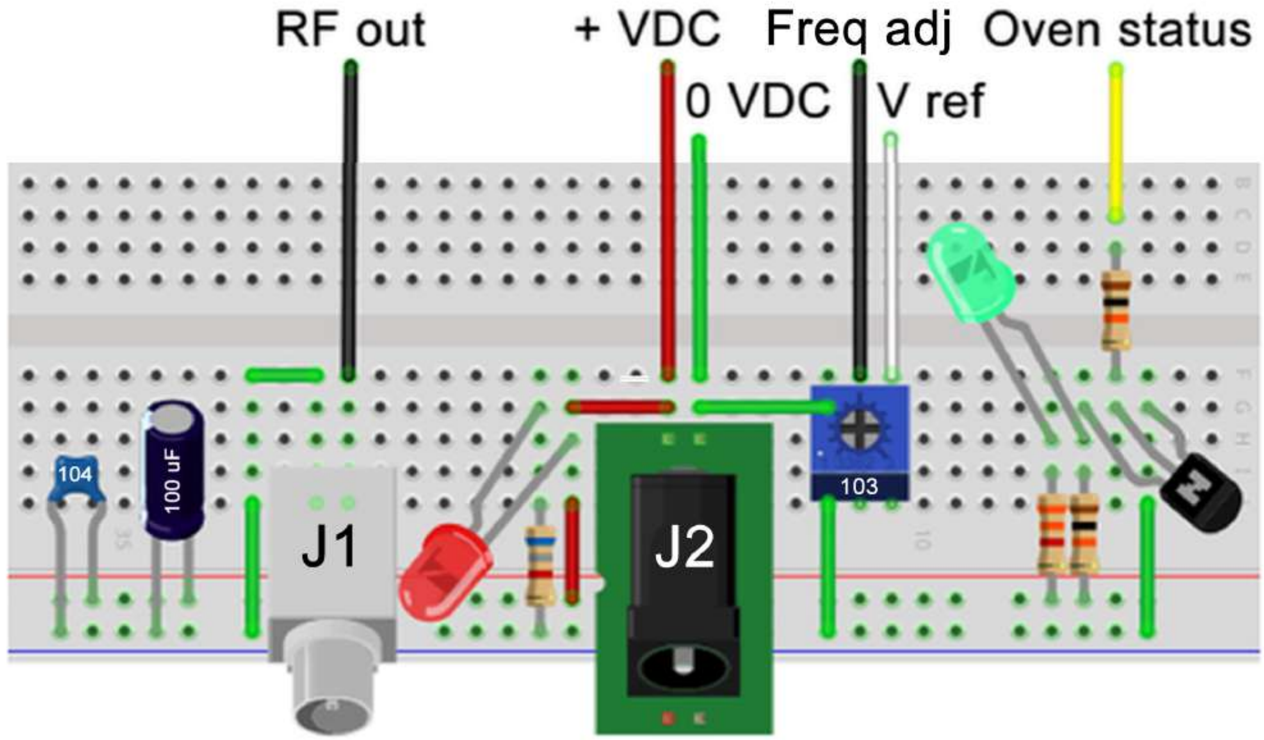
Rubidium and cesium atomic standard clocks are the ultimate in time and frequency accuracy. The National Institute for Standards and Technology (NIST) cesium “fountain” clock defines the new reference standard (April 2014) called “NIST-F2”, which is used to calibrate everything time-based in the world: other atomic clocks, GPS satellites, smartphones, internet time servers, GPSDOs, etc., with an frequency/timing error of only one second in 300 million years !

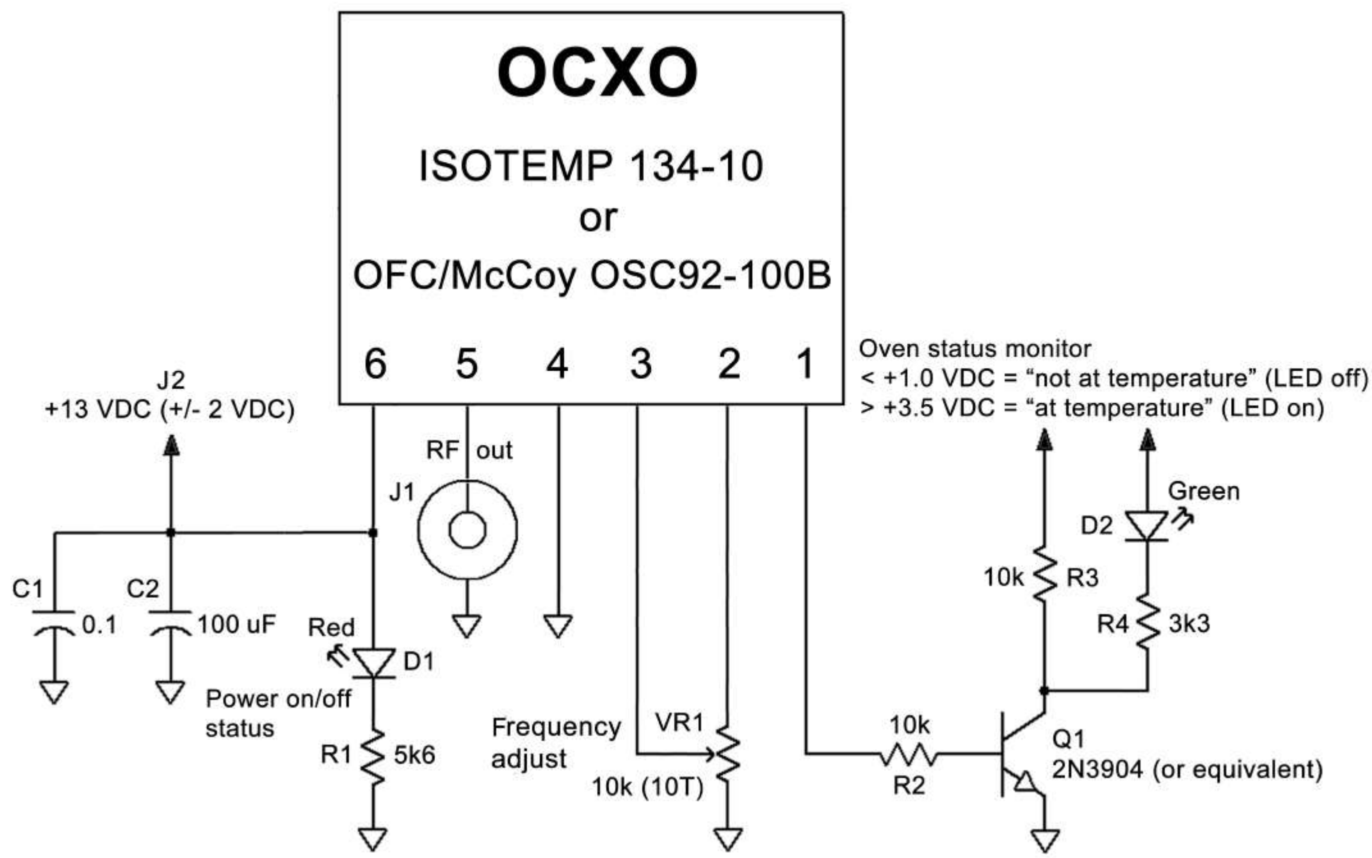
FREQUENCY MEASURING TEST

The ARRL sponsors annual frequency measuring tests in April and November using an extremely accurate reference station transmitting at specific times on various Amateur Radio frequencies. While it’s not really a contest, submitted results are published on the ARRL website for “bragging rights” from stations worldwide using various types of receivers from old tube “boat anchors”, homemade receivers, to the latest high-tech SDRs.

THE PROJECT BUILD

The block diagram and schematic (see next page) show how simple and easy this device is to build using a handful of components most of us already have on hand (except for the OCXO). There are two very popular 12 volt DC (VDC) OCXO’s (sine wave output) you can buy on the used market: the ISOTEMP OCXO 134-10 and the OFC /McCoy OSC92-100B. Both OCXOs have a single-load output impedance of 50-ohms albeit with different maximum RF signal level outputs. Supply voltage can be from a 12 VDC battery or a well-regulated [linear] power supply (13 VDC +/- 2 VDC) rated for the stated maximum oven heater current (this current drops steadily as the oven reaches operating temperature and stabilizes). *Note: Most of us only need to feed one external device at a time so I omitted adding a multiple load distribution RF amplifier or “fan-out” circuit.*


RF out
+ VDC
Freq adj
Oven status
0 VDC
V ref
104
100 uF
J1
J2
103


OCXO
ISOTEMP 134-10
or
OFC/McCoy OSC92-100B
6
5
4
3
2
1
Oven status monitor
< +1.0 VDC = “not at temperature” (LED off)
> +3.5 VDC = “at temperature” (LED on)
J2
+13 VDC (+/- 2 VDC)
RF out
J1
C1
0.1
C2
100 uF
Red
D1
Power on/off
status
R1
5k6
Frequency
adjust
VR1
10k (10T)
10k
R2
Q1
2N3904 (or equivalent)
10k
R3
R4
3k3
Green
D2

LED current limiting resistors (R1 and R4) where chosen to balance and dim their brightness for my [ageing] eyes, but you can change these values to suit yours. VR1 is a 10-turn potentiometer used to make slight frequency corrections to calibrate the OCXO. Also, Brian, VE3GEN, advises to initially adjust both sides of VR1 to read the same resistance; if the OCXO is spot on, an accurate frequency counter will read exactly 10.0000000 MHz (+/- 1 Hz). *Note: Amateurs who have built and published various 10 MHz OCXO circuits usually show VR1 as 5000 ohms (for some reason) but the ISOTEMP reference manual says to use 10000 ohms. My tests indicate that the higher value works much better for finer frequency adjustments. Also, cheap AC/DC switching "wall warts" and/or poorly regulated power supplies can add RF "hash" (noise/ ripple} so capacitors (C1 and C2) may not be able to filter this out enough.*

OCXO CAVEATS

The OFC/McCoy OSC92-100B is technically "equivalent" in pin layout and circuitry to the ISOTEMP OCX134-10 except it lacks the detachable side-rails and internal frequency adjustment control. Most resellers quote the ISOTEMP's specifications for both, but they just aren't "equal" in several important operating parameters (see below).

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

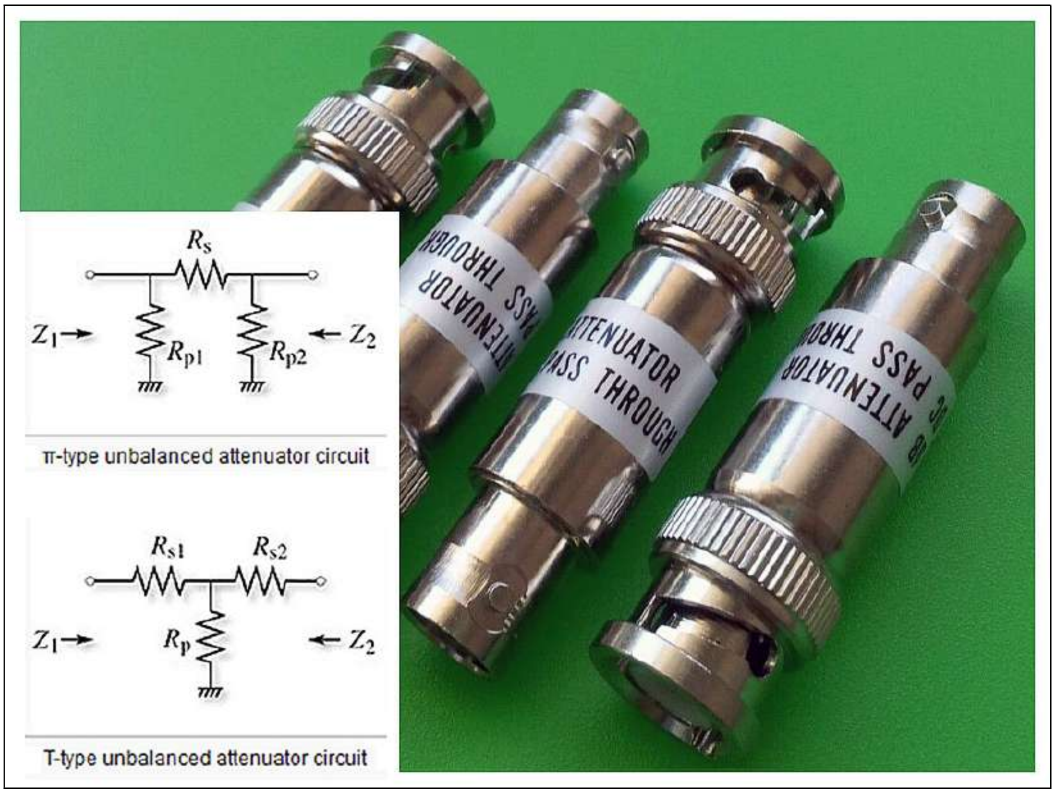
	VDC	I Oven (max) Heat (ma)	I Oven (min) Ready (ma)	Time Oven Ready	OCXO Case Temp ° C	Δ Freq. High (Hz)	Δ Freq. Low (Hz)	Time Freq. Stable	RF Out (mW/dBm)
OFC/McCoy	12	430	80	3m	28	1	-255	3m	9/9.5
ISOTEMP	12	750	200	10m	38	260	-9	15m	6/7.8
GPS Disciplined Clock	12	1300	380	18m	31	3	-250	11m	23/13.6

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.

An OCXO or GPSDO can have either a RF sine wave (what we want for most radio circuits) or a square wave output (good for digital circuits). In the case of the latter, feeding a square wave through a 10 MHz low pass filter (LPF) will produce a decent sine wave albeit with some attenuation. Carol, KP4MD, has a great YouTube video explaining the design and use of a 3-pole [Butterworth type] LPF for this purpose. *Note: Various electronics can accept square wave input signals but the FLEX radios require a sine wave input (or close approximation of one).*



ATTENTUATORS

Sometimes you need to reduce the OCXO or GPSDO output to a certain level, as with my FLEX-1500, which requires a 10 MHz sine wave reference input signal of no more than 10 decibel-milliwatts (10 dBm or 10 dB_{mW}). To do this, you can add a three resistor (Pi or T-pad) attenuator made from 1% precision non-inductive resistors, or use an external resistive step attenuator. I prefer commercial (see above) very precise, single-value attenuators (available from 3 to 20 dB) because they can be quickly swapped in and out of circuits, and they maintain a constant impedance right up to microwave frequencies.

Brian, VE3GEN, also uses attenuators for impedance matching so the OCXO (a very low-power or QRPp transmitter) always “sees” a constant 50-ohm load and maintains a constant RF output (within reason) even if the connected device has a slightly different input impedance (say 75 ohms) and PI-type resistive filters are prefect for this purpose.

MY FINAL

In part 2, we’ll look at some simple OCXO calibration techniques then do a few things with our device.–73

REFERENCES AND RESOURCES

ARRL FMT

http://www.k5cm.com

http://tinyurl.com/hbkpvdw

Crystal Oscillator

http://tinyurl.com/c3mg4mx

KA7OEI OCXO Design

http://tinyurl.com/jl5a7ad

KP4MD 10 MHZ LPF (YouTube Video)

http://tinyurl.com/gruwpzy

RESISTOR ATTENUATOR (PI type)

http://www.chemandy.com/calculators/matching-pi-attenuator-calculator.htm

VA3ROM: All Things Digital

http://tinyurl.com/og2acxq

WWV

https://www.nist.gov/pml/time-and-frequency-division/radio-stations/wwv