VHF/UHF WORLD

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VHF/UHF frequency calibration

Have you ever wondered whether you're really on frequency — especially when you don't hear the station you're scheduling? This is a constant problem for the VHF/UHFer, especially during meteor scatter or EME schedules. Because the focus of this issue is on test equipment, I thought it would be a good time to discuss frequency accuracy and offer some advice on accurately determining frequency. Then I'll describe a secondary frequency standard or calibrator you can build to satisfy most of the needs and pretty much guarantee that you're at least on the frequency you think you're on!

frequency determination

There are several ways to determine frequency. You can:

- read the frequency indicator on the gear in use;
- trust the frequency of the crystal in your up or down converter;
- have a reliable friend measure your transmitted frequency;
- buy or build a good frequency counter; or
- build or buy a good secondary frequency reference standard.

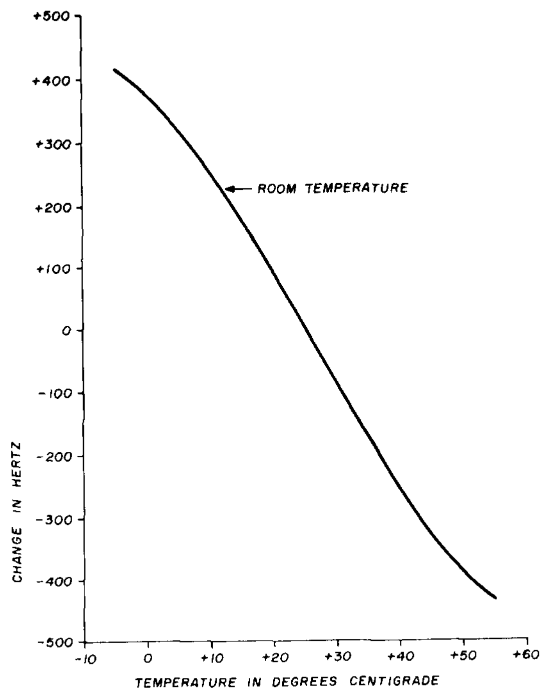


fig. 1. Typical frequency drift versus temperature for a 48-MHz overtone oscillator.

All of the above methods have advantages and disadvantages. While you may laugh at the thought of just reading your dial or frequency indicator, some modern commercial gear transmits CW at an offset frequency that may not be directly indicated.

Recently I tested one of the latest state-of-the-art VHF/UHF multi-mode transceivers complete with a built-in digital frequency readout. To my amazement, the frequency indicated was off by almost 1 kHz in the first 15 minutes; even after an hour the frequency indicated on UHF was off by over 0.5 kHz — admittedly not a serious problem, but one worth examining if frequency accuracy would affect the success of a QSO or the accuracy of measuring someone else's transmitted frequency.

crystal oscillators are used everywhere

All modern converters or transverters use crystal oscillators in one form or other. However, if 1.0 kHz accuracy is required at UHF, the cost of a crystal is prohibitive. Furthermore, the accuracy of the oscillator is also a function of the oscillator circuit and the temperature of the crystal. Some designs use small trimmers to tweak the frequency to the marking on the crystal, but this can have disastrous effects on phase noise, not to mention decreased temperature stability or drift.[1]

All crystals, regardless of price, suffer from a problem called "aging." This means that a crystal will always be drifting slightly away from its marked frequency even after it has been burned in for a predetermined time. (The typical commercial standard is full power for 30 days.)

Suppose a friend measured your

transmitted frequency. Did he or she tune you in properly on SSB? on CW? Was he or she at true zero-beat? Even if the measurement is accurate, how do you account for local ambient temperature changes, aging or drift and component changes in your own gear at a later time and date? How long does it take to properly warm up your gear?

Frequency counters are great, but until recently they were beyond the reach of most Amateurs. Several are now available, but suitable ones use a reference standard and a proportional control oven that takes time to stabilize — perhaps 15-30 minutes — and usually cost about as much as a typical multi-mode transceiver! Furthermore, frequency counters that read higher than 600 MHz are even more expensive.

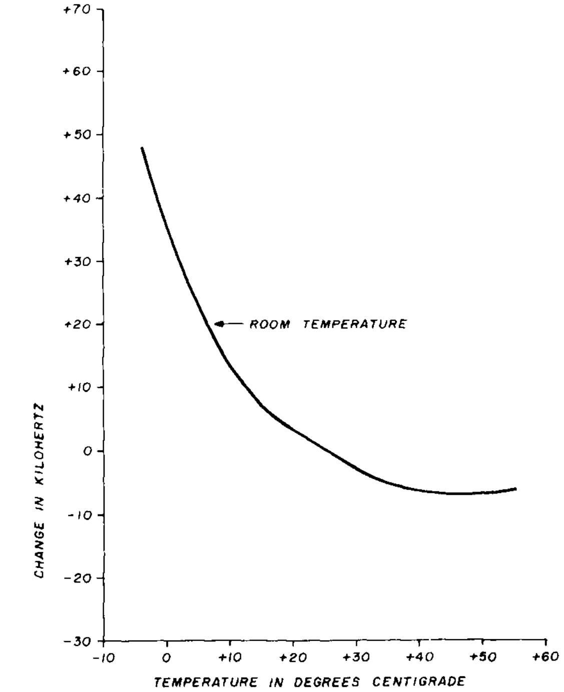


fig. 2. Typical frequency drift versus temperature for a 1.000 MHz secondary frequency standard.

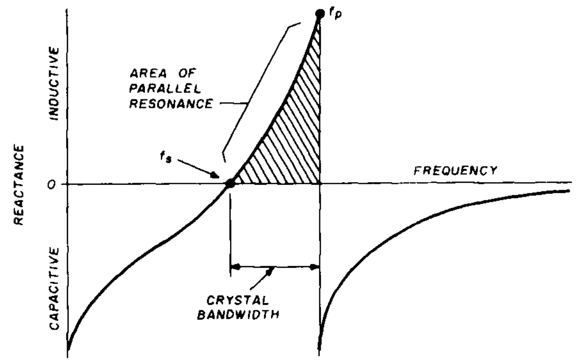


fig. 3. Typical impedance versus frequency variation for a quartz crystal operating in the fundamental mode. "f_s" is the series resonant frequency and "f_p" is the parallel or antiresonant frequency. The typical bandwidth is 5-10 kHz at 4.000 MHz. The parallel resonant frequency can be varied by the use of an external capacitor in series or parallel with the crystal.

there is another way

A good method that seems to have been almost forgotten by the users of modern rigs is the secondary frequency standard or crystal calibrator. If one is available with a comb generator (a device which generates many harmonics of the input frequency), it can be used up through UHF with surprising accuracy.[2]

After evaluating all these alternatives to accurate frequency determination at VHF/UHF frequencies, I decided many years ago that the least expensive and most accurate way to measure my frequency was to build a secondary frequency standard. Before designing one, I listed the features I wanted to include:

- convenient marker frequency in each VHF/UHF band above 6 meters
- good short and long-term stability, 1 to 2 parts per hundred million (0.01-0.02 ppm)
- easy adjustability to the correct frequency
- high harmonic output through 2304 MHz
- battery operation
- fast warmup
- reasonable size, including built-in antenna
- easy construction
- low cost

This is indeed quite a "wish list!" However, after some trial-and-error (over a period of 15 years) such a unit has evolved.

The most important consideration for a secondary standard is crystal stability. First, I tried a third-overtone 48-MHz crystal oscillator. Harmonics were no problem, but stability, the very property I wanted to measure, was no better than the local oscillators in my receiver or transmitter — about 3 to 4 parts in 10 million per degree Centigrade (**fig. 1**). Also, the only usable harmonics were on 144, 432, and 1296 MHz.

Next, a 1.000-MHz calibrator was tried, but proved quite unsatisfactory for several reasons.[2] First, it is difficult to produce sufficient harmonics to reach the lower UHF bands. After all, for 70 cm (432 MHz), that is the 432nd harmonic! Second, and more important, the frequency stability of a good 1-MHz crystal versus temperature is quite poor. I measured such a unit at typically 500 to 600 parts per million per degree Centigrade (see **fig. 2**).

After discussing this with crystal manufacturers I discovered that reasonably priced, stable crystals and oscillators can be designed and built without an oven if you choose an "AT" cut fundamental crystal in the 3 to 10 MHz region (more on this later). 4 MHz was chosen because harmonics would be present on all of the VHF bands above 6 meters, lending itself to easy calibration with WWV on a 20-MHz HF receiver. Later I built a 5-MHz unit to be used on 6 meters and other multiples of 5 MHz.

the circuit you choose is important

Crystals are usually classified as either fundamental or overtone. Because of cost and stability constraints, fundamental crystals are usually used below and overtones above 22 MHz. Each fundamental crystal has two basic resonances, a series and a parallel or anti-resonance. The series resonant frequency is typically a few kHz below the parallel resonant frequency and is very difficult to externally move or adjust. However, the parallel mode resonant frequency can be easily adjusted by placing a capacitor either in parallel or series with the crystal. These characteristics are shown in **fig. 3**. A parallel mode oscillator was chosen for this reason. The Pierce oscillator circuit was first used because it is reputed to be the most stable, but the parasitics of the active device in the oscillator are prominent. Therefore, a modified Colpitts oscillator circuit was later chosen because it was only slightly less stable than the Pierce oscillator, but more easily adjustable, and uses swamping capacitors to minimize the parasitics of the active device.

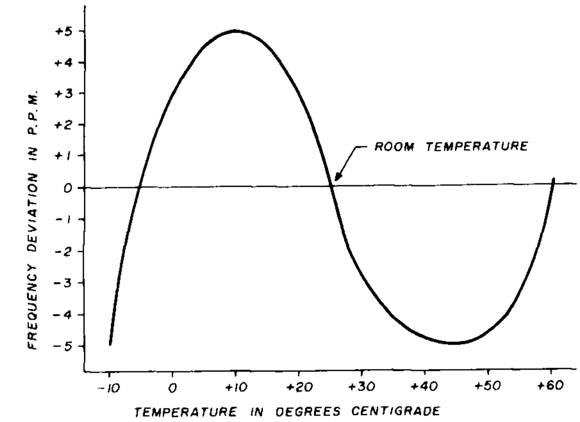


fig. 4. Typical frequency drift versus temperature for an "AT" cut high-accuracy crystal at 4.000 MHz.

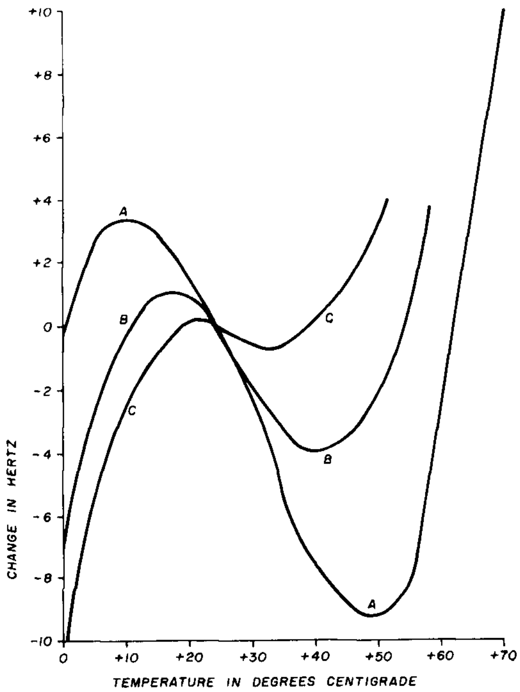
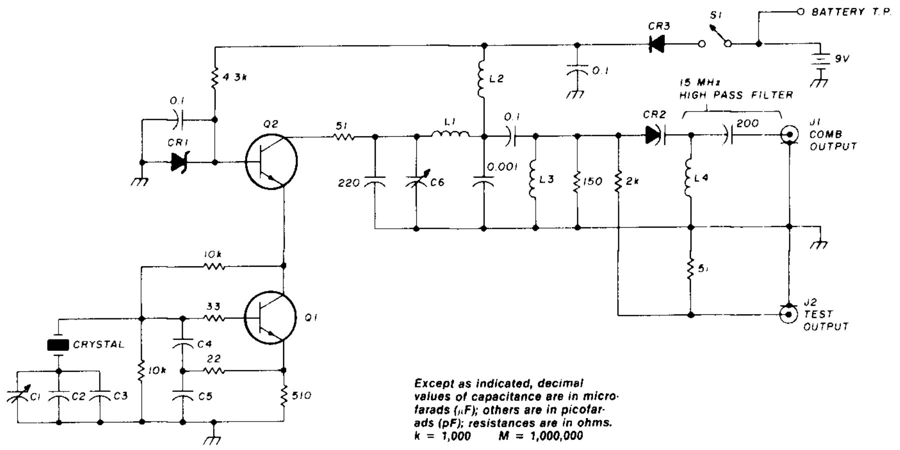


fig. 5. Frequency versus temperature variation of the 4.000 MHz calibrator in fig. 6. For various amounts of temperature compensation "A" is undercompensated while "B" and "C" are optimum versus desired temperature range, toward either cold or hot.

"AT" cut crystals have a known frequency versus temperature characteristic that is "S" shaped (**fig. 4**). Hoff has pointed out that if you want to operate only over a small temperature range such as experienced in most ham shacks, the frequency change is



item	description
C1	1-10 pF air variable capacitor, Johanson 5200 series or equivalent
C2,C3	10 pF N750 ceramic disc capacitor (see text)
C4,C5	390 pF NPO ceramic disc capacitor (see text)
C6	5-50 pF small ceramic or mylar variable capacitor
CR1	4.7 volt zener diode, 1N750 or equivalent
CR2	SRD, Microwave Associates No. MA44310, Hewlett-Packard No. 5082-0180, or equivalent (see text)
CR3	light emitting diode
J1,J2	BNC chassis mounted connector
L1	6.8 μH RF choke
L2,L3	27 μH RF choke
L4	0.47 μH RF choke
Q1,Q2	2N2222 transistor
S1	small toggle switch
crystal	4.000 MHz parallel mode 20 pF crystal (see text)

fig. 6. Schematic diagram for a 4.000 MHz secondary frequency standard.

quite linear and can be decreased over a small temperature range (perhaps 10 to 40 degrees Centigrade) by simply placing a temperature compensating capacitor in series or parallel with the crystal.[3]

Indeed, this is what I did. First an NPO (which has close to zero temperature drift) temperature compensating ceramic disc capacitor (in parallel with a tweaking capacitor) was placed in series with the crystal in an oscillator. Then the frequency versus temperature was measured in a laboratory oven in 5-degree Centigrade steps and the frequency was remotely measured with a good frequency counter having a proportional control oven. The NPO capacitor was then replaced with various combinations of 10 pF N750 type temperature compensating ceramic disc capacitors and data taken again. It soon became obvious that the temperature drift could be minimized by the right choice of temperature compensation. This is illustrated in **fig. 5** for a typical 4.000-MHz crystal oscillator.

now for those harmonics

Now that I had the oscillator working, I tried various schemes to generate a comb of harmonics. Integrated circuits were discarded because they required considerable current and did not extend high enough in frequency. Tunnel diodes were also tried but did not meet the UHF harmonic requirements.[2]

SRDs (step recovery diodes), properly chosen, fit the desired requirements. Furthermore, if used in the proper circuit, they required low RF drive and could generate power through 2304 MHz. Oscillator-multiplier isolation is required so that frequency stability or calibration is not affected by the multiplier or output circuitry. This was accomplished by using a separate amplifier or buffer stage between the oscillator and multiplier.

values are now chosen

Several solid-state devices and circuit configurations were tried. JFETs and MOSFETs were eventually discarded in favor of bipolar transistors since the variation from unit to unit necessitated additional tweaking for proper bias and compensation. An oscillator-amplifier approach was used in the first few calibrators but eventually replaced by a cascade bipolar transistor circuit that provided the required oscillator to multiplier isolation with low power consumption and could be powered by a 9-volt transistor radio type battery.

A schematic of the final circuit is shown in **fig. 6**. The modified Colpitts oscillator uses a bipolar transistor, Q1. The trimmer, C1, should be a high quality air dielectric variable with a multi-turn fine adjustment screw. C2 and C3 are the temperature compensating disc ceramic capacitors. The typical oscillator required 20 pF N750 capacitors and in the extreme case required 20 pF N1500 compensation. The feedback capacitors, C4 and C5, should be NPO-type ceramic disc capacitors. Do not use silver mica capacitors here; they have a positive temperature coefficient that will increase the drift!

Crystal specification is most important. Beware of bargain basement or computer-type crystals. They may be specified for series resonance or have a poor temperature coefficient, which will make it nearly impossible to tune or compensate the calibrator at the desired frequency. International Crystals* sells a "HA" (high accuracy) crystal that should meet the requirements. The price may be higher than you're used to paying for a crystal, but because you'll probably use this secondary reference standard for many years the crystal will pay for itself many times over. Remember to specify the crystal as *parallel* resonant with 20 pF of capacitance. The temperature tolerance should be ±0.0005 percent from −30 to 60 degrees Centigrade. The calibration tolerance can be ±0.0025 percent. Over-specifying the actual calibration frequency is a waste of money because the trimmer will adjust you precisely to zero-beat.

*International Crystals, P.O. Box 26330, Oklahoma City, Oklahoma 73126.

reducing supply voltage dependency

A recent addition to the circuit was a zener diode in the amplifier stage. This provides a good reference voltage to the oscillator over a wide battery voltage range with very little extra power consumption. A standard 9-volt transistor radio type of battery, preferably the longer life type, is all that is required because the current drain is typically 4 to 5 milliamperes. Another recent innovation is the LED (light emitting diode) in series with the battery. This provides a low-power indicator to remind you to turn off the calibrator when not in use. A battery test point is also provided so that you won't have to open the box to measure the battery voltage.

The multiplier circuit also evolved over the years. A simple pi-network matches the amplifier output to the SRD. The SRD chosen should be of the long lifetime type, typically 100 nanoseconds minimum, since 4 MHz is a very low input frequency for many SRD's. Other types of diodes will probably not work well. C6 peaks the circuit, which matches the amplifier to the SRD. The output of the SRD passes through a 15 MHz high-pass filter, suppressing the fundamental frequency of the comb output. Therefore a calibrator output circuit was added in case you desire to measure frequency directly (such as with a frequency counter) at 4.000 MHz. The typical comb generator output power versus frequency curve is shown in **fig. 7**.

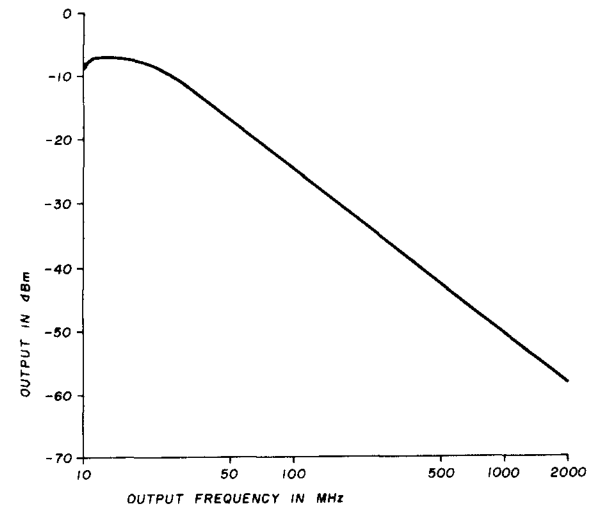


fig. 7. Typical output power versus frequency from a secondary frequency standard comb generator.

construction

The entire circuit including battery can be built *on the cover* of a Pomona model 2901 or equivalent cast box. First a double-clad printed circuit board about 1-7/8 × 3 inches (48 × 76 mm) is attached to the cover of the box and held in place by the output connectors, switch, trimming capacitor, and LED. A suitable battery clip is mounted on the remaining available space on the box cover. Two insulated standoff terminals are used to hold the crystal leads and associated temperature compensation capacitors. The wiring is done point-to-point in space, as suggested in previous articles.[1]

initial testing and calibration

If you don't want to go through the temperature calibration procedure described, just use 10 pF N750 capacitors for C2 and C3 and you should be very close. A small 2-meter quarter-wave pull-up type whip makes a suitable radiating antenna for the entire spectrum of interest. The calibrator is now ready for testing. This can be easily done by listening for the 7th harmonic on a 28-MHz HF receiver (the signal may not be strong at this frequency) or the 36th harmonic at 144 MHz on a 2-meter receiver. First peak C6 for maximum output on a 2-meter or higher receiver. Next, vary the calibration trimmer, C1, and check that the frequency varies a few hundred Hertz and that it is approximately correct. If the frequency is too low, either C2 or C3 will have to be decreased by perhaps 5 pF.

To verify adequate temperature compensation, you'll have to measure the output, preferably with an accurate frequency counter, or zero-beat it with WWV at 20 MHz using a suitable HF receiver. The entire circuit can then be placed in a refrigerator, (typically about 41 degrees Fahrenheit or 5 degrees Centigrade). Measure the frequency after it's been in the refrigerator for 15 to 30 minutes. Compare the reading to the one made earlier at room temperature. After a few tries, you will see if the calibration is adequate. If the temperature drift when the calibrator is cold causes the frequency to go *below* the room reference frequency, too much compensation is being used, and vice versa. (See **fig. 5** for further information.) Also, whenever you change a capacitor, allow at least 15 minutes for its temperature to stabilize before taking data.

Zero-beating to WWV can be tricky. It's best to move the calibrator around the room until the proper amount of injection is experienced. Also try to zero-beat during the interval when the tones are not present (usually the last 15 seconds of each minute). Watching the "S" meter can be quite helpful. When close to zero-beat, the meter will waiver noticeably and the beat will sound like a chirping canary. When the meter moves once per second, *you are within 1 Hertz* of the correct frequency. One beat every 15 to 30 seconds is very satisfactory. Be aware that because of atmospheric effects the accuracy of WWV on the HF spectrum is good only to about 1 part per hundred million. However, this should be

short circuit

VHF/UHF World

A chart in **fig. 9** (page 88) of W1JR's "VHF/UHF World" column in April, 1984, made reference to "Note 1." Unfortunately, Note 1 was not included at the bottom of the figure, as the author intended. Note 1 should read, "Not used on this frequency."

more than sufficient for Amateur work.

using the calibrator

At first, it will be worthwhile to test the accuracy of the calibrator several times during the first few months of operation because some aging will inevitably occur. This will also let you develop confidence in its use. After initial burn-in, I usually test calibration against WWV about once a year. One caution is advised: *Do not place the calibrator where it will be subjected to temperature variations such as on top of another piece of electronic gear.* I usually place mine on a table or desk one or two meters away from the receiver in use. This yields more than adequate injection even at 2304 MHz. Typical warmup is 15 seconds. To conserve battery life, don't forget to turn the calibrator off when not in use!

summary

Even though the state-of-the-art in accurate frequency determination has advanced significantly in recent years, a secondary frequency standard is still useful for verification of true frequency. The calibrator just described is easy to construct and adjust, relatively inexpensive, very stable, and portable. I now have six of these units operating on different frequencies and always carry one along on expeditions. Once you have one, you'll never want to be without it.

references

1. Joe Reisert, W1JR, "VHF/UHF World: VHF/UHF Receivers," *ham radio*, March, 1984, page 46.
2. Mike Metcalf, W7UDM, "A VHF-UHF Marker Generator," *VHFer Magazine*, May, 1965, page 3.
3. Irvin M. Hoff, W6FFC, "The Mainline FS-1 Secondary Frequency Standard," *QST*, November, 1968, page 34.

VHF/UHF coming events

October 6: *Mid-Atlantic States VHF Conference, Warrington, Pennsylvania. (Contact W3CCX for information.)*
October 6-7: *International Region I UHF/SHF Contest. (Contact RSGB for information.)*
October 20 and 21: *ARRL International EME Contest* (second weekend).
October 20: *Predicted peak of Orionids Meteor Shower at 0515 UTC*
October 24: *EME Perigee*

ham radio