A Measurement of Frequency Accuracy and Doppler of the QO-100 Satellite Transponder and Beacon

Andy Talbot G4JNT   6 April 2019

I wanted to know, once-and-for-all, what sort of frequency uncertainty can be expected though this transponder, and how much the beacon can be relied on.   So a fully locked receiving system and uplink test signal were used.

Receive System

This starts with a Dual Octagon LNB modified for external 27MHz reference. This comes from a VCXO locked to a master 10MHz reference using an MC145170 synthesizer chip.

739MHz IF from the LNB (with the known and previously calibrated and independently verified 50Hz offset removed) is converted to 28MHz using a U2794 quadrature downconverter chip and LMX2541 fractional-N synthesizer clocked from the 10MHz reference. Taking the known 50Hz offset into account, the LO is 711.000050MHz

The 2nd IF from the mixer goes to an Elad FDM-Duo tuned to 28.549MHz. The net result is that a beacon on 10489.55MHz should come out as a tone frequency of 1000.0Hz and the local reference uplink at a tone of 3500.0Hz

Reference Uplink

An ADF4351 Synthesizer locked to the same 10MHz reference generates 2400.0525MHz so it appears 2.5kHz above the nominal beacon frequency. This feeds a 0.8 Watt amplifier going to a 30 turn helix antenna, approximately 18dBiC, located indoors and looking at the satellite though a closed window.   The received downlink from this was 26dB down on the beacon signal

Master Frequency Reference

The master 10MHz reference comes from a HP5061 Caesium frequency standard with the Cs beam turned on an hour before the 24 hour measurement period was started.   A timing comparison of this reference divided down to 1 Hz against the 1 PPS signal from a GPS receiver was used to confirm the Cs accuracy.   Timing shift of the two 1 PPS signals was less than the 100us of timing measurement resolution and meant that over the 24 hour period there was certainly no more than 10^{-12} mean frequency error on the 10MHz reference.

Measurement System

The two tones from the receiver, the beacon on nominally 1kHz and the local reference at 3.5kHz, were fed to two instances of *SignalToNoiseMon.exe*, each tuned to one of the two tones. Both were set to 12kHz sampling, FFT size 64K and 43 seconds averaging. Frequency measurements of the two tones to a resolution of 0.18Hz were stored approximately every two minutes for the 24 hour monitoring period.   Although the exact timing of each two minute period was asynchronous between the two instances of the software, the resulting epochs were never more than 90 seconds apart, so differential drift between the two due to measurement time offset is insignificant

Results

Figure 1 shows the absolute received tone frequency of the beacon and that of the local reference after subtracting the 2.5kHz fixed offset.

There is clearly a cyclic variation due to Doppler of around 50Hz peak-to-peak.

The mean is around 1100Hz and as this offset can be seen equally on both beacon and local reference uplink, it means the satellite LO is 100Hz high at this time (5 April 2019

(*This absolute frequency error does assume the 50Hz offset in the Octagon LNB local oscillator, discovered recently and confirmed independently, is EXACTLY 50Hz*)

Figure 2 shows the difference between the two received tones with the 2.5kHz offset removed. With a tone frequency measurement uncertainty of 0.18Hz a massive granularity in this measurement can be seen in the green points on the plot. Excel's trendline tool was used to add a 6th order polynomial trendline to this differential tone measurement. This appears as the smoothed black line.

There is a mean difference of approximately 2Hz between the received and corrected uplink tone and the beacon. Until known otherwise, this has to be assumed to be in the uplink frequency accuracy. A 2Hz error at 10GHz, (0.2 parts per billion) is considerably in excess of what the HP5061 caesium reference is capable of (even without local magnetic field compensation) and tests described earlier suggest less than 10^{-12}. A 0.2 PPB error is probably beyond what might be expected if the beacon were generated from a good quality ovened oscillator, but is typical of the absolute accuracy of a rubidium source that has not been recently calibrated.

Looking at the trend line, there a cyclic difference between the two signals in the order of 0.26Hz which is possibly due to the differential Doppler introduced by the separation of the two uplinks, in Germany and the South Coast of the UK. The value needs to be taken with care as this 0.26Hz is an average of many measurements, each made with an instantaneous measurement uncertainty of the same order as this averaged value.

One other residual source of frequency error (absolute) is the Elad-FDM duo that uses a Numerically Controlled Oscillator as its LO. This introduces a systematic frequency setting uncertainty of up to 0.016Hz

Short term variations with durations of tens of minutes, visible on the curves and common to both signals cannot be accounted for; possibly they could be PLL locking glitches in the HP5061 reference source, or propagation anomalies.

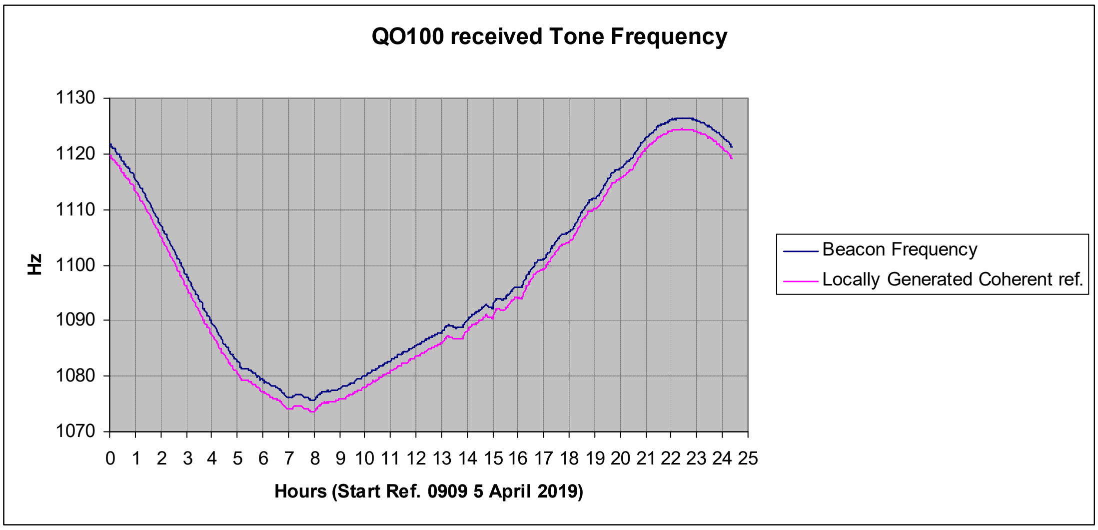

Figure 1 - Measured Tone Frequencies, corrected for the 2.5kHz offset

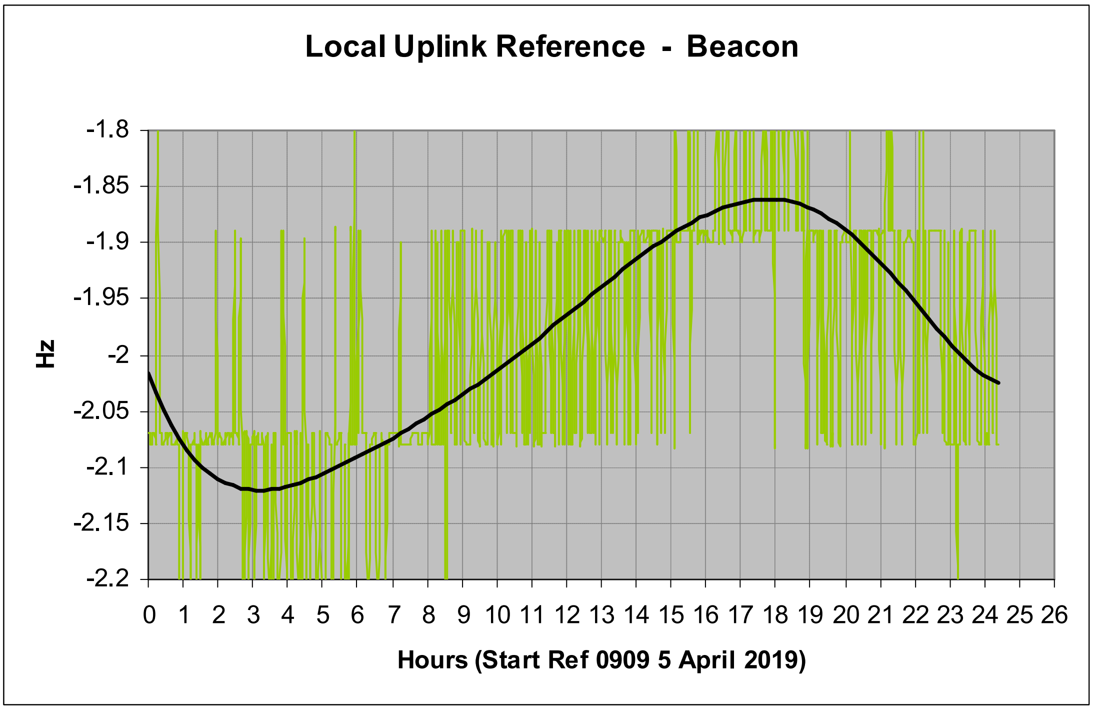

Figure 2 - Difference between the two received tones, corrected for the 2.5kHz offset. (6^{th} order trendline)

Tests Using the BATC Goonhilly Web SDR

A set of measurements on the beacon frequency using the same system were made a few days earlier and the results can be seen in Figure 3. This has about the same start time, around 09:00a, as the later plot where a similar tone frequency and drift can be seen.

While this was underway, a similar recording was made using audio from the Web SDR tuned arbitrarily. Audio was looped-around to the mic input of a laptop for the *SigToNoiseMon* software.

Figure 4 shows the results where the short term wobble due to the GPSDO controlling the WebSDR is clearly visible as random frequency shifts of several Hz spread over tens of minutes. This is normal behaviour for the frequency stability characteristics of a typical GPSDO.

A 6^{th} order polynomial trendline is shown by the black line. This plot mirrors very closely the corresponding interval in the local measurement and suggests most frequency measurement tests on the satellite transponder could be made using the Web SDR or a GPSDO source for locally frequency locked measurements, provided a reliable averaging, such as a trendline, is applied to the results and they are taken over a long-enough period.

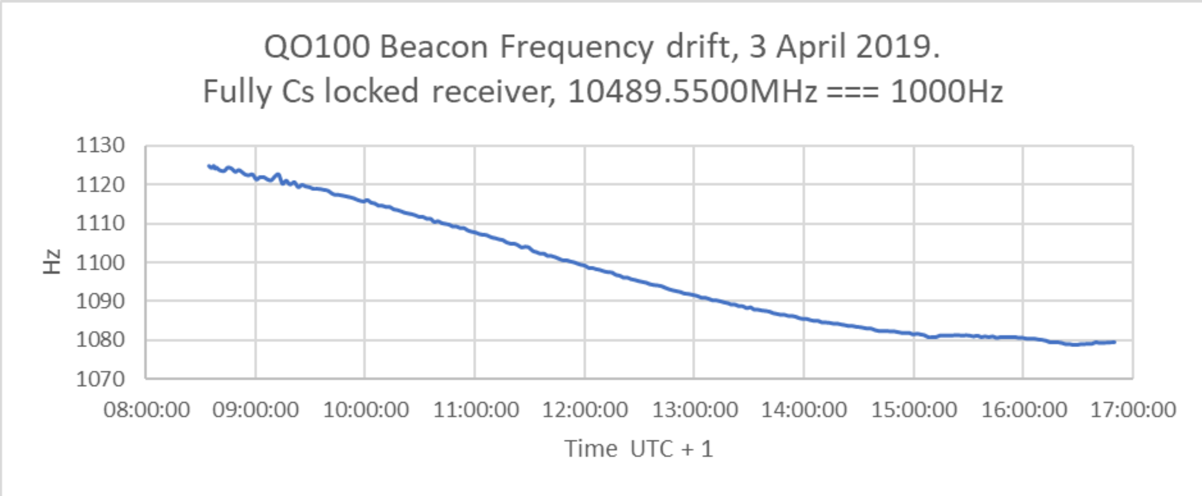

Figure 3 Earlier Test using the locked receiver system.

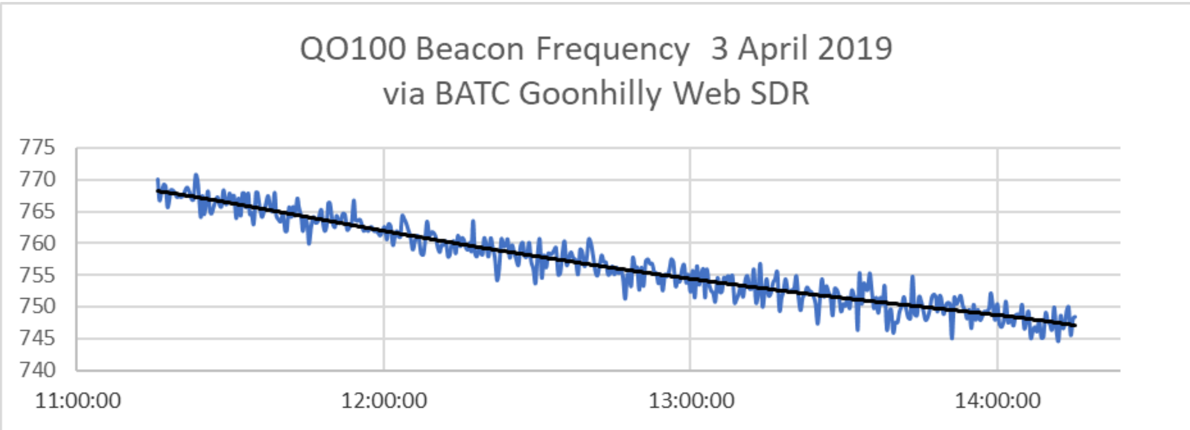

Figure 4   Frequency Measurement of the CW Beacon frequency using the BATC Web SDR