AN001

Frequency drift reduction in the Ultimate3S transmitter

1. Long-term vs short-term frequency drift

Mid- to long-term over the course of hours or days, is frequency drift usually caused primarily by environmental temperature changes. This could be the temperature change between day and night, or seasonal temperature changes. This type of drift can be eliminated in the Ultimate3S kit by the use of a GPS receiver with 1pps output such as the QRP Labs QLG1 GPS receiver kit. The Ultimate3S transmission sequence is configured such that there is a pause in transmissions at the end of each cycle, during which the GPS 1pps is used to measure the reference frequency of the Si5351A Synthesiser (27MHz crystal) and compute a correction in software. It will not be discussed further in this document.

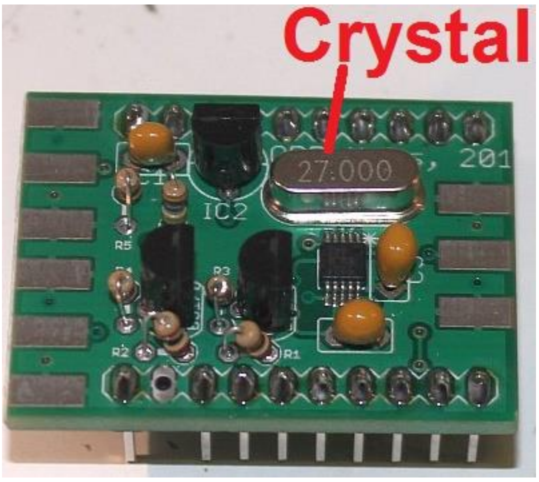
Short-term drift is the frequency change during a transmission itself. It is a frequent misunderstanding that a connected GPS unit should prevent this frequency drift during the transmission. However the Ultimate3S does not use the optional GPS to measure frequency during transmission, since the presence of strong RF may interfere with the GPS reception or may create noise on the 1pps signal that may corrupt the measurements. Short-term frequency drift is therefore NOT solved by connection of a GPS receiver to the Ultimate3S.

2. Causes of short-term frequency drift

There are three potential causes of frequency drift.

1) Frequency drift at the transmitter (the Ultimate3S)
2) Frequency drift at the receiving station
3) Propagation effects in the path, such as ionospheric Doppler effect as the height of the reflective layers of the ionosphere change rapidly at certain times of day, or ionospheric dispersion effects

All three causes of drift are commonly seen, but only the first one is within the Ultimate3S' operator's power to improve.



Frequency drift in the transmitter occurs in the RF source, in this case the Si5351A Synthesiser kit. It is caused by a combination of components whose value changes with temperature, and temperature changes to actually cause that value change. Power supply voltage changes can also cause the oscillation frequency to change. The 27MHz reference oscillator drift is the critical part of this synthesiser since the Si5351A PLL output is locked to this reference.

Many people think of the 27MHz quartz crystal as the only important component whose value has temperature sensitivity. In fact this is not the case. The oscillator is made up of both the resonant component (the quartz crystal), and active amplification and biasing components within the Si5351A chip itself. These internal components also have temperature sensitivity and can alter the oscillator frequency. Therefore improving drift requires consideration of all these sources of drift.

3. Transmitter frequency and the importance of drift

It is particularly important to understand that the issue of drift is directly related to the transmitter frequency. This is because drift acts as a percentage of the oscillator frequency. It is often expressed in parts per million (ppm) or parts per billion (ppb).

If the 27MHz reference drifts by 2Hz during a transmission, a 20m band (14MHz) transmission will actually drift by a little over 1Hz. The transmitter frequency is a little over half the 27MHz reference frequency and therefore the drift will proportionately be a little over half the drift of the 27MHz reference frequency. If the output frequency is changed to the 40m band, now the same drift will cause a 0.5Hz drift in the transmitter frequency.

In this way it can be seen that the higher the frequency, the more important it is to reduce frequency drift. If no action is taken the drift during a transmission may be 4Hz on 10m band which can be enough to prevent WSPR mode decodes (for example); and proportionately even worse at the higher bands 6m, 4m and 2m. The same drift on 160m will be ¼ Hz approximately, which will hardly be noticeable. Everything gets more difficult in regard to frequency drift, the higher frequency you choose for transmission!

4. How much drift is acceptable?

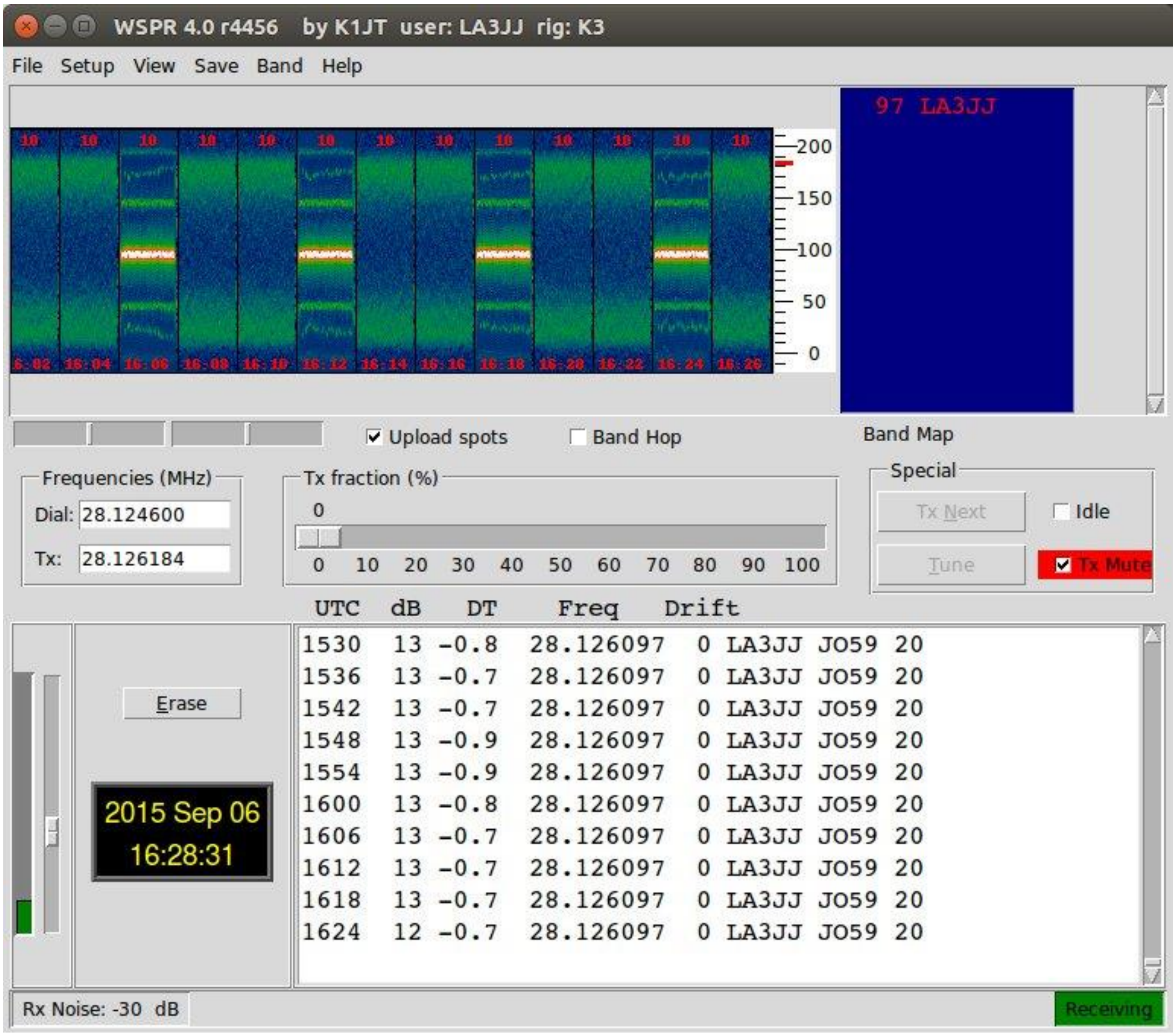
The answer to this question depends on your application for the Ultimate3S transmitter, the mode you are transmitting, and many other factors. But let us discuss the WSPR mode (Weak Signal Propagation Reporter). WSPR transmissions on HF consist of 162 symbols, each of which is transmitted for 0.68 seconds and consists of one of 4 tones. The 4 tones are spaced 1.46Hz apart resulting in a signal with 6Hz bandwidth. The transmission lasts 110.5 seconds (almost 2 minutes).

The receiving station runs WSPR decoding software on a computer, which applies Digital Signal Processing (DSP) to the received audio, searching for the weak signals of distant WSPR transmitters. This software is capable of correctly decoding signals with a drift of up to 4Hz (up or down) during the transmission. However the drift model applied is a linear straight-line drift from start to finish. Any deviation from this will result in missed symbols; the system includes Forward Error Correction and so missed symbols can be tolerated, but it does reduce the probability of successful decoding.

The amount of drift is reported by the receiving station into the internet database at http://wsprnet.org. Transmitting WSPR is an ideal way to work on improving (reducing) your transmitter drift because you can easily check on http://wsprnet.org how much drift is beingreported. Although as mentioned previously, there are other factors (receiving station drift, ionospheric effects), the data on average will still give you a very good idea of your transmitter drift. The reported number is the amount of Hz of drift during the 2 minute WSPR transmission.

Where WSPR drifts of 3 or 4Hz are reported, you can expect that the number of successful decodes your station is getting is being impaired by your transmitter drift. By taking simple measures to reduce your transmitter drift you will be able to increase the number of reception reports received.

Below: perfect 0Hz drift WSPR transmissions by Jon Ove LA3JJ, after applying drift-taming techniques described below. Here Jon Ove is receiving his own strong transmission locally, but on-air reception reports are also a useful indication of how well your transmitter is performing.



5. Six ways to reduce drift

These are some remedial actions that will reduce the frequency drift of your Ultimate3S transmitter if it is found to be a problem (most likely on higher frequency HF bands, and VHF). The last of these is to use the QRP Labs 27MHz OCXO/Synth kit which is plug-in compatible with the basic Si5351A Synth kit; however this should not be necessary to obtain excellent results.

When most of these steps have been implemented correctly, the WSPR drift reports on the 10m band should on average be 0Hz. Even on 2m band (144-6MHz) people have reported 0Hz WSPR drift using their Ultimate3S transmitter.

Many of the measures listed below are based on the work of Jon Ove LA3JJ and have since been repeated by many radio amateurs around the world.

a) Use a good power supply!

The above exclamation mark "!" is included because poor power supplies are the number 1 cause of problems with the Ultimate3S kits! A good stable power supply is very important! Many operators have tried to use cheap 5V USB cellphone chargers. Often these use a very minimalist (also known as CHEAP) switch mode regulator circuit. For charging a phone battery, that is fine. But any voltage glitches can convert to frequency drift. If the supply voltage drops significantly when the transmission starts, due to the extra load caused by the Power Amplifier (BS170 transistor), then this can also cause drift.

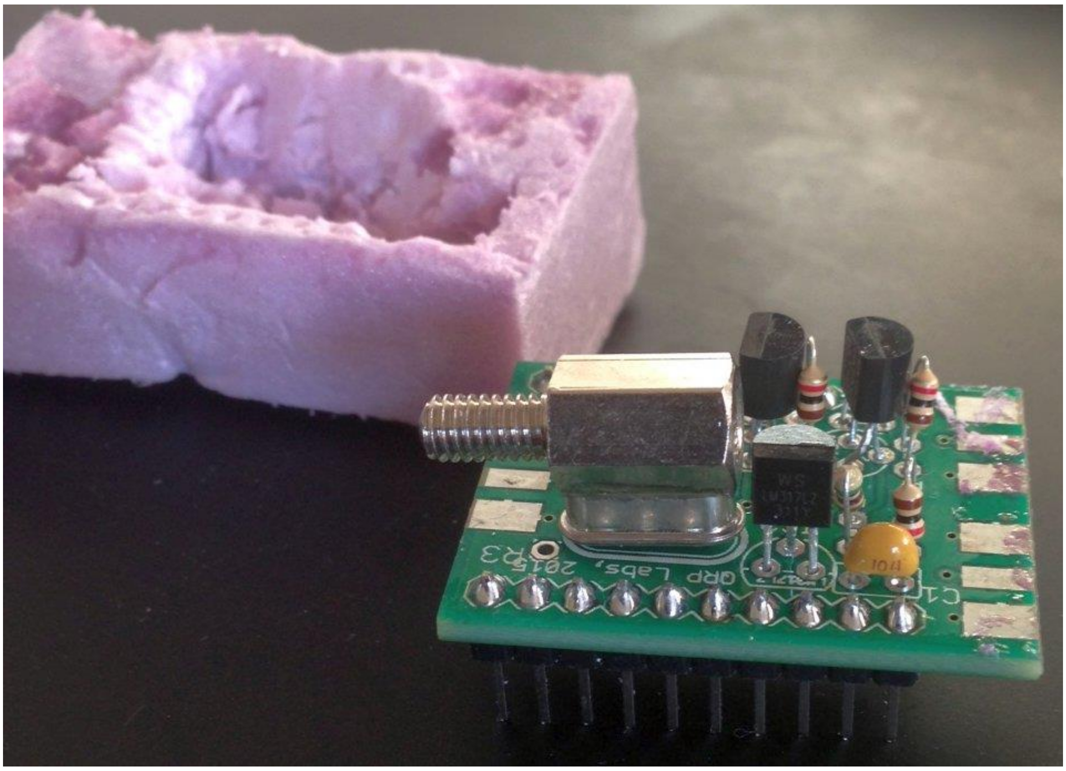
Therefore use a good power supply! The meaning of "good" is a little hard to define precisely in this context. Even expensive bench (laboratory) variable power supplies can have voltage glitches or sags. So it is not even safe to assume that spending lots of money is the answer. In general it seems that linear regulators are less problematic than switched mode regulators. Many constructors have obtained good results with a basic 3-terminal 7805 linear regulator, with appropriate electrolytic capacitors at the input and output of the regulator.

b) Apply a heat sink to the crystal

A heat sink on the 27MHz reference crystal will slow down the temperature changes in the crystal enclosure. Many suitable heatsinks can be salvaged, it is not necessary to use anything purpose-made. Jon Ove LA3JJ used a metal hex spacer, on its side, glued to the top of the crystal. Good results were obtained at QRP Labs HQ using a small TO-220 style heatsink, strapped on to the crystal with a rubber band.

c) Install thermal insulation around the crystal

Thermal insulation around the crystal helps in several ways. Firstly it helps to keep air currents away from the crystal, which would be capable of slightly altering its temperature. Secondly the PA transistor (BS170) may heat up considerably during the transmission; putting some insulation around the crystal will prevent this heat from reaching the crystal and changing its oscillation frequency.



Jon Ove carved out a piece of foam to fit over the top of the Si5351A board. But good results can even be obtained simply by installing the Ultimate3S unto an enclosure such as the standard QRP Labs enclosure. That is sufficient to keep air currents away and greatly reduces the drift. But for sure, Jon Ove's solution is more thorough and elegant.

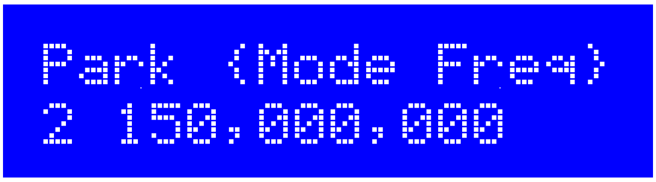
d) Use the firmware "Park" features

This solution is implemented in the firmware of the Ultimate3S microcontroller itself. It attacks the temperature-induced drift of the other components in the oscillator circuit, which are the internal components within the Si5351A chip itself. The Si5351A component is 3 x 3mm. Within that 3 x 3mm blob of plastic is an even tinier slab of silicon. When that slab of silicon is producing oscillations it consumes more power than when it is sitting idle. Consuming more power is another way of saying, dissipating more power – which is dissipated as heat, raising the temperature of the chip, and contributing to drift. The power consumption is higher when the frequency is higher, too. Using the output stages or driving a load will also increase the power dissipation.

Whilst it is difficult to know or predict how all of these factors interact, it is easy to conclude from observations that the self-heating of the Si5351A chip is a significant factor in the drift of the 27MHz reference oscillator.

The "Park" feature of the firmware was introduced in the Ultimate3 which used the AD9850 DDS module, for much the same reasons. In the Ultimate3S, it provides a way to configure the unused Clk1 output of the Si5351A so that the chip is kept artificially "busy" during key-up. Then when the transmitter is switched on (key-down) the current consumption of the Si5351A will hopefully not change much, which means the temperature won't change, and there won't be any frequency drift.

The different modes of operation of this feature ("Park Modes") are described in the Ultimate3S Operating manual. The default is mode 0, which sets the Clk1 output to the same frequency as the transmit frequency (of the next transmission). But since the Clk1 output is not connected to anything, there is no load. So the Si5351A current consumption won't be as high as the actual transmission, when Clk0 is driving the PA input. Therefore operating Clk1 at a higher frequency than the transmit frequency is useful. A higher frequency will compensate for the fact that Clk1 isn't driving anything.



Park Mode 2 is most effective because it allows you to set the Clk1 output to a fixed frequency of your choice during key-up. Start with 150MHz, for example. Observe the drift before and after this change. If the direction of the drift is reversed, then you will know that you have OVER-compensated the drift; in this case you can experiment with lower Park Frequencies e.g. 100MHz.

e) Re-order the transmission bands

There is some evidence and experience that suggests that the order of bands transmitted can have an effect on drift reports. This applies of course, only when you are transmitting a sequence of multiple different bands using the optional 6-band relay-switched filter kit. Starting with the highest frequency band first, then stepping gradually down towards the lower frequency end, seems to produce lower drift. But this is something that will require experiment in your particular situation.

f) Install the OCXO/Si5351A Synth kit

As mentioned previously, it should be possible to eliminate drift using the techniques described in a) to e). It should not be necessary to go to all the effort of using the OCXO kit. Nevertheless there are some constructors who enjoy the challenge provided by the construction of this kit. It cannot be denied that an OCXO reference is the ultimate absolute solution to the problem of drift. When using the correctly built and adjusted OCXO kit, beat against the laboratory 10MHz frequency reference, the drift is not detectable in Argo (see below) which has 0.01Hz frequency resolution. This means less than 0.01Hz of drift in the 2 minutes.