µBITX Calibration

WV3S

Generating a frequency in the Si5351 clock generator requires setting three variables: the voltage controlled oscillator (VCO) multiplier, the primary divisor of the VCO's frequency, and an output divisor.

$$f_{out} = \frac{35 f_{xtal}}{multisynth\ \ R}$$

Where f_{xtal} is the frequency of the crystal and 35 f_{xtal} gives the voltage controlled oscillator frequency, f_{vco}, *multisynth* is the primary frequency divider, and *R* is the optional output stage divider, used to get frequencies below approximately 1 MHz.

The first step is to set the VCO frequency, f_{vco}. The VCO frequency is set by multiplying the crystal frequency by a multiplier, in the case of the uBITX software, 35. With a 25 MHz nominal crystal frequency and a multiplier of 35, the nominal VCO frequency is 875 MHz. Crystal errors are also multiplied by this same amount. This multiplier is set via software by programming three registers. See the si5351 datasheet for more information.

$$f_{vco} = 25MHz(35)$$

The output frequency, f_{out}, is set by dividing f_{vco} by the factor *multisynth*

$$f_{out} = \frac{f_{vco}}{multisynth\ R}$$

where *multisynth* is programmed into the Si5351 in a similar fashion as above and because we are generating frequencies above 1 MHz, *R* is set to unity.

In the software, *multisynth* is calculated by dividing f_{vco} by the desired output frequency f_{out}

$$multisynth = \frac{f_{vco}}{f_{out}}$$

where f_{out} is also the display frequency. Note that the software shipped with the radio adds a sidetone frequency to the actual transmitted frequency which means the transmitted frequency is different from the display frequency by the sidetone frequency.

Any crystal inaccuracy – error – propagates through the system as follows.

Let f_{outD} be the desired output frequency. This is the display frequency and should be the frequency sent to the si5351 frequency routines.

Let f_{vco} be the VCO frequency, nominally 875 MHz.

Let f_{oute} be the output error.

Let f_{out} be the actual output frequency. $f_{out} = f_{outD} + f_{oute}$.

Let e be the crystal error such that $f_{xtal} = f_{xtal\_nom} + e$.

The calculated divisor in the software is *multisynth*.

$$f_{outD} = \frac{f_{vco}}{multisynth}$$

Multisynth is calculated in software by

$$multisynth = \frac{f_{vco}}{f_{outD}}$$

From the above,

$$f_{outD} + f_{oute} = \frac{35(f_{\text{xtal\_nom}} + e)}{multisynth}$$

which can be expanded

$$\begin{aligned}
f_{outD} + f_{oute} &= \frac{35\left(f_{xtal_nom} + e\right)}{multisynth} \\
\left(f_{outD} + f_{oute}\right) multisynth &= f_{vco} + 35e \\
\left(f_{outD} + f_{oute}\right) multisynth - f_{vco} &= 35e \\
\frac{1}{35}\left[\left(f_{outD} + f_{oute}\right)\frac{f_{vco}}{f_{vcoD}} - f_{vco}\right] &= e \\
\frac{1}{35}\left[f_{actual}\frac{875MHz}{f_{vcoD}(MHz)} - 875MHz\right] &= e
\end{aligned}$$

For example, if the display reads 7.200000 MHz and the radio transmits 7.201170 as measured using a modern digital receiver and fldigi,

$$\begin{aligned}
e &= \frac{1}{35}\left[f_{actual}\frac{875MHz}{f_{vcoD}(MHz)} - 875{,}000{,}000\right] \\
&= \frac{1}{35}\left[7201170\frac{875MHz}{7.2MHz} - 875{,}000{,}000\right] \\
&= 4062.5
\end{aligned}$$

The error in this example is +4062 Hz.

The calculated error reflects the different between the assumed crystal value of 25.000000 MHz and the actual crystal value. To correct the assumed crystal value, the assumed value must be adjusted by the calculated error. Once the software has the correct value of the crystal, all further calculations are accurate.

The line in file ubitx_si5351.ino (near line 114)

```
si5351bx_vcoa = (SI5351BX_XTAL * SI5351BX_MSA) + MASTER_CAL;
```

should be changed to

```
si5351bx_vcoa = ((SI5351BX_XTAL + MASTER_CAL) * SI5351BX_MSA);
```

To the best of my knowledge, changing this line in the original code, without other modifications, will not correctly calibrate the device given that the calibration is pulled from EEPROM each time the radio boots; you need to change the stored number.

It is best to measure calibration numbers in the 10 meter band.

For example, KE3FL's radio, with software from WV3S and calibrations set to zero, in the 10-m band, transmitted at 28,255,540 Hz when the display showed 28,250,000 Hz.

$$\begin{aligned} e &= \frac{1}{35}\left[f_{actual} \frac{875MHz}{f_{vcoD}(MHz)} - 875{,}000{,}000 \right] \\ &= \frac{1}{35}\left[28255540 \frac{875MHz}{28.25MHz} - 875{,}000{,}000 \right] \\ &= 4902.65 \\ &\Rightarrow 4903 \end{aligned}$$

The error due to the integer nature of the calibration factor, itself simply a reflection of the software encoding the number as a LONG[1], is calculated by finding the frequency error if the calibration factor is off by 1.

At 1.6 MHz, *multisynth* = 546.875 and at 30 MHz, *multisynth* = 29.1667. The error for Δcal = 1 at 1.6 MHz is 0.064 Hz and at 30 MHz the error is 1.2 Hz. The radio tunes in 50 Hz increments so this is an acceptable error.

[1] This may change in subsequent versions of my software.