T41 IQ Calibration Directions

Several functions of the T41 require calibration at the outset before putting the radio into service. More robust calibration routines are now included in the latest T41 software for the V12.6 hardware. These include calibration of several key parameters:

- Frequency
- CW transmit power
- SSB transmit power
- Receive IQ calibration and
- Transmit IQ calibration.

Some external measuring devices or sources may be required for the best results, including

- Standard RF frequency source or reception of WWV or CHU, etc.
- External HF receiver or spectrum analyzer
- RF power meter

Since calibration does not have to be done frequently, the user may elect to borrow or share these resources with other amateurs.

Naturally, the quality of the calibration results depends on the accuracy of the standard measuring device or source.

Frequency Calibration

Frequency calibration of the T41 local oscillator (LO) requires an external RF frequency standard source such as WWV or a calibrated signal generator or a standalone source such as a Rubidium Frequency standard. The resulting T41 frequency accuracy is dependent on the accuracy of the source. WWV (or others) is best if a strong signal is available on one of the several standard frequencies.

V12 T41 RF board has the option of using a TCXO (Temperature Controlled Crystal Oscillator). It is important to make sure that the Si5351 reference is *either* a TCXO or a 25MHz crystal – *not both*. Having both will yield a situation in which the unit cannot be calibrated.

Note on using WWV or other HF standard broadcasts:

WWV broadcasts on several frequencies in the US, such as 5MHz, 10MHz and 15MHz. Outside the US other frequencies are available. These stations transmit a variety of information, such as one minute tics and spoken information. Periodically the one second tics are turned off and only the standard carrier is transmitted. This is the best time to make final adjustments. Patience is also required for best results.

The suggested WWV process is as follows:

- Tune to the strongest WWV (or other) signal.
- Set Filter to 1KHz or less.
- Select SAM demodulation *prior* to starting the frequency Cal routine
- Manually tune for the lowest error during the regular broadcast.
- When the error is close to 0.0, use the Auto Tune function to complete the process. With crystal Si5351 reference (no TCXO), several Auto adjustment cycles may be necessary.

Frequency Calibration details

The T41 Frequency Calibration routines provide tools to allow the LO calibration to be adjusted as closely as possible to the selected frequency standard. These tools utilize a demodulation function called SAM – Synchronous Amplitude Modulation. The routine compares the internal LO frequency to the receive frequency and displays the difference in Hz. This approach appears to be accurate to better than 1Hz during routine T41 use. In fact, with the optional TCXO, the SAM function in the frequency calibration routines appears to allow setting the T41 LO to better than 0.1Hz. A linear regression process is used to determine the best Frequency Correction Factor for either crystal or TCXO reference.

The frequency calibration tools include the following:

- Display of the current Si5351 correction factor and the calibration difference in Hz.
- Manual adjustment of the Si5351 correction factor using the Filter encoder to change the correction factor.
- Auto calculation to the best correction uses linear regression. The Si5351 frequency is a linear function of the correction factor. The zero error point is found by varying the applied correction value measuring

the frequency error and then creating a linear regression trend equation to predict the zero error correction factor value.

- Plot of Frequency difference vs. correction factor created by:
    - Automatically varying the Correction Factor and computing the best value for minimum error, using a linear regression routine. Figure 1 shows the calibration plot.

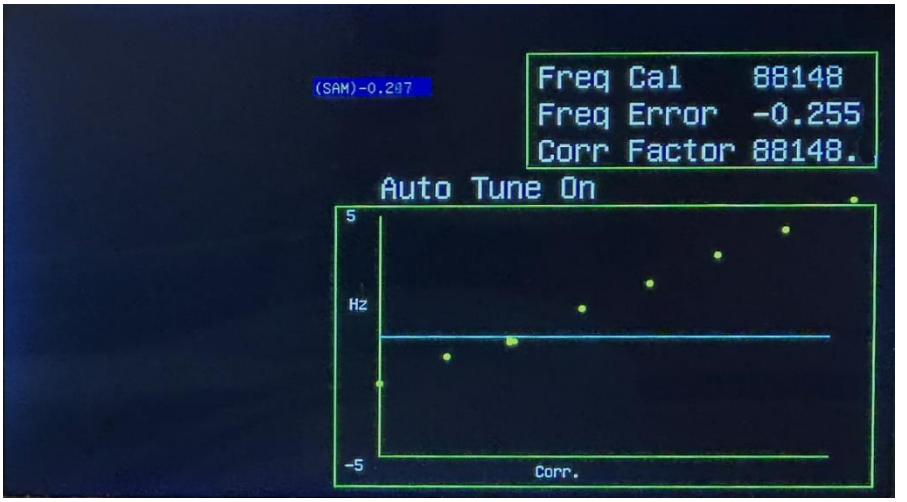

Figure 1Frequency Calibration Plot

- A plot of the frequency error versus time at a specific Si5351 Correction Factor is also included. This plot allows verification of the Frequency Calibration Factor value over selectable periods of time. Figure 2 shows a T41 TXCO frequency stability plot for an 8 hour period. The T41 Frequency offset is about .03Hz, with a Std.Deviation of .023Hz. The reference source is a Rubidium 10MHZ standard.

Figure 2 TXCO 8 hour Frequency Error Plot

To make the most effective use of these tools, it is suggested that the process should be applied as follows:

1. Allow the T41 and the frequency standard to warm up for at least 30min.
2. For best results the T41 should be in a closed case to minimize temperature variations.
3. Set Filter to 1KHz.
4. Set the T41 Demod to SAM.
5. Select Calibrate/Freq from T41 menu
6. After the T41 Frequency Calibration is initiated, first manually adjust the correction factor with the Filter encoder for minimum frequency difference as a starting point. (This can be bypassed, but then several additional iterations of the Auto function may be necessary.
7. With the Auto plot routine a frequence difference vs correction factor plot is created. Note the displayed recommended Correction Factor.
8. Repeat the plot several times and average the Correction Factor values if there is variation because of noise on the signal.
9. Set the Correction Factor to the average value just calculated if different from the displayed value.
10. Then observe the T41 frequency stability using the time plot. With the TXCO, If the result is not less than +/- 0.1Hz over a reasonable period of time, the process should be repeated.
11. On-screen directions are available by pressing “Dir Freq” button.
12. Press “Select” to exit and save the Frequency Correction factor to EEPROM.

Additional notes on the process:

- The nature of the T41 with the optional TXCO, based on a limited sample, is that the frequency stability is better than +/- 0.1 Hz.
- Frequency stability with crystal reference is several times worse, on the order of 0.5 to1Hz variation over a period of hours, depending on the variations of temperature in the case.
- On a short term basis, the frequency difference appears to vary randomly around the set point as much as approximately +/- 0.07Hz, so manually setting the correction factor is not precise. Because the Si5351 frequency is a linear function of the correction factor, a linear

regression approach yields better results. For this reason the Auto Calibration option is preferred.

- Temperature variations may cause the LO frequency to vary. For instance, Figure 3 shows the result of opening and closing the T41 case during the plot time. The plot duration is approximately 1.3

Figure 3 Effect of Temperature Variation

hours.

- Using a TXCO makes a large difference in the frequency stability over time, as shown in Figure4. In this case the error is plotted for a 25MHz crystal instead of the TXCO. Compare Figure 4 to Figure2. The TXCO

Figure 4 Crystal Frequency Error

average mean over 8 hours was 0.034 Hz, compared to the crystal average mean of 0.367 over just 1.3 hours.

Receive Calibration

Receive calibration is self-contained, requiring no external equipment.

The Quadrature approach to demodulation of SSB signals requires that the two quadrature signal paths, I and Q be balanced in both gain and phase in order to reduce or eliminate unwanted “images of the desired signals. Gain and phase differences arise from the tolerances of parts in the summing amplifiers and antialiasing filters. These slight differences are compensated for in the Receive Calibration factor applied to the digital signal. The variation are also frequency dependent, so calibration of each Band is necessary.

The current version of Receive Calibration has been completely rewritten to better use the regular Receive DSP calculation process. The resulting calibration has been verified using external signals to determine that minimization of IQ images agrees with the calibration result. The agreement is very good.

The reference signal for Receive calibration is provided by using the T41 CW output from Si5351 CLK2 and the T41 V12 attenuators.

Setup is as follows:

- Disconnect the T41 antenna input.
- On the RF board, jumper J4 – Cal Isolation jumper on the V12.6 RF board.
- Select the Band to calibrate.
- Select a frequency either near the band center or near specific operating frequencies.
- Select the Menu item: Calibration/Rec Cal.
- Make sure that the signal level shown in the blue band is about the mid-point or higher on the display.
- Figure 5 shows the Receive Cal screen, with starting values of Gain=1.0 and Phase=0.0.
- Minimize the IQ Image level in the Red block and IQ Image level (adjdB) readout:

Figure 5 Receive Calibration

- Option 1 Manual adjustment
  - Alternately adjust IQ Gain and IQ Phase with the Filter and Volume encoders.
  - Use User3 to toggle the adjustment increment. Increments are 0.1, 0.01 and 0.001.
  - adjdB shows the ratio of the IQ Image to the input reference in dB. Better than -50dB should be attainable.
- Option2 Auto adjustment
  - Press the Decode Button to calculate the parameters. Figure 6 shows the Auto Cal in progress.

Figure 6 Auto Cal in Progress

- Repeat, if necessary, especially when the initial images level(red) is high. Each Auto cal cycle takes about 75 seconds to complete.

- Press Select to Exit and save values.
- Repeat for all Bands

Figure 7 show the result of inputting an RF reference to the Antenna input from a signal generator, simulating a 1KHz SSB signal at about S9. The

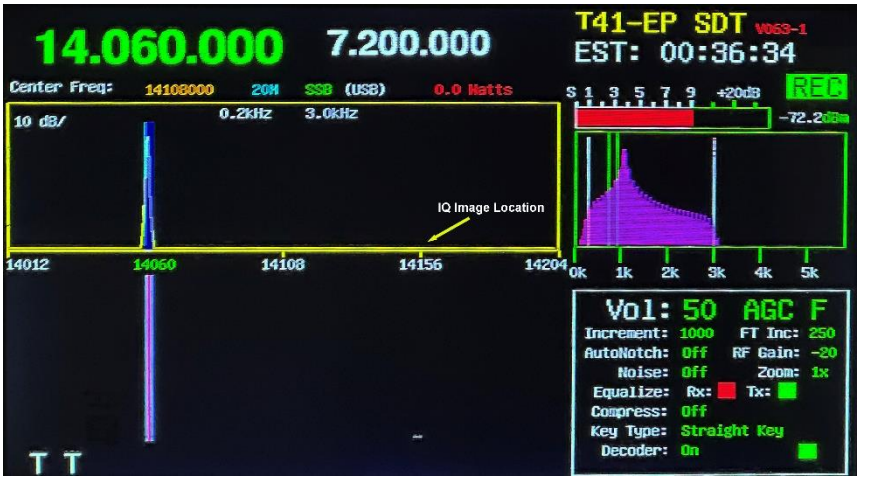

Figure 7 Reference Signal After Rec Cal

location of the IQ image is indicated on the 1X zoom spectrum. The image is better than 70dB below the reference.

Transmit Calibration

Transmit IQ calibration requires external equipment to monitor the transmit IQ image. This can be either a Spectrum analyzer or a suitable HF receiver, either one should be connected to the T41 RF output through an attenuator/dummy load capable of at least 40dB of attenuation and power levels of 15W.

See Figure 8 for 40M hookup details.

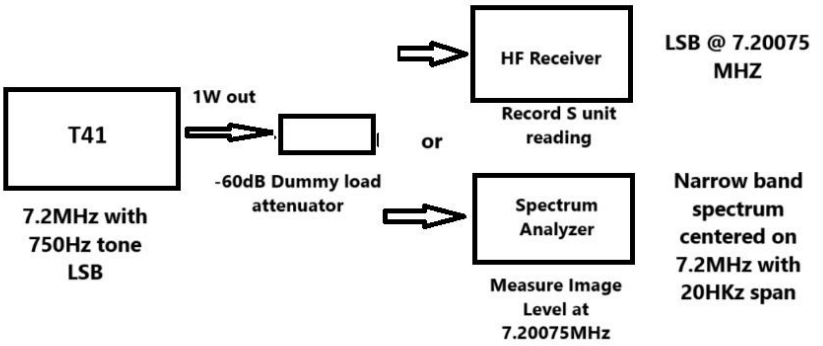

Figure 8- Xmit Calibration Hardware Setup

- Remove JP4 jumper on RF board.
- Set T41 to 7.2MHz LSB or any other band center
- Select Calibrate/Xmit Cal from the Menu
- Plug in a switch to the PTT jack
- Set the external receiver as follows:
    - AGC to Normal.
    - For 40M, receiver Frequency=7.2MHz and Sideband to USB or Frequency to 7.20075 and sideband to LSB.
    - Either combination will tune the IQ Image.
    - If the Receiver has narrow band IF capabilities, tune for the narrowest BW that will give a good result when T41 is transmitting the 750Hz tone. The objective is to tune the IQ Image in the adjacent band, not the primary signal.
- Press the PTT switch and set the IQ gain to 0.8. to view the unwanted image on the receiver. Change the IQ Gain to IQ Phase using USER3 button and tune for the lowest reading on the receiver S-meter. The IQ image appears to have a broad minimum as the Phase setting is varied.
- Change back to IQ Gain and observe the S-meter reading.

- Use the Volume encoder to set the IQ Image Level value to the observed S-meter reading for plotting.

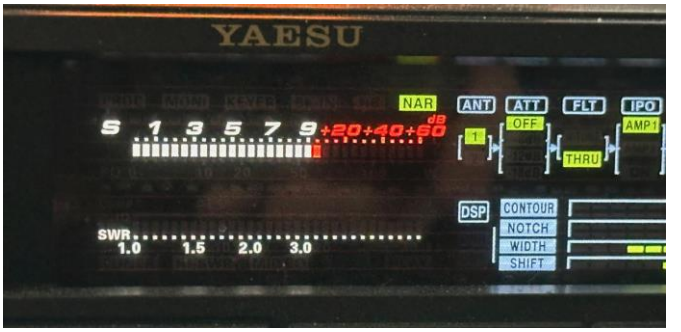

Figure 9 – Receiver S-meter at about .85 IQ Gain

- Switch back to Phase and make adjustments as necessary.
- Press the Filter encoder switch to plot the point.
- Change the IQ Gain and repeat the process. The S meter minimum vs gain is shown in Figure 10.

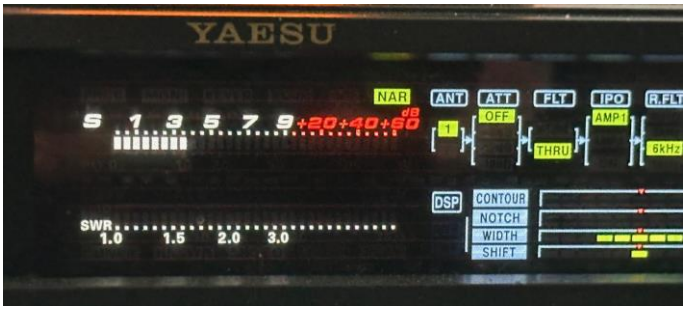

Figure 10- S-meter at Minimum

- A clear minimum should appear on the plot.
- Change the increment to 0.001 and tune for the best minimum.
- Once the minimum reading has been obtained, **reset the IQ Gain to the value that gave the minimum and press Select** to exit and save the IQ Gain and IQ Phase values. The T41 Gain plot is shown in Figure 11.
- Repeat for the other bands.

- Finally Press Dir Freq Button to display the on-screen Directions

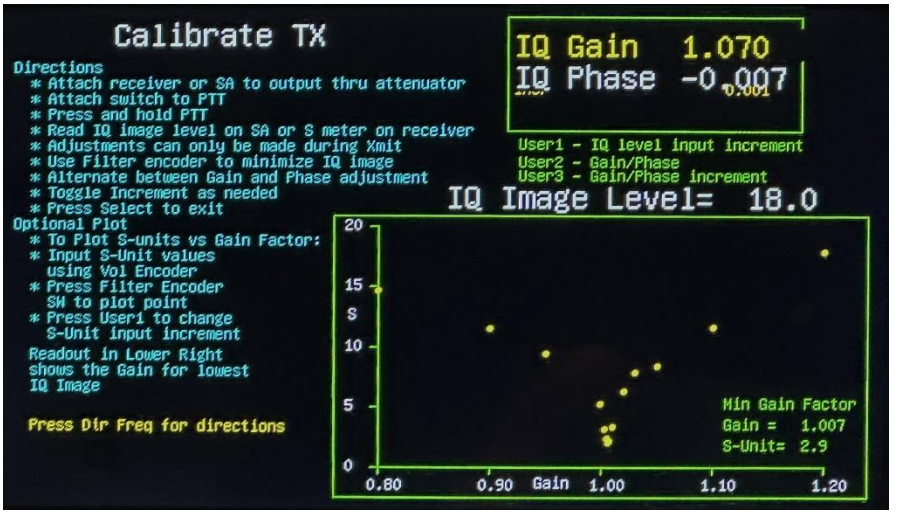

Figure 11 T41 Xmit Gain plot

which is also shown in Figure 11.

Finally, Figure 12 shows the results for 3 receivers and a spectrum analyzer. Note that the Iq image minimum occurs at the same gain value using each of the receivers and the SA.

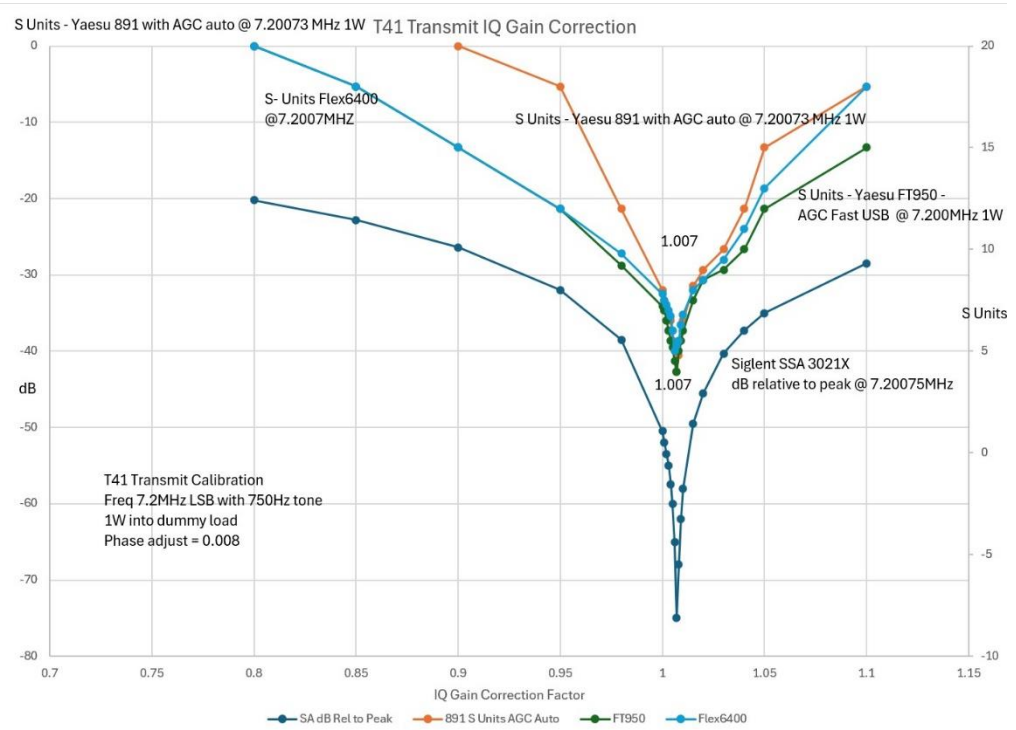

Figure 12Transmit IQ image minimum

CW transmit power

(More to come.)

SSB transmit power

(More to come.)

Conclusion

The new calibration routines for Receive IQ, Transmit Q and frequency have all been updated and appear to give very good results.

Frequency Cal and Receive Cal have both manual and automatic mode. Transmit Cal is only manual.