T41 Calibration Directions

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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 and later hardware. These include calibration of several key parameters:

- Frequency
- Receive IQ calibration
- Transmit IQ calibration
- CW transmit power
- SSB transmit power
- SWR and power readouts

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.

The initial T41 setup should be performed in the following order:

1. Frequency calibration
2. Receive Calibration
3. Transmit IQ calibration
4. CW PA Power level and Power readout calibration
5. SSB PA Power level calibration
6. SWR calibration

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 the best results.

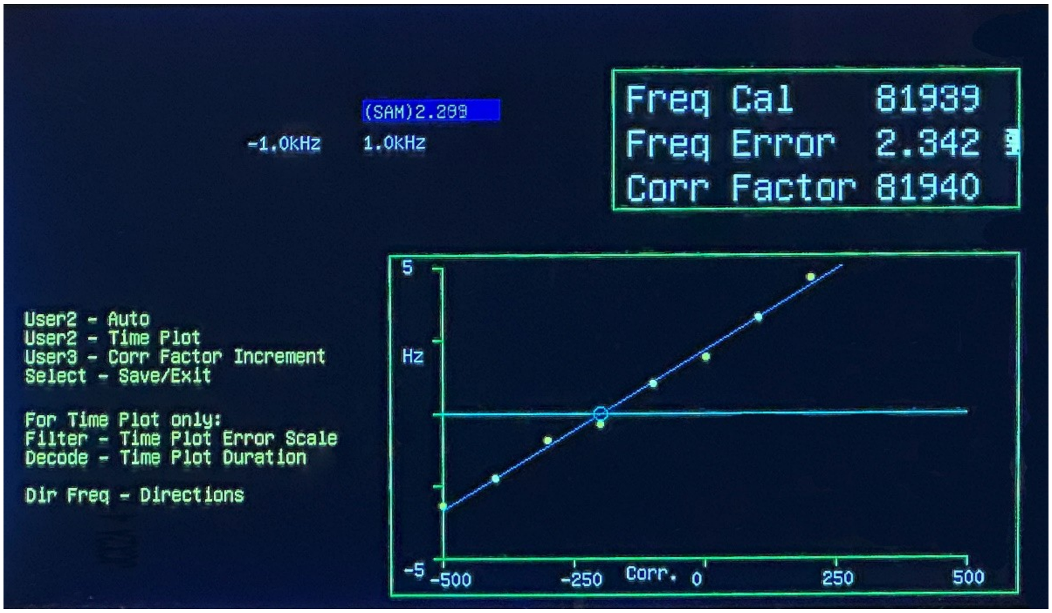

Figure 1 Auto Frequency Calibrate

The suggested WWV process is as follows:

- Tune to the strongest WWV (or other) signal using the Dir Freq button.
- 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.

It is possible to skip the manual tune steps and use several Auto Tune passes instead, in which case the plots will not be correct until the correction factor has brought the LO to within a few Hz of the standard.

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 factor 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. Figure 1 shows the linear regression plot for a crystal reference fir the Si5351.
- 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.
- 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 Standard.Deviation of .023Hz. The reference source is a Rubidium 10MHz frequency standard.

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

- Allow the T41 and the frequency standard to warm up for at least 30min.
- For best results the T41 should be in a closed case to minimize temperature variations.
- Set Filter to 1KHz.
- Set the T41 Demod to SAM.
- Select Calibrate/Freq from T41 menu
- 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. The error plot will only be correct when the LO is within a few Hz of the standard.

- With the Auto-plot routine, a frequency difference vs correction factor plot is created. Note the displayed recommended Correction Factor.

Figure 2 TXCO 8 hour Frequency Error Plot

- Repeat the plot several times and use the Correction Factor values that give the lowest frequency error if there is variation because of noise on the signal.
- Set the Correction Factor to the best value just calculated if different from the displayed value.
- 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.
- On-screen directions are available by pressing “Dir Freq” button.
- 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 over at least a day.
- Frequency stability with crystal reference is several times worse, on the order of 0.5 to 1Hz variation over a period of hours, depending on the change 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 output 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.
- As mentioned, 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 hours.

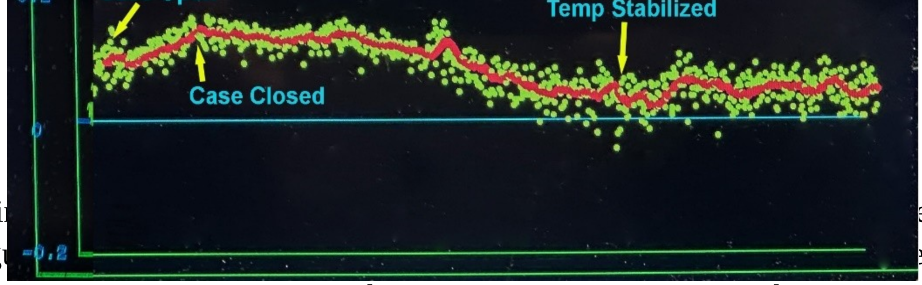

Figure 3 Effect of Temperature Variation

- Usi… e, as shown in Fig… TXCO. Compare Figure 4 to Figure2. The TXCO average mean over 8 hours was 0.034 Hz, compared to the crystal average mean of 0.367 over just 1.3 hours. Average Mean is computed using all of the samples, while the Running Mean is calculated using a running average over 20 samples.

Figure 4 Crystal Frequency Error

Receive IQ Calibration

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

Why IQ Calibration?

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 frequency 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 reference signal for Receive calibration is provided by using the T41 CW output from Si5351 CLK2 through 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.
- Verify 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 Before

- 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 User2 Button to calculate the parameters. Figure 6 shows the Auto Cal in progress.

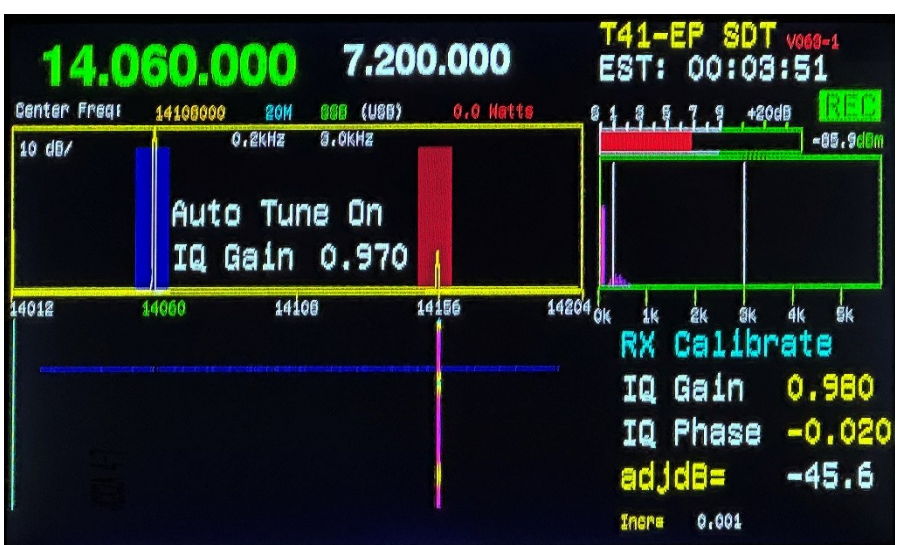

Figure 6 Auto Cal in Process

- Repeat, if necessary, especially when the initial images level(red) is high. Each Auto cal cycle takes about 7.5 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 location of the IQ image is indicated on the 1X zoom spectrum. The image is better than 70dB below the reference.

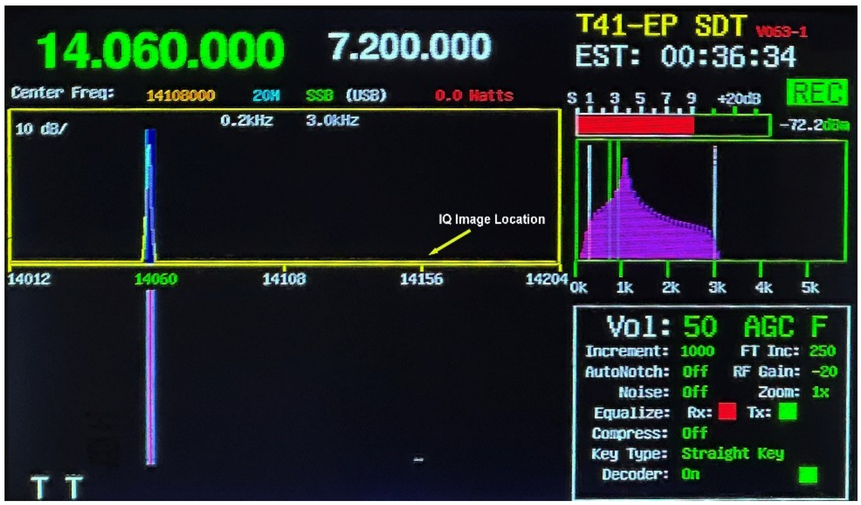

Figure 7 Reference Signal After Rec Cal

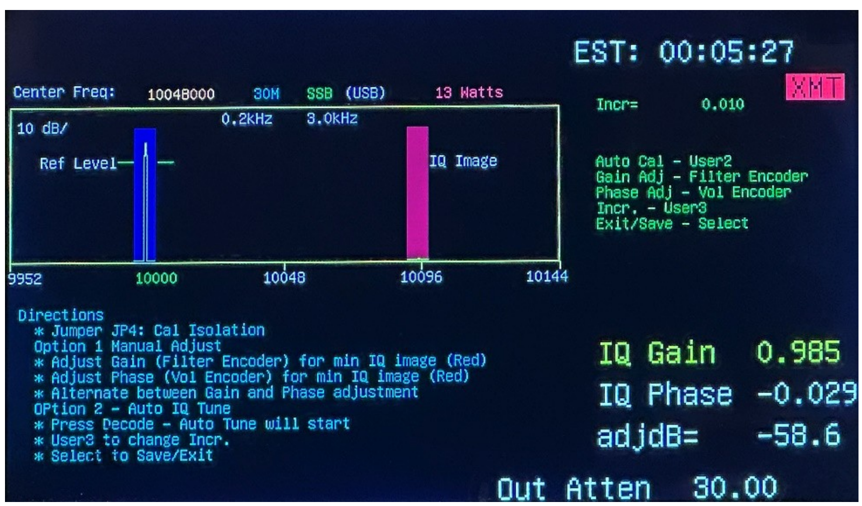

Figure 8 Receive IQ On-Screen Directions

Figure 8 shows the on-screen directions displayed when the DirFreq button is pressed in calibrate.

Transmit IQ 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.

Figure 9 shows the 40M hookup details as an example. Other bands require different frequency settings.

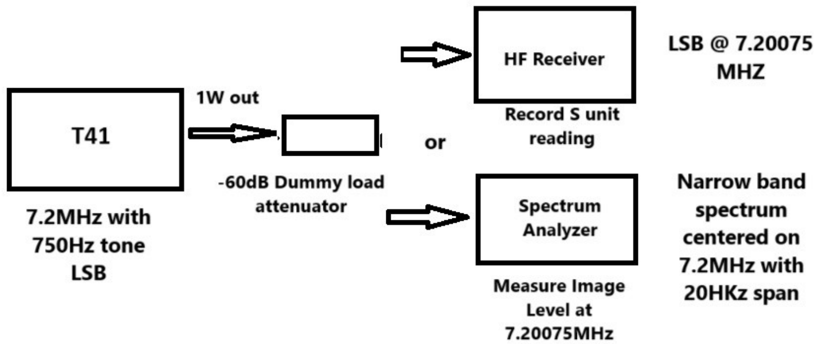

Figure 9 Xmit Calibration Hardware Setup

Calibration steps:

- 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.
- If using a Spectrum Analyzer (SA), setup is as follows:
  - Set center frequency to 7.2MHz for 40M
  - Set Span to 20KHz and BW to 30Hz.
- 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, shown in Figure 11. The narrow-band spectrum is shown in Figure 12.
- Use the Volume encoder to set the IQ Image Level value to the observed S-meter reading for plotting.
- 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 13. Figure 14 shows the narrow-band spectrum.

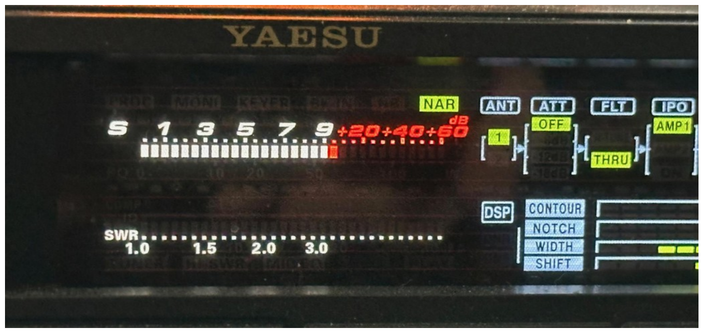

Figure 11 Receiver S-meter at about .85 IQ gain Gain

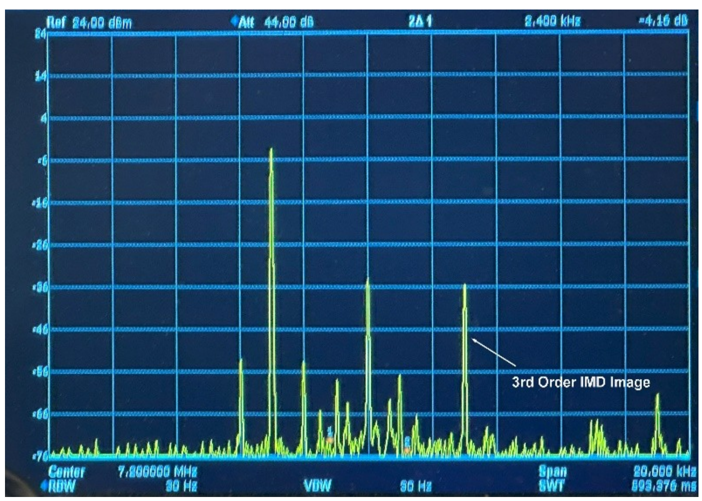

Figure 12 Narrow-band Spectrum Before Calibration

- A clear minimum should appear on the plot.
- Change the increment to 0.001 and tune for the best minimum.

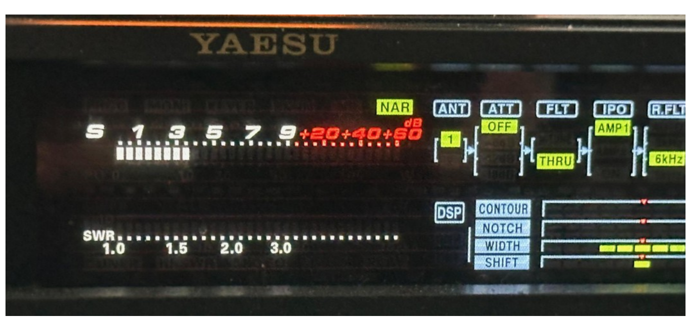

Figure 13 S-meter at Minimum

- A plot of the S-meter readout vs IQ Gain can be obtained by varying the gain with the Filter encoder, reading the S-meter value and using the Vol encoder to adjust the value to the S-meter reading. Press the Filter encoder switch to plot the point. Repeat for various gain values. A clear minimum should be seen on the plot, along with the minimum plot value, as shown in Figure 15.
- 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.
- Repeat for the other bands.
- Finally Press Dir Freq Button to display the on-screen Directions which are also shown in Figure 15.

Finally, Figure 16 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.

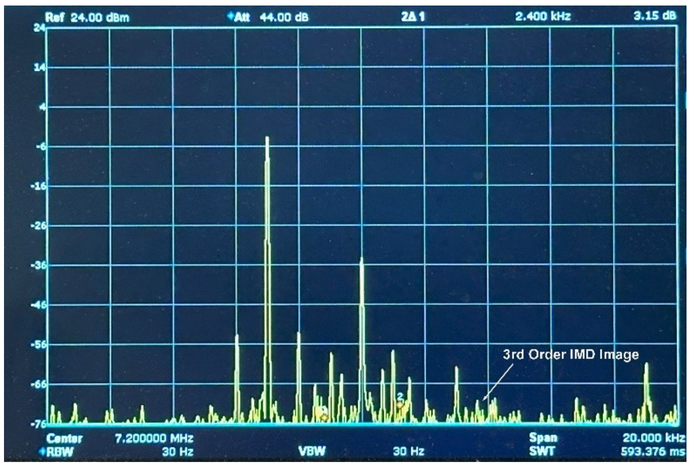

Figure 14 Narrow-band Spectrum After IQ Calibration

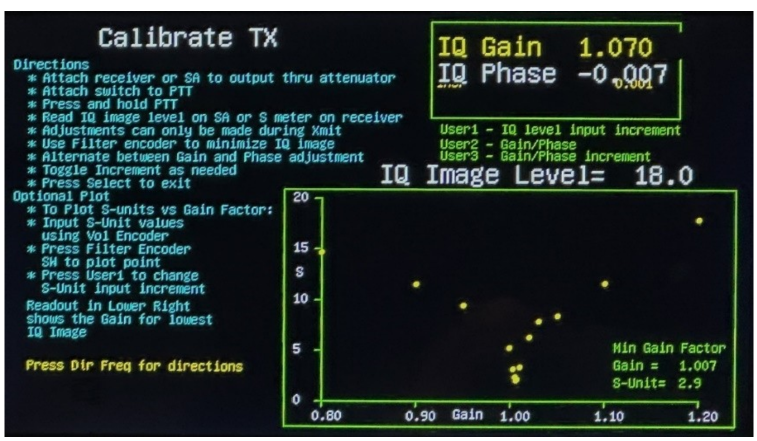

Figure 15 T41 Xmit IQ Gain plot

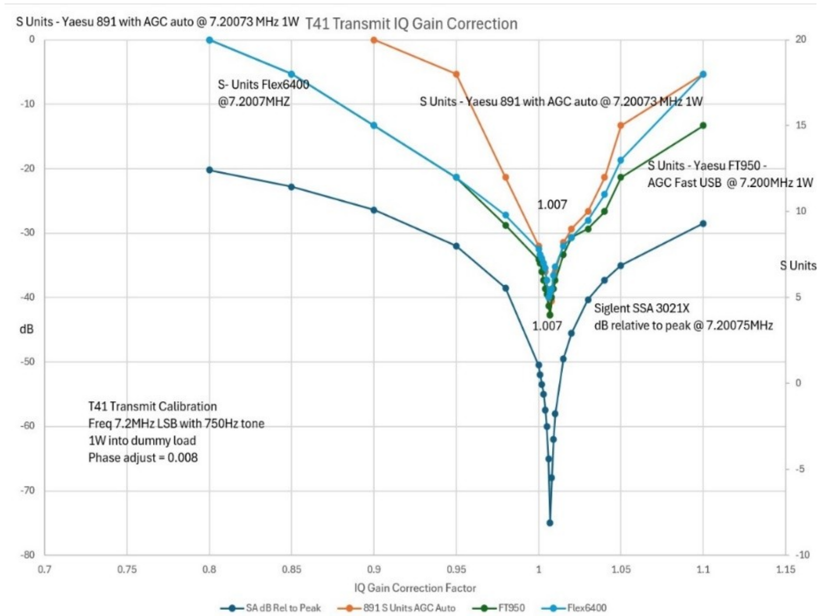

Figure 16 Transmit IQ image minimum

CW and SSB Transmit Power Calibration

T41 transmit power levels are controlled by the setting of the Output Attenuator on the RF board. Output levels can be adjusted in 0.5dB steps to -31.5dB. Because there are differences in the RF Exciter levels as a function of frequency, the Calibration routines have options to set the level of CW output and SSB separately and by frequency band.

Please note that because the attenuator has a 0.5dB step, the levels set may be only be close to the desired set point. Power output is a two-step process.

1. Using the Power set menu option, select a set-point for the calibration, such as 5W.
2. In the calibration function for CW and SSB, separately, adjust the Attenuation setting to give the desired power level output on the external power meter.

Perform CW PA calibration before performing SSB PA calibration; the CW PA calibration also calibrates the internal power meter, which is useful for SSB PA calibration.

CW PA Power level and Power readout

- First connect the T41 output to a suitable Power Meter and then to a Dummy Load.

- Under the RF Set / Power menu, set the power level to 5 W.
- Connect a key to the Key input jack.
- In the Menu, select Calibrate/CW PA Cal.
- Figure 17 shows the CW Power Calibration screen.

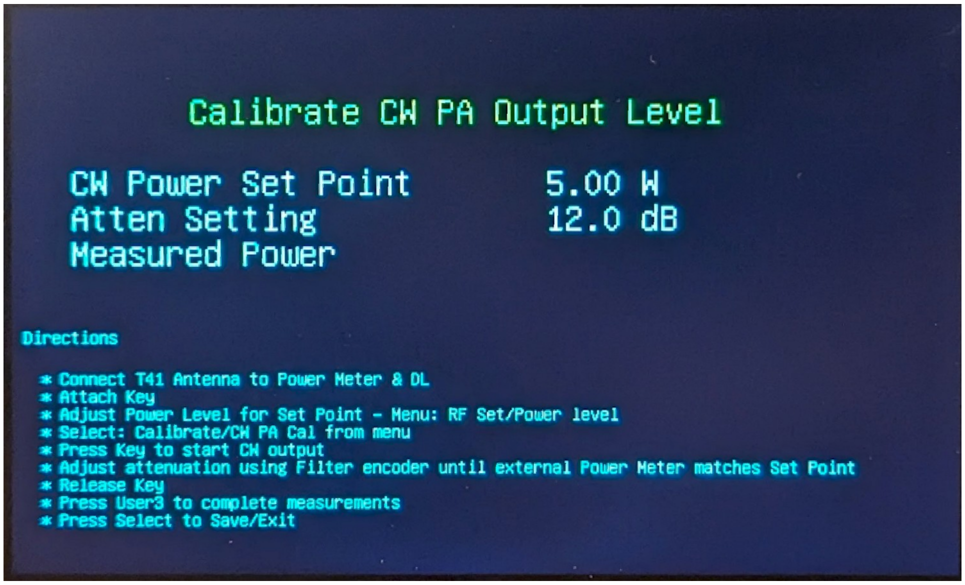

Figure 17 CW Power Calibration

- The CW power set point is shown.
- Press the key and using the Filter encoder, adjust the attenuator until the output as read on the power meter is as close to the setpoint as possible. Again, because of the available 0.5dB steps, an exact match is not feasible.
- Release the key.
- Press the User3 button to run the internal power meter calibration step.
- Press Select to save the settings and exit.
- Repeat for the other CW frequency bands.
- Note the on-screen directions.

SSB Power Calibration Detail

Note that the CW PA Calibration step above should be completed before the SSB PA Calibration step.

- First connect the T41 output to a suitable Power Meter and then to a Dummy Load.
- Set the power-out level in the RF Set / Power level menu to no more than 5 W.
- Connect a switch to the PTT input jack.
- In the Menu, select Calibrate/SSB PA Cal.
- Figure 18 shows the SSB Power Calibration screen.
- The SSB power set point is shown.
- Press the PTT switch and using the Filter encoder, adjust the attenuation level until the output as read on an external power meter or the internal power meter are as close to the

setpoint as possible. Again, because of the available 0.5dB steps, an exact match is not feasible.

- Press Select to save the setting.
- Connect a microphone to the input.
- Adjust the mic gain under the Mic Gain / Set Mic Gain menu such that speaking into the microphone produces the desired power output.
- Repeat for the other SSB frequency bands.

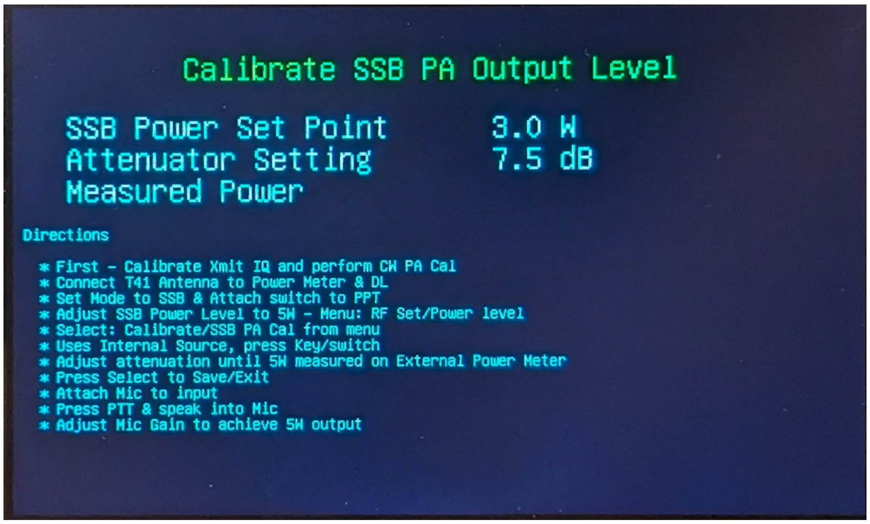

Figure 18 SSB Power Amp Calibration Screen

SWR Meter Calibration

Note that the CW PA Calibration step above **must** be completed before the SWR Meter Calibration step. The V12 LPF Control board contains a circuit for SWR and Power measurements on the fly. The CW PA Calibration step also calibrates the part of the SWR bridge that measures the forward power – this SWR Meter Calibration step calibrates the part of the SWR bridge that measures the reverse power. Hence both calibration steps need to be completed for accurate SWR measurements.

You will need a 100 Ohm dummy load to perform this calibration step. Note that this dummy load must not be inductive – a regular wirewound resistor has a high inductance that makes it unsuitable for this calibration step. Use a non-inductive wirewound resistor.

- First connect the T41 output to a non-inductive 100 Ohm Dummy Load.
- Set the power-out level in the RF Set / Power level menu to no more than 5 W.
- In the Menu, select Calibrate/SWR Cal.

- Press the User3 button to run the calibration sequence.
- Press Select to save the setting and exit.

Other Functions

In the Calibrate sub-menu there is an entry for a Two-tone Test signal generation.

Two-Tone tests are frequently run to evaluate the IMD performance of a transceiver power amplifier. This menu pick simply provides the input to allow such a test to be performed. The details of this test are beyond the scope of this discussion but are readily available in the literature. Simply follow the on-screen directions to set up the outputs.

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, requiring an external measuring device.