

Quick-Start Guide to Q65

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WSJT-X 2.4.0 introduces Q65, a digital protocol designed for minimal two-way QSOs over especially difficult propagation paths. On paths with Doppler spread more than a few Hz, the weak-signal performance of Q65 is the best among all *WSJT-X* modes. Q65 is particularly effective for tropospheric scatter, rain scatter, ionospheric scatter, and EME on VHF and higher bands, as well as other types of fast-fading signals.

Q65 uses 65-tone frequency-shift keying and builds on the demonstrated weak-signal strengths of QRA64, a mode introduced to *WSJT-X* in 2016. Q65 differs from QRA64 in the following important ways:

- A new low-rate Q-ary Repeat Accumulate code for forward error correction
- User messages and sequencing identical to those in FST4, FT4, FT8, and MSK144
- A unique tone for time and frequency synchronization. As with JT65, this “sync tone” is readily visible on the waterfall spectral display. In addition, Q65 provides a sensitive “sync curve” near the bottom of the waterfall window. Unlike JT65, synchronization and decoding are effective even when meteor pings or other short signal enhancements are present.
- Optional submodes with T/R sequence lengths 15, 30, 60, 120, and 300 s and different tone spacings.
- A new, highly reliable list-decoding technique for messages that contain previously copied message fragments. No use is made of a callsign database.
- Highly effective message averaging for situations where single transmissions are too weak to be decoded.
- A “multi-decode” option that attempts to decode all Q65 signals in the received passband.

Basic parameters of Q65 for each of the five T/R sequence lengths and their minimum tone spacings (“A” submodes) are summarized in the table below. Threshold sensitivities (SNR in 2500 Hz bandwidth yielding 50% probability of decode) were measured for each submode using simulations over the additive white Gaussian noise (AWGN) channel. As with other recently developed modes in *WSJT-X*, a feature called *a priori* (AP) decoding improves sensitivity by several additional dB as information is accumulated during a standard minimal QSO.

| T/R Period (s) | Symbol Length (s) | “A” Tone Spacing (Hz) | “A” Occupied Bandwidth (Hz) | Transmission Duration (s) | SNR (dB) | Max AP SNR (dB) |
|-----------------------|--------------------------|------------------------------|------------------------------------|----------------------------------|-----------------|------------------------|
| 15 | 0.150 | 6.667 | 433 | 12.8 | -22.2 | -23.7 |
| 30 | 0.300 | 3.333 | 217 | 25.5 | -24.8 | -26.6 |
| 60 | 0.600 | 1.667 | 108 | 51.0 | -27.6 | -30.2 |
| 120 | 1.333 | 0.750 | 49 | 113.3 | -30.8 | -32.5 |
| 300 | 3.456 | 0.289 | 19 | 293.8 | -33.8 | -37.4 |

Forward error correction (FEC) in Q65 uses a specially designed (65,15) block code with six-bit symbols. Two symbols are “punctured” from the code, yielding an effective (63,13) code with a payload of $k = 13$ information symbols conveyed by $n = 63$ channel symbols. The punctured symbols consist of a 12-bit CRC computed from the 13 information symbols. The CRC is used to reduce the false-decode rate to a very low value. A 22-symbol pseudo-random sequence spread throughout a transmission is sent as “tone 0” and used for synchronization. The total number of channel symbols in a Q65 transmission is thus $63 + 22 = 85$.

For each T/R sequence length, submodes A - E have tone spacings and occupied bandwidths 1, 2, 4, 8, and 16 times those specified in the above table. Full submode designations include a number for sequence length and a letter for tone spacing, as in Q65-15A, Q65-120C, etc. Tone spacings and occupied bandwidths for the wider submodes are summarized in the table below. Additional submodes 120F, 300F, and 300G might be implemented in future if there is a perceived need.

| T/R Period (s) | A | | B | | C | | D | | E | |
|----------------------|-----------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|---------------|-----------------|---------------|
| | Spacing (Hz) | Width (Hz) | Spacing (Hz) | Width (Hz) | Spacing (Hz) | Width (Hz) | Spacing (Hz) | Width (Hz) | Spacing (Hz) | Width (Hz) |
| 15 | 6.67 | 433 | 13.33 | 867 | 26.67 | 1733 | N/A | | N/A | |
| 30 | 3.33 | 217 | 6.67 | 433 | 13.33 | 867 | 26.67 | 1733 | N/A | |
| 60 | 1.67 | 108 | 3.33 | 217 | 6.67 | 433 | 13.33 | 867 | 26.67 | 1733 |
| 120 | 0.75 | 49 | 1.50 | 98 | 3.00 | 195 | 6.00 | 390 | 12.00 | 780 |
| 300 | 0.29 | 19 | 0.58 | 38 | 1.16 | 75 | 2.31 | 150 | 4.63 | 301 |

On-the-air experience during the first six months of testing has shown that Q65 is more sensitive than any other *WSJT-X* mode when path Doppler spread is more than a few Hz. An excellent example of targeted uses of Q65 is ionospheric scatter on the 6 m band. Extensive tests on the 1150 km path between K1JT and K9AN have shown that with 300 W power output, nearly every Q65-30A transmission is copied correctly by the other station. Q65 will enable stations with a modest Yagi and 100 W or more and to work one another on 6 m at distances up to ~1600 km on most days of the year, in dead band conditions. Ionospheric scatter is best near mid-day and in summer months, but is present at all times.

Many tests of Q65 on EME, troposcatter, rain scatter, optical scatter, and other potentially interesting paths have been conducted over the past six months. We find that suitable Q65 submodes perform well in a wide variety of conditions. Decoding is effective for signals with Doppler spread up to ten times the tone spacing, and even beyond.

Recommended submodes known to be effective for specific applications include the following.

Obviously, you should feel free to experiment with other combinations. Please report your results on a suitable forum!

- Ionospheric scatter on 50 MHz: **30A**
- QRP ionospheric scatter on 50 MHz: **120E**
- Ionospheric scatter on 144 MHz: **60C**
- Troposcatter and rainscatter at 10 GHz: **60D**
- Small-dish EME, 10 and 24 GHz: **120E**
- Other EME: 50, 144 MHz **60A**; 432 MHz **60B**; 1296 MHz: **60C**; 10 GHz: **60D**

Some representative sensitivity curves from simulation measurements are presented in Figures 1 and 2.

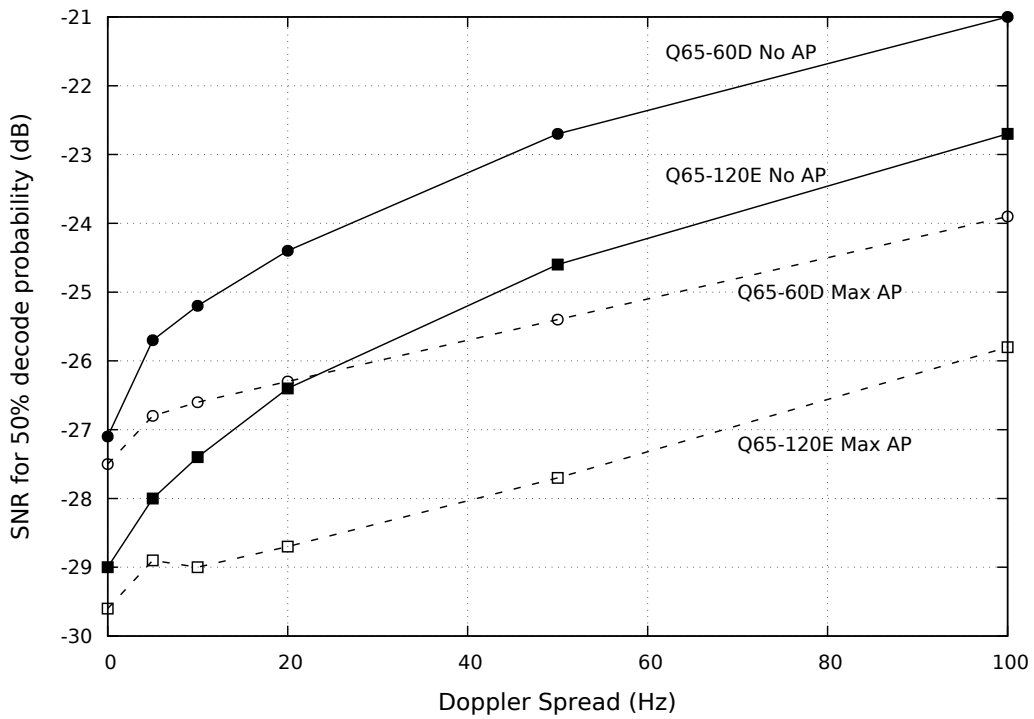


Figure 1. – Threshold sensitivities for Q65-60D and Q65-120E as a function of frequency spread.

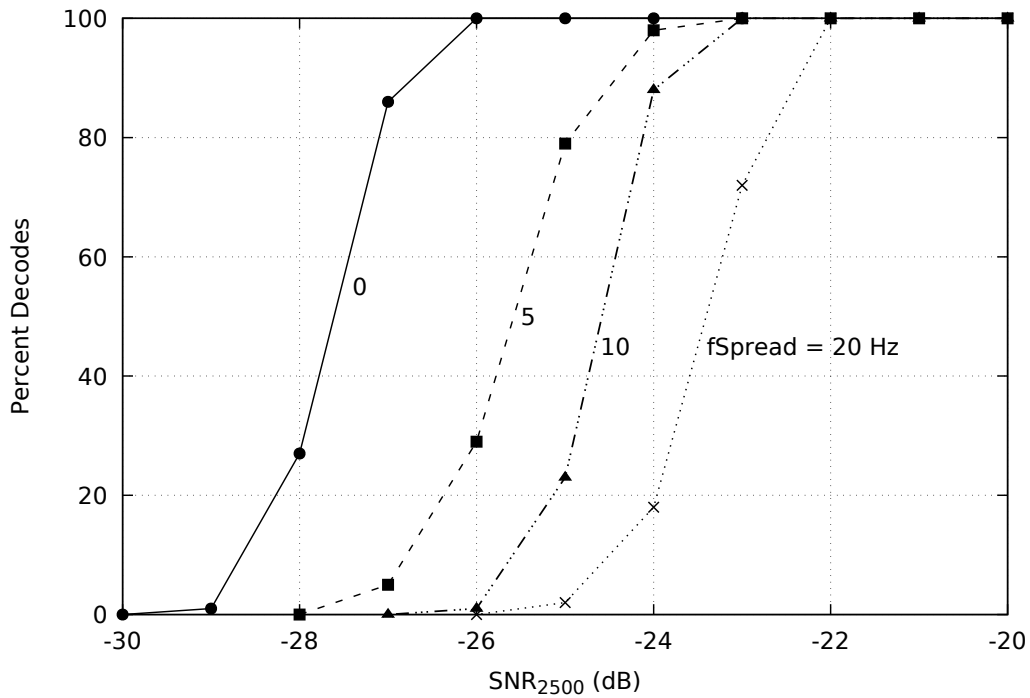
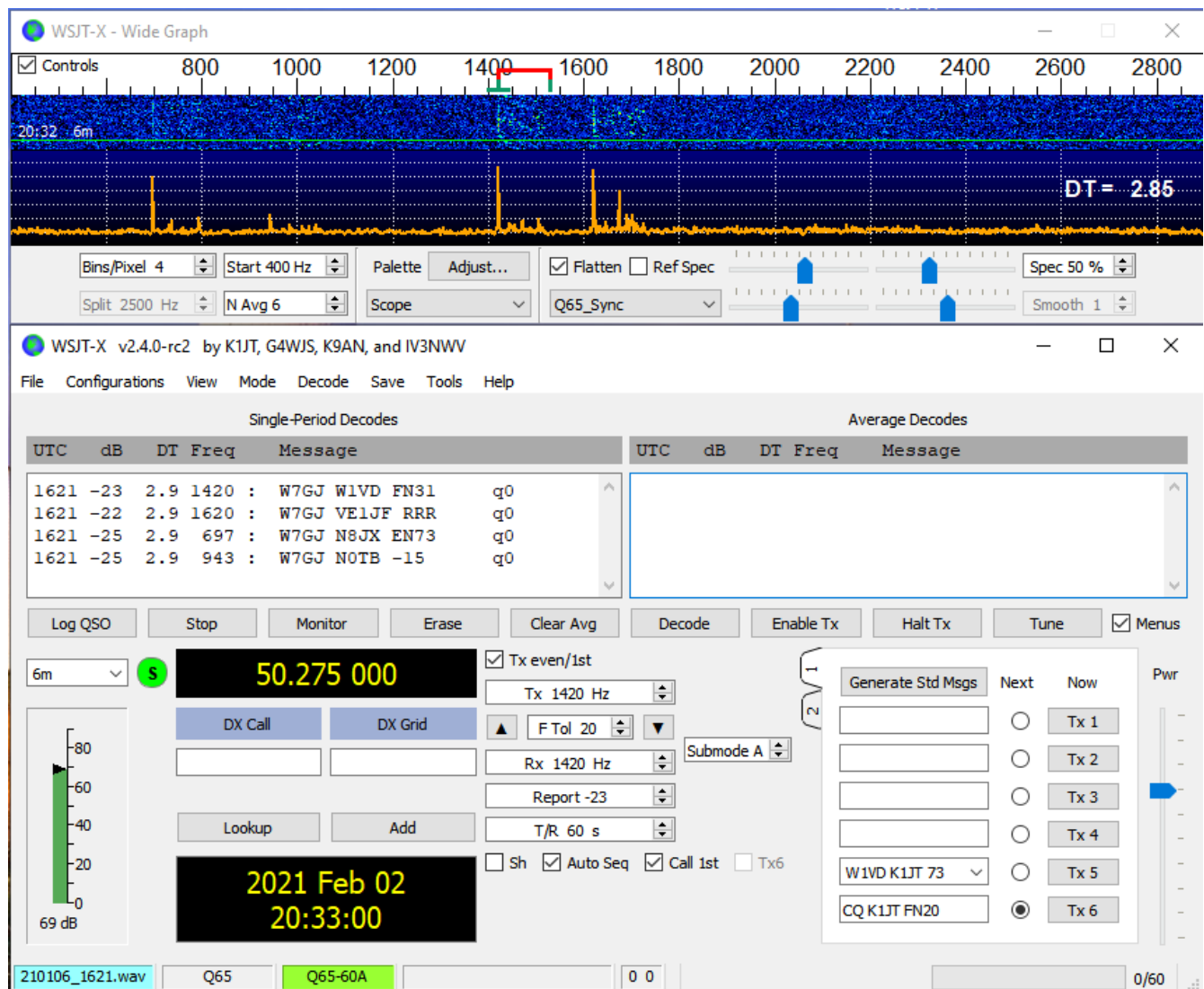


Figure 2. – Decoding probability of Q65-60A (no AP) as a function of SNR and frequency spread.

In most ways operating with Q65 is like that for other popular *WSJT-X* modes, but you should know about some differences. Many of these are introduced in the following short tutorial, which I recommend following before you proceed to make QSOs with Q65.

1. Download a collection of Q65 sample files from https://physics.princeton.edu/pulsar/k1jt/Q65_Samples.zip and unzip it into a convenient directory such as C:\WSJT-X\Q65_Samples
2. Start *WSJT-X 2.4.0*, select Q65 mode, and configure other parameters as shown in the screen shot below. On the **File** → **Settings** → **General** tab, be sure to check **Enable VHF and submode features** and **Decode after EME delay**, and uncheck **Single decode**. On the **Decode** menu select **Fast**, **Enable averaging**, and **Auto Clear Avg after decode**.
3. Go to **File** → **Open**, navigate to where you saved the sample files, and open the file ...\Q65_Samples\60A_EME_6m\210106_1621.wav. You should see something like this screen shot, which shows decodes of four 6-meter EME signals received at W7GJ on January 6, 2021. Note that decoding takes place first at the selected **Rx Freq**, then at other frequencies.



4. Notice that **Q65 Sync** has been selected at the bottom of the Wide Graph window. This choice enables the orange “sync curve,” a special Q65 feature that provides sensitive indications of

where Q65 sync tones may be present. Here you can see significant spikes at the frequencies 697, 943, 1420, and 1620 Hz, and the **Single-period Decodes** panel shows decodes at each of these frequencies. Strong Q65 signals show additional “grass” on the orange curve to the right of the sync tone. The decoder generally ignores these.

5. Q65 decodes are always tagged with the lower-case letter “q” followed by one or two decimal digits. The first digit indicates the type of *a priori* (AP) information used, if any. When present, a second digit shows the number of Rx sequences that have been averaged to produce the decode.
6. To get a feeling for some of these features, switch to submode Q65-30A, set **RxFreq** to 1000 Hz, and open the first sample file in directory `... \Q65_Samples\30A_Ionosscatter_6m`. This file will not decode, but if you select **File** → **Open next in directory** (or hit **F6**) twice to read the next two files, you should see

```
022900 -19 0.4 1010 : K1JT K9AN R-16      q03
```

in the **Average Decodes** panel. (Be sure to wait until the blue **Decode** indicator has cleared, before hitting **F6**.) None of the files at 022700, 022800, or 022900 UTC will provide a decode by itself, but the average of all three does.

7. Go to **File** → **Settings** → **General** (or hit **F2**) and set **MyCall** temporarily to K1JT. Double-click the **Erase** button to clear both panels of decoded text and then repeat the sequence of opening the first two sample files in the `30A_Ionosscatter_6m` directory. You should now see

```
022900 -20 0.4 1010 : K1JT K9AN R-16      q22
```

in the **Average Decodes** panel. The “q22” flag shows that with the first callsign already available as AP information, a valid decode is obtained from the signals in just two Rx sequences.

8. Hit **F6** two more times to read and process the third and fourth files in this directory. The file at 022900 UTC will not decode, but the one at 024000 produces the result

```
024000 -21 0.3 1010 : K1JT K9AN R-16      q2
```

in the **Single-Period Decodes** panel. Again, AP information for the first callsign has made the decode possible.

9. Double-click on the line of decoded text so that K9AN will be copied into the **DX Call** entry field. You should now find that two of the four files in the `30A_Ionosscatter_6m` directory will decode immediately with “q3” flags. This happens because both callsigns are now available as AP information. You may also notice that a red sync curve now appears along with the orange curve. For “q3” decodes the red curve is the most sensitive indicator of proper synchronization.
10. By now you should know enough to examine and decode signals in all the remaining subdirectories of sample files. Signals in these files are weak and may not be readily seen on the waterfall. Set the submodes as indicated by the subdirectory names and **RxFreq** to the values shown in the table on the next page. All of the sample files are real over-the-air signals, recorded by users of *WSJT-X 2.4.0* who were part of the Q65 test group. They provide good examples of signals on a wide variety of propagation paths.

| Subdirectory | Rx Freq | Message |
|------------------------------|---------|------------------|
| 60B_1296_Troposcatter | 1000 | VK7MO VK7PD QE38 |
| 60D_EME_10GHz | 1000 | VK7MO K6QPV DM12 |
| 12D_Rainscatter_10GHz | 1000 | VK3WE VK7MO QE37 |
| 120E_Ionoscatter_6m | 1800 | KB7IJ N0AN 73 |
| 300A_OpticalScatter | 1000 | VK7MO VK7PD QE38 |

11. While exercising the sample files you should experiment with turning on and off various program features such as **Single decode**, **Enable averaging**, and **Auto Clear Avg after decode**. Try double-clicking on the waterfall to decode a particular signal, using for example signals in the 60A_EME_6m subdirectory. Do not pay too much attention to displayed values of SNR for received signals. We are working toward a more reliable algorithm for estimating these numbers.
12. To get an even better feeling for how Q65 works for EME on lower VHF bands, you can download many additional files here:
https://physics.princeton.edu/pulsar/k1jt/60A_EME_6m_2.zip Each of these files recorded on 6 meters by W7GJ includes at least two decodable EME signals. For reasons you should now understand, full sensitivity will require decoding them with **MyCall** set to W7GJ.
13. Finally, here's a summary of meanings of the "q#" flags:
 - o q0 ? ? ?
 - o q1 CQ ? ?
 - o q2 MyCall ? ?
 - o q3 MyCall DxCall ?
 - o q4 MyCall DxCall [<blank> | RRR | RR73 | 73]