MAP65 User's Guide

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Introduction

MAP65 is a computer program designed for EME communication using the JT65 protocol. When used with RF hardware providing coherent signal channels for two orthogonal polarizations, the program offers automatic polarization-matched reception for every JT65 signal in a 90 kHz passband. Where linear polarization is in use, *MAP65* eliminates the effect of mismatched polarization angles on reception, so you are never faced with Faraday lockout or one-way propagation. On bands where circular polarization is the norm, *MAP65* is highly effective in its single-channel mode — again providing visual display of all signals in a 90 kHz window and decoding all the JT65 signals.

Hardware and Software Requirements

MAP65 requires specialized receiver hardware to convert an RF band to a digitized I/Q (in-phase and quadrature) data stream at baseband. The program was originally designed for use with the WSE converters designed by Leif Asbrink, SM5BSZ, together with his *Linrad* software. *Linrad* controlled the WSE hardware and handled the data acquisition tasks, forwarding digital data to *MAP65.* These choices remain good ones, but today there are many other possibilities. *MAP65* can be used with the SoftRock, FUNcube Dongle, SDR-IQ, Perseus, IQ+ and other comparable receiver hardware. These receiver types have different interfacing requirements, summarized below. Some are usable with *SDR-Radio* as an alternative to *Linrad*, or with *MAP65* in its stand-alone mode.

The SoftRock, IQ+, and WSE receivers mix signals from RF to baseband and use a computer soundcard for the analog-to-digital conversions. The FUNcube Dongle has a built-in silicon tuner and its own A/D converters; it plugs into a computer's USB port and presents itself to the operating system as a two-channel audio input device. The SDR-IQ and Perseus receivers do their A/D conversions at RF and accomplish down-conversion digitally, in a field-programmable gate array. Any of these systems, and many others with comparable features, can be used with *MAP65*. Obviously, those designed for input frequencies in the HF range will require another receive converter mixing down from a VHF/UHF band of your choice to an intermediate frequency in the HF range, say 28 MHz.

The SoftRock, FUNcube Dongle, SDR-IQ, and Perseus are all single-channel receivers, so they cannot support adaptive polarization. You could, however, configure a pair of modified SoftRocks (or approximate equivalents) for use in a dual-polarization system.

They would need to be driven by a single local oscillator, to maintain coherence between the two RF channels. The IQ+ and WSE converters are high-performance, two-channel systems that can support adaptive polarization directly.

Some example receivers and their interfacing requirements are summarized in Table 1. The SoftRock, FUNcube Dongle, and IQ+ use programmable synthesizers for their local oscillators. Their input frequencies can be set from within *Linrad*, *SDR-Radio*, or *MAP65* via a USB port. Center frequencies for the SDR-IQ and Perseus receivers are set in the same way, although in these cases the “local oscillator” is a numerically controlled oscillator (NCO) implemented in software. To achieve very low phase noise and high spurious-free dynamic range, the WSE converters use a sequence of switchable crystal oscillators for frequency control. Their switching is accomplished from within *Linrad* through the computer’s parallel port.

Table 1: Examples of receiving equipment and configurations for use with MAP65, with interfacing requirements

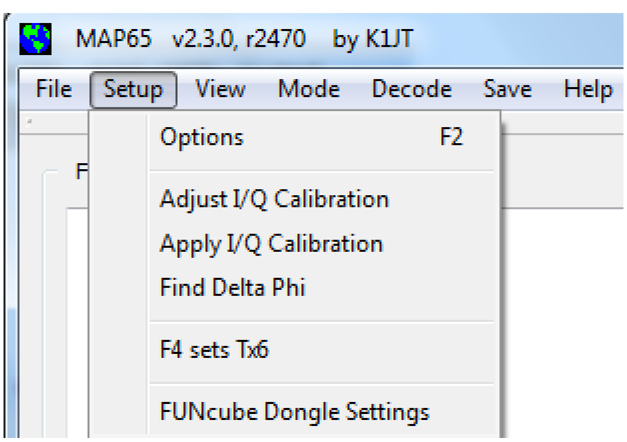
	SoftRock	**FUNcube Dongle**	**SDR-IQ, Perseus**	**SoftRock × 2**	**IQ+ VL, V, U**	**WSE**
Input Freq (MHz)	28, 144	144, 432, 1296	28	28, 144	50, 144, 432	144
Polarizations	1	1	1	2	2	2
Soundcard Channels	2	–	–	4	4	4
Digital Interface	USB	USB	USB	USB	USB	Parallel Port
Frequency Control*	L, S, M	L, S, M	L, S	L, M	L, M	L
Front-End Software*	L or S optional	–	L or S required	L optional	L optional	L optional

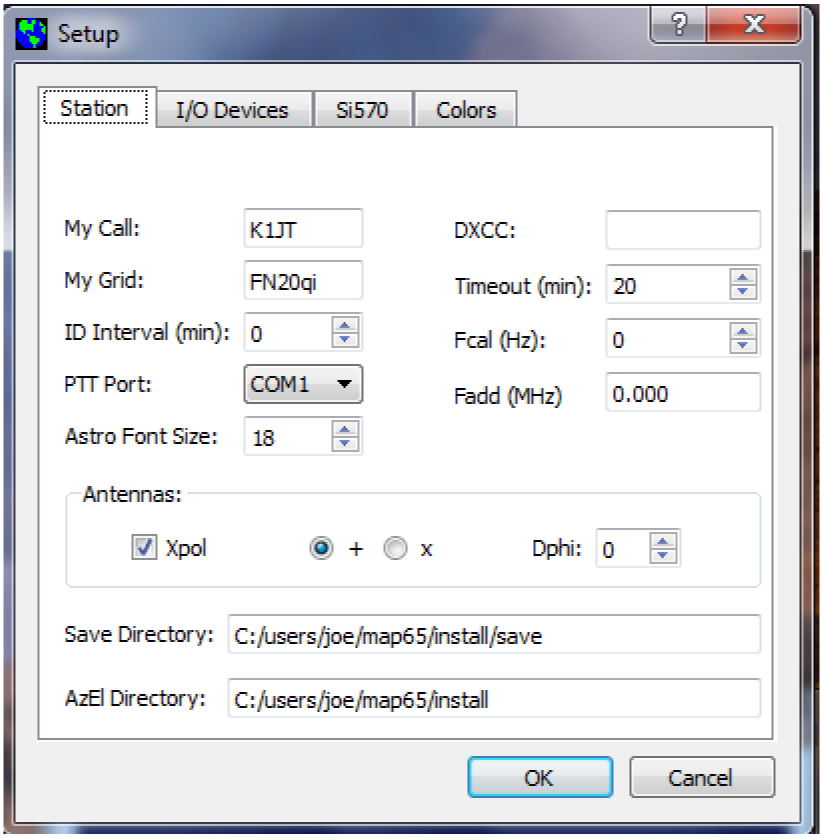
* L = *Linrad*, S = *SDR-Radio*, M = *MAP65*

Using *Linrad* as a data-acquisition front end provides some significant advantages. Its noise-blanking capabilities are superb. It provides many flexible configuration options and other receiver amenities including mode-specific demodulation with audio output to headphones or speaker. It interfaces directly to the SDR-IQ and Perseus receivers, handling their necessary control and data acquisition tasks. In single-polarization systems, *SDR-Radio* can manage the data input and control functions, again providing demodulation and audio output and forwarding wideband digital data to *MAP65*. *SDR-Radio* is polished, commercial-quality software available free to hams, and some have found it an easy way to get started with *MAP65.* Finally, *MAP65* can be used in stand-alone mode with I/Q signal inputs taken directly from a soundcard or a FUNcube Dongle. Stand-alone operation of *MAP65* with the IQ+ receiver is a particularly attractive option for a low-cost, high-performance system for digital EME.

Installation and Setup

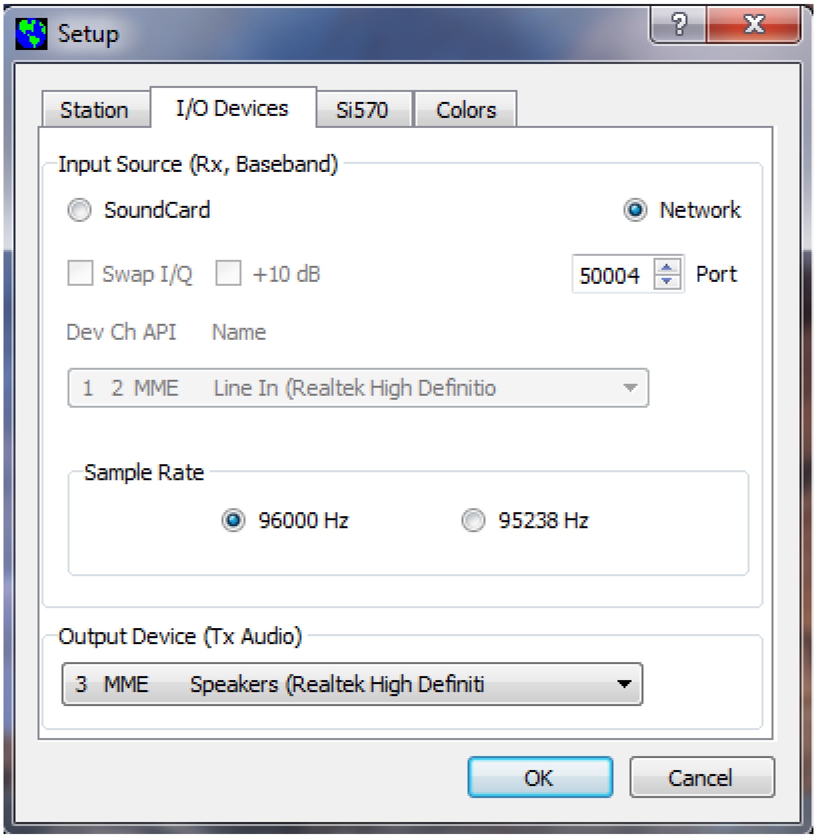
1. Use something like "C:\MAP65" or "C:\Radio\MAP65" rather than "C:\Program Files\MAP65" for the installation directory. All *MAP65* files are normally located in the installation directory and its subdirectories. The program makes no use of the Windows registry, so it can be uninstalled by simply deleting these directories and their contents.
2. Download and install MAP65 from a link on the following page: http://www.physics.princeton.edu/pulsar/K1JT/map65.html
3. On the final screen of the installation wizard you will be offered a chance to run a program that configures optimized FFT routines for your particular computer. Choosing the first (default) checkbox will be adequate for most purposes, and will result in an optimization process that proceeds silently for several minutes. Be sure to allow the optimization procedure to finish before proceeding. It is not necessary to repeat the FFT optimization if you install a program update in the same directory.
4. Start MAP65 by clicking on its desktop icon.
5. Choose **Options** on the **Setup** menu and select the **Station** tab (screen shot on next page). Enter your callsign, 6-digit grid locator, and other parameters as required for your station. Be sure to check **Xpol** if yours is a dual-polarization system, and uncheck it for single polarization.





6. If you will be using *Linrad* or *SDR-Radio* for data acquisition, the box labeled **Fadd** can be used to enter a nominal difference between the frequency reported by that program and your corresponding on-the-air frequency. For example, if your RF chain converts 144 to 28 MHz, enter 116.0 for **Fadd**. For now you can leave parameters **Fcal** and **Dphi** set to zero. You may wish to optimize their values later. **Timeout** sets the number of minutes that callsigns and messages persist in the **Band Map** and **Messages** windows. Buttons labeled **+** and **x** inform MAP65 of the orientation of your dual linear-polarization antenna.

7. Select the **I/O Devices** tab:



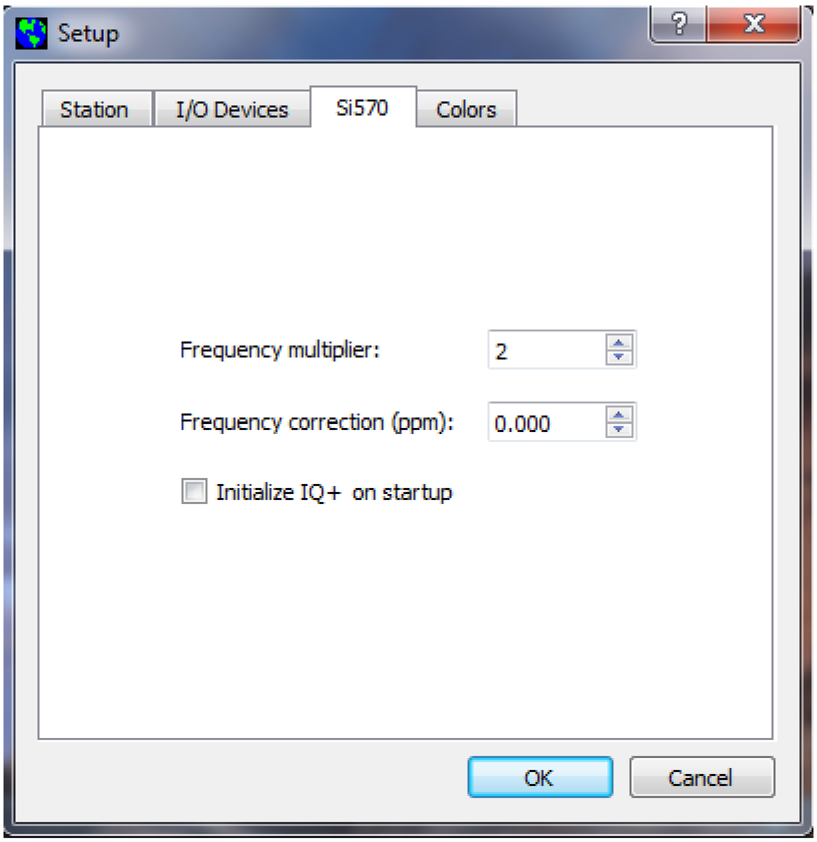
If you will use sound card input or a FUNcube Dongle, check **SoundCard** and choose the proper audio input device from the drop-down list. Depending on your hardware setup, it might be necessary to check the **Swap I/Q** box. (An incorrect setting reverses the direction of increasing frequency in the received passband.) If you will use *Linrad* or *SDR-Radio* for data acquisition, check **Network** and select the correct input sample rate for your hardware — either 96000 or 95238 Hz. These are the only sample rates supported by *MAP65*. You might need to change the network **Port** number from the default value 50004, so as to match the port selected in *Linrad* or *SDR-Radio*. Finally, select the output device you wish to use for Tx audio.

8. If your receiver uses the Si570 synthesizer chip and you want *MAP65* to be able to set its frequency, go to the **Si570** tab and set the parameters **Frequency multiplier** and **Frequency correction (ppm)** as required. The IQ+ receiver uses a frequency multiplier of 2, while the SoftRock uses 4. If you have determined that the Si570 master oscillator is slightly off frequency, you can

enter a suitable correction in parts per million (ppm). The commanded Si570 frequency will be

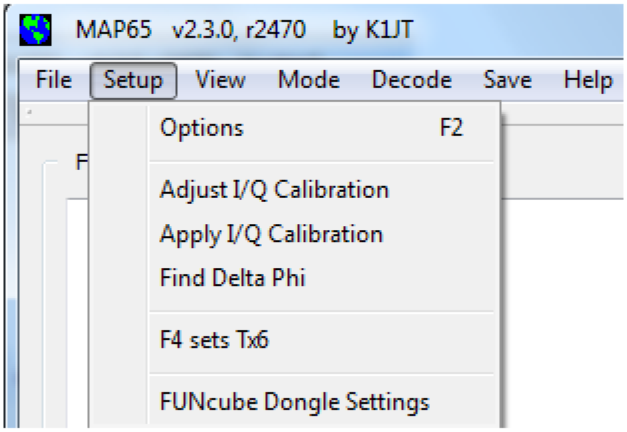
Multiplier × (1.0 + 0.000001 × Correction) × ForceCenterFrequency

where **ForceCenterFrequency** is a value (in MHz) entered in a box at bottom right of the Wide Graph window. Be sure to check the box labeled **Initialize IQ+ on startup** if you want your IQ+ receiver to be reset each time MAP65 starts.

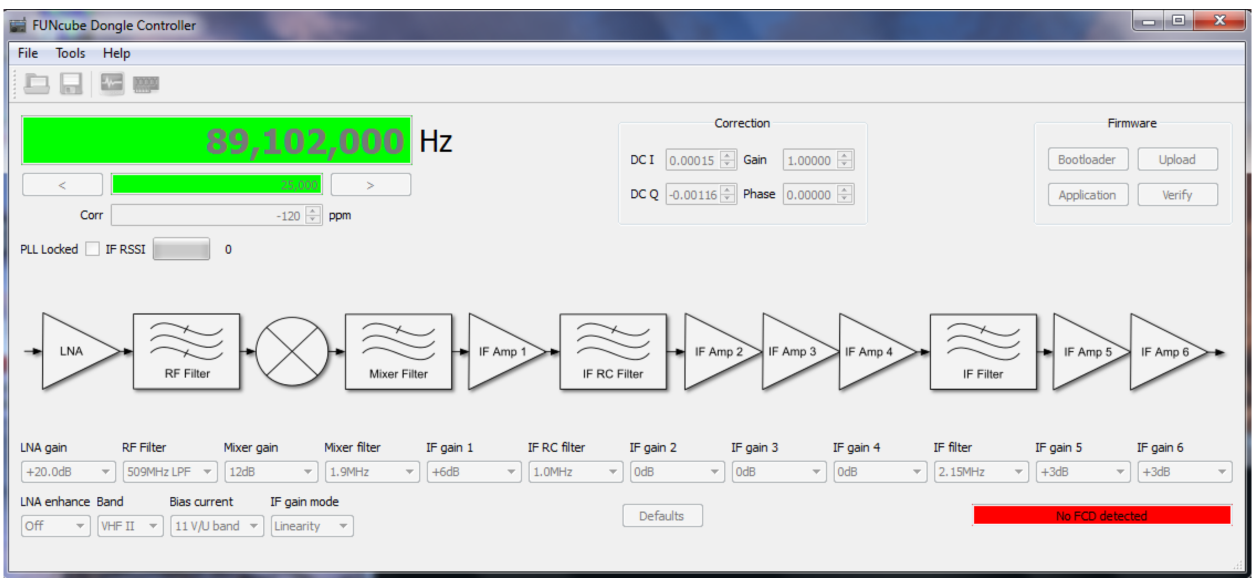


9. Click **OK** to dismiss the Setup dialog window.

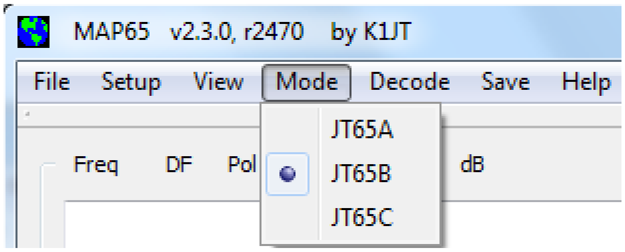
10. If you are using a FUNcube Dongle, you can set its parameters by clicking **FUNcude Dongle Settings** on the **Setup** menu.



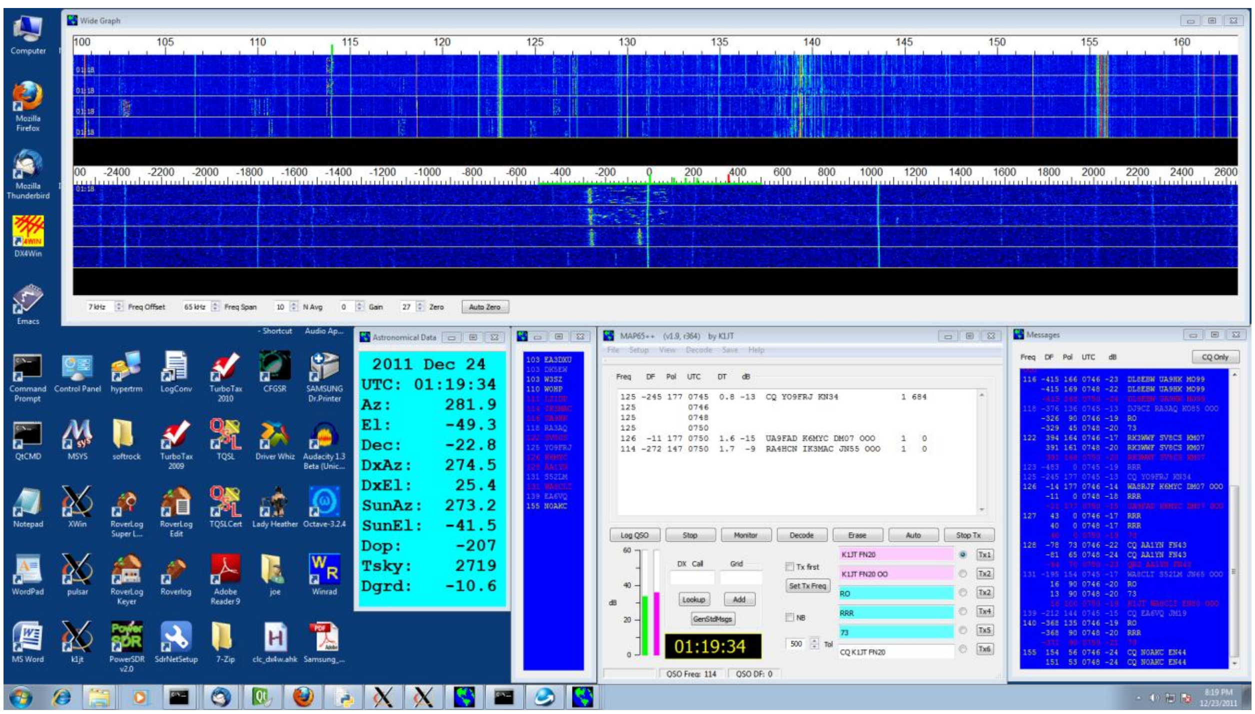
This action will start a program to configure your FUNcube Dongle. Detailed instructions can be found [here](#).



11. On the **Mode** menu, select JT65 sub-mode A, B, or C. By convention JT65A is generally used for EME on 50 MHz, JT65B on 144 and 432 MHz, and JT65C at 1296 MHz and above.



12. Position the five main windows of MAP65 as you wish, possibly resizing some of them as desired. As an example, my typical screen setup looks something like the picture below. In an EME contest you will probably want to widen the Band Map window to display callsigns in two columns.



13. If you will be using *Linrad* or *SDR-Radio*, start that program and be sure it is configured to send data packets to *MAP65* on the port selected in step 7. You want the “timf2” data packets from *Linrad*. When everything is working properly the vertical thermometer bars (at lower left of the main window) should show signal levels around 20–30 dB. In a single-polarization system, only the left bar will be active. Click the **Auto Zero** button at the bottom of the waterfall window

to adjust the zero level for its display. If you are using direct soundcard input or a FUNcube Dongle, enter the center frequency (for example, 144.125) at bottom right of the Waterfall and check the box labeled **Force Center Freq (MHz)**. This is the frequency converted by your receiver hardware to zero frequency in the baseband data stream. If you are using the IQ+ receiver, click **Set Rx Freq** to program the receiver's Si570 synthesizer to the correct frequency.

14. Adjust the spinners labeled **Freq Span** and **Freq Offset** for the most pleasing display of the desired portion of the band. For normal EME activity on the 2m band you will probably want to display a range something like 144.100 to 144.160 (displayed on the waterfall scale as 100 to 160). On 432 or 1296 MHz, an appropriate range is something like 0 to 90 (i.e., 432.000 to 432.090, etc.).
15. Check the box labeled **NB** to activate the noise blanker. With *MAP65* running in Monitor mode, adjust the blanking level by moving the horizontal slider. The percentage of blanked samples is displayed as the last number in the status-bar box labeled **Rx noise**. A good setting is somewhere around 1 – 5 % under quiescent conditions.

Decoding Tutorial

The best way to become familiar with *MAP65* is to play with some recorded data files. The program's wideband capability means that its recorded data files are large — about 20 MB per minute for single-polarization data, 40 MB for dual polarization. Compressed versions of one such file with dual-polarization data are available at http://physics.princeton.edu/pulsar/K1JT/061111_0746.tf2.zip (for Windows, 25.3 MB compressed) and http://physics.princeton.edu/pulsar/K1JT/061111_0746.tf2.bz2 (for Linux, 20.7 MB compressed). Download and decompress one of these files to produce a file named 061111_0746.tf2.

Start *MAP65*. On the **Setup | Options** screen, check **Xpol** and **+** and set **Dphi** = –50 so your settings will be consistent with those of the system that made the example recording. On the Wide Graph window, set **Freq Span** = 60 kHz, **N Avg** = 10, and **Zero** = 26. Check **NB** on the main window to turn on the noise blanker. Select **File | Open**, navigate to the directory to which you extracted the file 061111_0746.tf2, and open it.

In a short time (perhaps 5-20 s, depending on the speed of your computer) the text reproduced below should appear in the Messages window. *MAP65* decodes EME transmissions from 16 different stations in this one-minute interval. W3SZ is detected and decoded twice: his tropospheric signal at DF=360 Hz and EME signal at DF=471 Hz overlap in frequency as well as time, but *MAP65* decodes them correctly anyway.

```
Freq  DF Pol  UTC  dB
101  113   0 0746 -19  RRR
103  155 135 0746 -13  RO
     360 152 0746  -5  DK5EW W3SZ FN20         H
     471  58 0746 -21  DK5EW W3SZ FN20         V
110  321  56 0746 -18  LX/PA3FPQ W0HP
     485 135 0746 -14  73
111  -17  90 0746 -17  RRR
114  367 135 0746  -6  73
116  218 167 0746 -23  DL8EBW UA9HK MO99       H
118  307  90 0746 -19  RO
123   21 159 0746 -17  RK3WWF SV8CS KM07       V
127 -381 174 0746 -14  WA8RJF K6MYC DM07 OOO   H
128 -327 135 0746 -11  RRR
129 -448  67 0746 -21  CQ AA1YN FN43           V
132 -357  90 0746 -17  RO
140  262  90 0746 -20  RO
156 -216  54 0746 -23  CQ N0AKC EN44           H
```

MAP65 does a quick decode at the selected QSO frequency before processing the wideband data. At program startup the QSO frequency defaults to the center of the displayed region, in this case 144.125 MHz. Nobody was transmitting an EME signal at 144.125 at 0746 UTC on November 11, 2007, so in the main text window you should see a single line indicating that no JT65 signal was found at the selected QSO frequency at 0746:

```
125          0746
```

Quick decodes can be done at other frequencies by clicking on the desired frequency in the waterfall and then on **Decode**, or simply double-clicking on the desired frequency. Either action resets the QSO frequency and then invokes the quick decoder. Note that you can click to select a signal on either the upper (wideband) or lower (zoomed) waterfall.

Double-click on the upper waterfall at each of the frequencies 101, 103, 110, 111, 114, 116, 118, 123, 127, 128, 129, 132, 140, and 156. Your main text window should now look something like the following:

Freq	DF	Pol	UTC	DT	dB					
125			0746							
101	113	0	0746	2.3	-19	RRR	0	0	0	
103	155	135	0746	1.9	-13	RO	0	0	0	
103	360	152	0746	0.3	-5	DK5EW W3SZ FN20	1	0	152	H
103	471	58	0746	2.8	-21	DK5EW W3SZ FN20	1	0	58	V
110	321	56	0746	2.9	-18	LX/PA3FPQ W0HP	1	0	0	
110	485	135	0746	1.9	-14	73	0	0	0	
111	-17	90	0746	2.3	-17	RRR	0	0	0	
114	367	135	0746	1.9	-6	73	0	0	0	
116	218	167	0746	1.8	-23	DL8EBW UA9HK MO99	1	0	24	H
118	307	90	0746	2.3	-19	RO	0	0	0	
123	21	159	0746	2.9	-17	RK3WWF SV8CS KM07	1	0	86	V
127	-381	174	0746	2.4	-14	WA8RJF K6MYC DM07 OOO	1	0	147	H
128	-327	135	0746	1.9	-11	RRR	0	0	0	
129	-448	67	0746	2.8	-21	CQ AA1YN FN43	1	0	61	V
132	-357	90	0746	2.1	-17	RO	0	0	0	
140	262	90	0746	2.3	-20	RO	0	0	0	
156	-216	54	0746	3.4	-23	CQ N0AKC EN44	1	0	40	H

You might be interested to see specific examples of the difference between single-polarization and dual-polarization reception. A single-polarization version of the example data file can be downloaded from the following link: http://physics.princeton.edu/pulsar/K1JT/061111_0746.iq.zip. Download and decompress this file to produce a file named 061111_0746.iq. It contains exactly the same data as the dual-polarization file 061111_0746.tf2 for horizontal polarization, but data from the vertical receiver has been removed. Hit the **F2** key to open the **Options** window, and uncheck the **Xpol** box. Select **Erase Band Map and Messages** on the File menu, to clear those windows; then select **File | Open**, navigate to the directory where you extracted the file 061111_0746.iq, and open it. After a few seconds the following text should appear in the Messages window:

Freq	DF	Pol	UTC	dB	
103	155	0	0746	-14	RO
	354	0	0746	-6	DK5EW W3SZ FN20
110	324	0	0746	-22	LX/PA3FPQ W0HP
	485	0	0746	-14	73
114	367	0	0746	-7	73
116	218	0	0746	-23	DL8EBW UA9HK MO99
123	21	0	0746	-17	RK3WWF SV8CS KM07
127	-381	0	0746	-14	WA8RJF K6MYC DM07 OOO
128	-327	0	0746	-16	RRR
132	-357	0	0746	-21	RO
156	-216	0	0746	-25	CQ N0AKC EN44

Now only 10 EME transmissions are copied, compared with the 16 that were copied with adaptive polarization. (The transmission copied here from W3SZ is his terrestrial signal, not the EME signal.) This example is typical, but certainly not extreme. On 144 and 432 MHz, a receiver with adaptive polarization capability can double the number of EME signals copiable at any particular time. For signal levels close to the decoding threshold, the ratio is even higher.

If you are an experienced user of *WSJT* and its JT65 mode, you should now know enough to use *MAP65* effectively. If you don't have such experience, be sure to read Appendix B of this manual and the following documents:

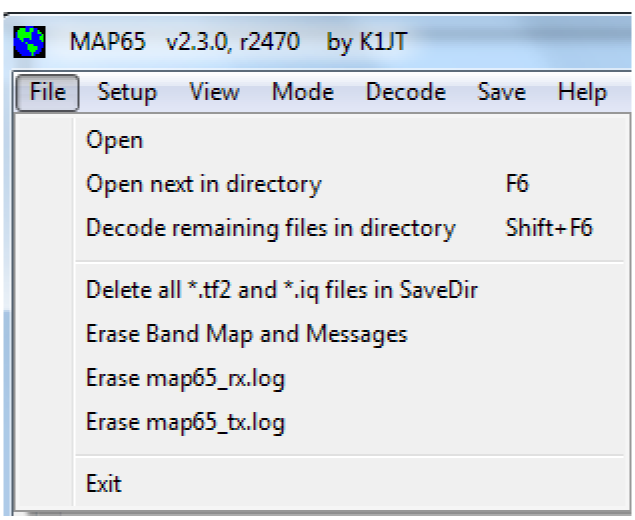
http://physics.princeton.edu/pulsar/K1JT/WSJT_User_600.pdf

http://physics.princeton.edu/pulsar/K1JT/WSJT_9.0_Supplement.pdf

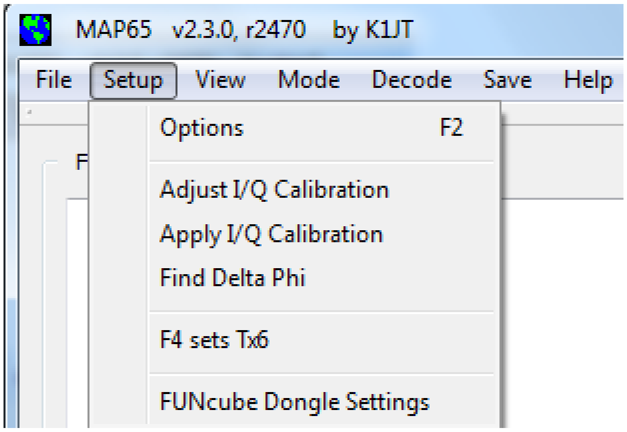
http://physics.princeton.edu/pulsar/K1JT/JT65.pdf

Additional Features and Options

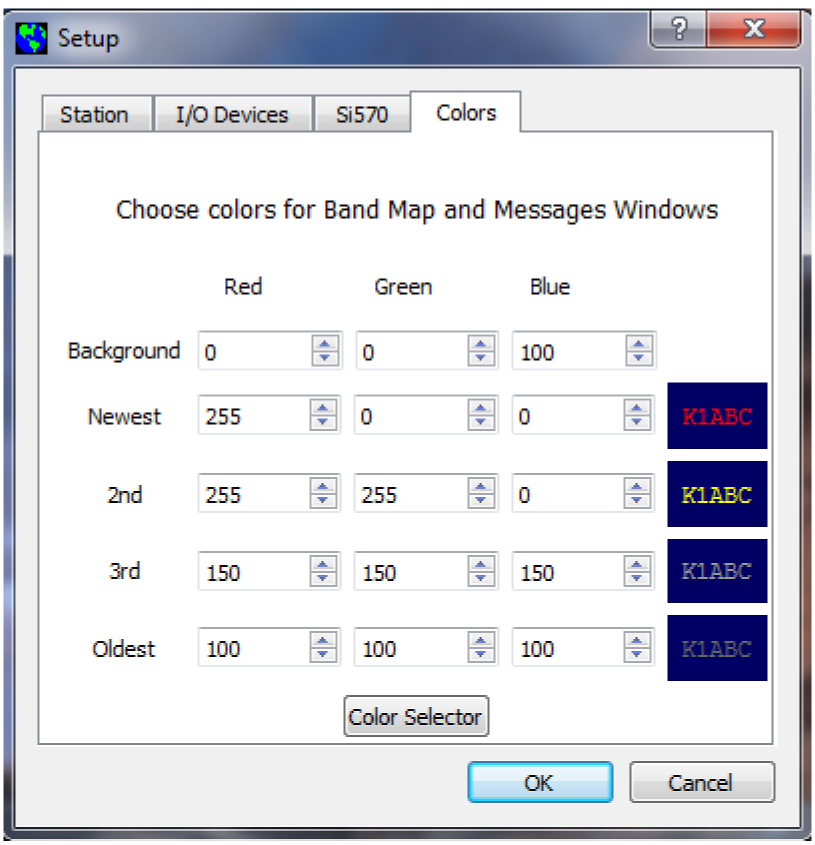
File: The File menu provides access to previously recorded wideband data. Functions are also provided for deleting all *.tf2 and *.iq files in the Save sub-directory, erasing the Band Map and Messages windows, and erasing the log files map65_rx.log and map65_tx.log.



Setup: The Setup menu offers a number of functions in addition to those already described.



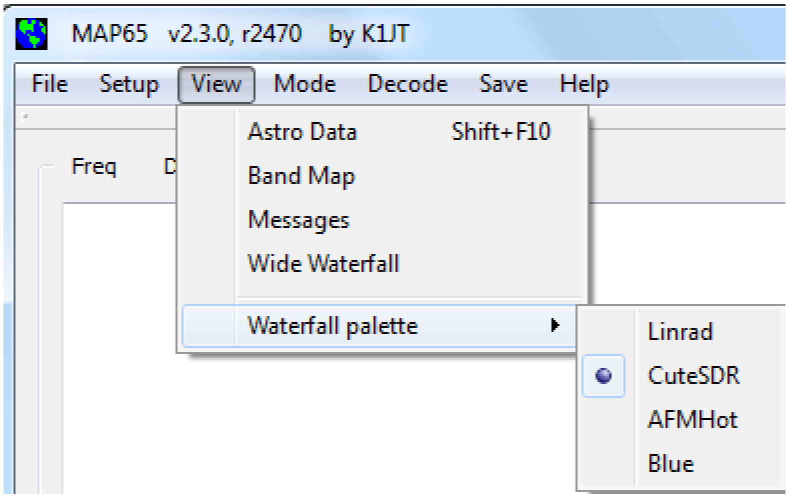
On the **Colors** tab of the **Setup | Options** screen (screen shot on next page) you can select any desired scheme for background and foreground colors in the Band Map and Messages windows. Colors are specified in RGB (red, green, blue) format, on a scale of 0 (dark) to 255 (brightest) for each color. Experiment with these settings for best visibility and contrast in the rectangular color patches at right.



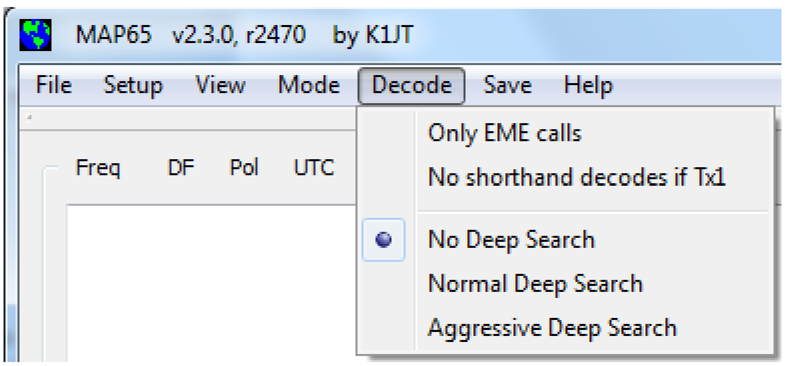
Setup | Adjust I/Q Calibration: When *MAP65* acquires input directly (i.e., without using *Linrad* or *SDR-Radio* as an intermediary) you may need to apply amplitude and phase calibrations to achieve adequate opposite-sideband rejection. To accomplish this task, have *MAP65* running in the usual way. Check **2D Spectrum** on the Wide Graph window, which causes the lower (zoomed) waterfall to be replaced by a spectral plot. Reduce the value of **N Avg** to 2, and introduce an unmodulated test signal strong enough to produce a narrow spike 2-3 cm high in the spectral plot. Click on this spike, thus marking it with a green tick on the upper and lower frequency scales. A red tick will appear at the image frequency, an equal distance on the other side of the zero-frequency bump. You will probably see a signal at the image frequency, perhaps something like 35 dB down from the main signal (roughly 1/3 its height). Select **Adjust I/Q Calibration** on the **Setup** menu. In a few seconds a message will appear in the decoded text window showing the relative amplitudes and phase errors (in radians) of the I and Q channels. Finally, check **Apply I/Q Calibration** on the **Setup** menu. The image signal should disappear, attenuated by at least 60–70 dB relative to the test signal.

Setup | Find Delta Phi: A dual-polarization system will ideally have matched phase-shift and delay in the X- and Y-channel hardware, including amplifiers, conversion stages, and feed lines. This condition is seldom the case in practice, but it's easy to compensate by means of a software calibration. Find a reasonably strong EME signal with roughly the same strength in the X and Y channels. (If your antenna is mounted in the "**+**" configuration, with horizontal and vertical elements, such a signal will have polarization angle around 45ºor 135º.) Activate Deep Search decoding (see the **Decode** menu, below) and double-click on this signal in the waterfall, making sure that a normal (not shorthand) message is decoded properly with both the Koetter-Vardy and Deep Search algorithms. Select **Find Delta Phi** on the **Setup** menu, and *MAP65* will then find the best-fit value of phase shift, **Dphi**. It's best to repeat this procedure with several signals, making sure you get results that are consistent to within ± 20 degrees or better. Enter the average value of **Dphi** on the **Station** tab of the **Setup | Options** screen.

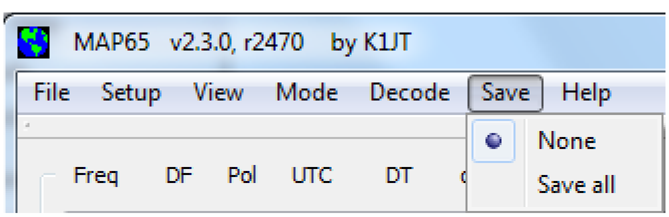
View: The View menu lets you redisplay any of the secondary program windows, in case you have deleted them, and allows you to choose different color palettes for the waterfalls.



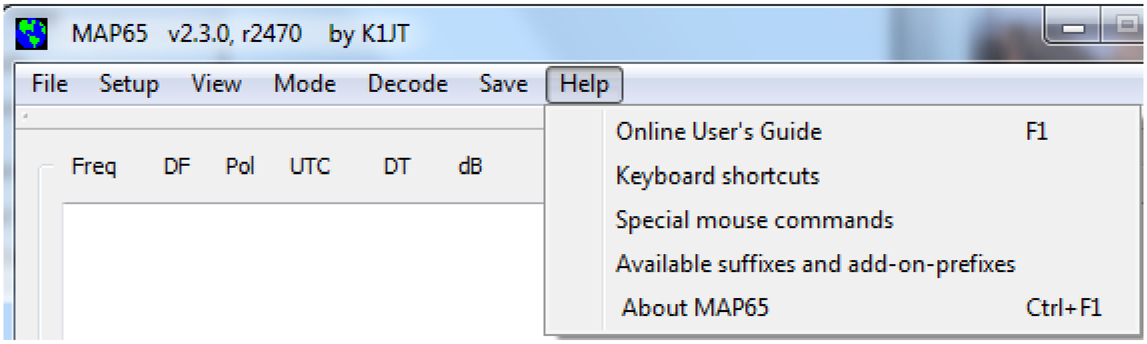
Decode: The Decode menu provides controls that adjust behavior of the JT65 decoder.



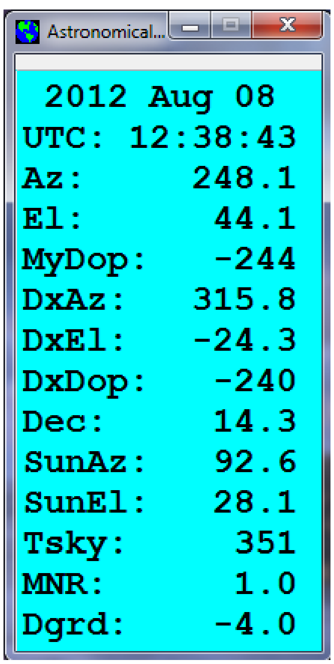
Save: Choose **Save All** on this menu to record wideband data for future use. (Remember that the data rate is about 20 MB/minute for a single-polarization system and 40 MB/minute for dual-polarization!)



Help: Choose **Online User's Guide** or hit **F1** to display the *MAP65 User's Guide* (the document you are now reading) in your browser. Choose **About MAP65** or hit **CTRL-F1** to see a brief message about MAP65 and its copyright information. The remaining items on this menu have yet to be implemented.



Astronomical Data: This window displays the current UTC date and time, the azimuth and elevation of the moon and sun at your location (and of the moon at the DX station's location), the EME Doppler shift of your own echo and of the DX station, declination of the moon, sky background temperature in direction of the moon, worst-case non-reciprocity of the EME path in dB, and the approximate path degradation from ideal EME conditions. You may select a desired font size for this window on the **Setup | Options | Station** tab.



Appendix A: Installed and Generated Files

After installing *MAP65* as described in steps 1–3 on page 5, the following files will be present in the installation directory:

```
afmhot.dat          Data for AFMHot palette
blue.dat            Data for Blue palette
CALL3.TXT           Callsign database
fftwf-wisdom.exe    Program for FFT optimizations
fftwf_wisdom.dat    Results of running fftwf-wisdom.exe
kvasd.exe           Koetter-Vardy decoder
m65.exe             Slave program, controls all decoding steps
map65.exe           Master MAP65 program
qthid.exe           Slave program for configuring FUNcube
save                Directory for saved files of wideband data
unins000.dat        Data for uninstall utility
unins000.exe        Default uninstall program
wisdom1.bat         Batch file to run short FFT optimizations
wisdom2.bat         Batch file to run long FFT optimizations
wsjt.ico            WSJT icon
```

In addition, the following *.dll support files will have been installed in your system directory, typically C:\Windows\System32 on a Windows system:

```
libfftw3f-3.dll
libgcc_s_dw2-1.dll
libstdc++-6.dll
libusb0.dll
mingwm10.dll
palir-02.dll
QtCore4.dll
QtGui4.dll
QtNetwork4.dll
QtSvg4.dll
qwt.dll
```

You might be curious about additional files that appear in the *MAP65* installation directory after using the program for a while. These include:

```
kvasd.dat           Data for the Koetter-Vardy decoder
livecq.txt          Information for web-based "LiveCQ" display
map65.ini           Saved configuration parameters
map65.log           Log file for decoder diagnostics, etc.
map65_rx.log        Log of all decoded messages
map65_tx.log        Log of all transmitted messages
prefixes.txt        List of available add-on DXCC prefixes
timer.out           Profile showing times in decoder routines
tmp26.txt           Intermediate file used by decoder
```

Appendix B: The JT65 Protocol

A detailed description of the JT65 protocol was published in QEX for September-October, 2005 (see http://physics.princeton.edu/pulsar/K1JT/JT65.pdf). Briefly stated, JT65 uses 60 s T/R sequences and carefully structured messages. Standard messages are compressed so that two callsigns and a grid locator can be transmitted with just 71 bits. A 72^{nd} bit serves as a flag to indicate that the message consists of arbitrary text (up to 13 characters) instead of callsigns and a grid locator. Special formats allow other information such as callsign prefixes (e.g., ZA/PA2CHR) or numerical signal reports (in dB) to be substituted for the grid locator. The aim of source encoding is to compress the common messages used for EME QSOs into a minimum fixed number of bits. After compression, a Reed Solomon (63,12) error-correcting code converts 72-bit user messages into sequences of 63 six-bit channel symbols.

JT65 requires tight synchronization of time and frequency between transmitter and receiver. Each transmission is divided into 126 contiguous time intervals or symbols, each of length 4096/11025 = 0.372 s. Within each interval the waveform is a constant-amplitude sinusoid at one of 65 pre-defined frequencies, and frequency changes between intervals are accomplished in a phase-continuous manner. Half of the channel symbols are devoted to a pseudo-random synchronizing vector interleaved with the encoded information symbols. The sync vector allows calibration of relative time and frequency offsets between transmitter and receiver.

A transmission nominally begins at t = 1 s after the start of a UTC minute and finishes at t = 47.8 s. The synchronizing tone is at 11025*472/4096 = 1270.5 Hz, and is normally sent in each interval having a "1" in the following pseudo-random sequence:

100110001111110101000101100100011100111101101111000110101011001
101010100100000011000000011010010110101010011001001000011111111

Encoded user information is transmitted during the 63 intervals not used for the sync tone. Each channel symbol generates a tone at frequency 1275.8 + 2.6917 Nm Hz, where N is the value of the six-bit symbol, $0 \le N \le 63$, and m is 1, 2, or 4 for JT65 sub-modes A, B, or C. The signal report “OOO” is conveyed by reversing sync and data positions in the transmitted sequence. Shorthand messages dispense with the sync vector and use intervals of 1.486 s (16,384 samples) for the alternating tones. The lower frequency is always 1270.5 Hz, the same as that of the sync tone, and the frequency separation is 26.92 nm Hz with n = 2, 3, 4 for the messages RO, RRR, and 73.

Appendix C: Astronomical Calculations

MAP65 carries out a number of astronomical calculations to provide tracking data for the sun and moon, Doppler shifts for EME signals, sky background temperatures, etc. You may find it useful to know something about the nature and accuracy of these calculations.

The state of the art for establishing three-dimensional locations of the sun, moon, and planets at a specified time is embodied in a numerical model of the solar system maintained at the Jet Propulsion Laboratory. The model has been numerically integrated to produce tabular data that can be interpolated with very high accuracy. For example, the celestial coordinates of the moon or a planet can be determined at a specified time to within about 0.0000003 degrees. Although the ephemeris tables and interpolation routines could easily be incorporated into *MAP65*, the accuracy provided would be overkill for our desired purposes. Instead, *MAP65* uses closed-form calculations based on a limited number of harmonic terms fit to the high-accuracy data.

The precise algorithms used for solar and lunar positions were developed by Van Flandern and Pulkkinen (*Astrophysical Journal Supplement Series,* 44, 391–411, 1979). Series expansions from this paper yield accuracies of about 0.02 and 0.04 deg for the sun and moon positions, respectively, and they will remain almost this good for nearly a thousand years. At this level of accuracy the effects of nutation and aberration can be ignored, as can most of the smaller planetary perturbations. (Perturbations involving the Moon, Jupiter, Saturn, and Uranus are included, however.) Ephemeris Time and Universal Time are taken as equivalent, and the time steps associated with leap seconds are ignored. These and all other approximations employed are consistent with the specified accuracy level.

The coordinates displayed for the sun are geocentric. Since the moon is much closer its diurnal parallax is significant, and therefore topocentric coordinates are given for your specified location. For both sun and moon, the listed elevation is the apparent position of the center of the disk.

To improve the accuracy of predicted Doppler shifts of EME signals, a larger number of terms was used in the series expansion for lunar distance. *MAP65* properly accounts for the oblateness of the Earth when establishing locations relative to the Earth's center. Final accuracy of the Doppler shifts computed by *MAP65* is better than 1 Hz at 10 GHz, and this has been confirmed by direct comparison with a calculation based on the JPL ephemeris.

Sky background temperatures reported by *MAP65* are derived from the all-sky 408 MHz map of Haslam et al. (*Astronomy and Astrophysics Supplement Series, 47, 1, 1982)*, scaled by frequency to the (–2.6) power. This map has angular resolution of about 1 degree; most amateur EME antennas have much broader beamwidths than this, so the data have been smoothed to 15-degree resolution.

Appendix D: Source Code

MAP65 is an open-source program released under the GNU General Public License. Source code is available from the public repository at http://developer.berlios.de/projects/wsjt/. To compile the program you will need to install open source packages for Subversion, QtSDK, qwt, g++, and g95 or gfortran. The full source code may be downloaded by using the command

```
svn co svn://svn.berlios.de/wsjt/branches/map65 map65
```