

# MAP65: A Panoramic, Polarization-Matching Receiver for JT65

Joe Taylor, K1JT

Presented at Microwave Update: October 20, 2007

MAP65 is a computer program designed as the back end of a wideband polarization-matching receiver for JT65 signals. It works together with the Linrad<sup>1</sup> software written by SM5BSZ, and ideally takes advantage of RF and IF hardware providing signal channels for two orthogonal polarizations. As an example, my current 144 MHz station uses dual-polarization yagis and matched baseband converters. Linrad uses a four-channel 24-bit soundcard to sample I and Q baseband signals for each polarization at 96 kHz. After Linrad's superb wideband noise blanking has been applied, the digitized signals are passed on to MAP65. MAP65 automatically finds all detectable JT65 signals in a 90 kHz passband, matches the linear polarization angle of each one, decodes their messages, and provides the operator with a "band map" displaying callsigns, operating frequencies, polarization angles, and messages received over the past 20 minutes or so. MAP65 provides a companion transmitting facility, and it runs under either Windows or Linux. Its principal intended application is EME or "moonbounce" on the amateur VHF and UHF bands. Many of its features will also be useful on the microwave bands, for both EME and terrestrial contacts.

MAP65 uses the JT65 protocol<sup>2</sup> popularized in the program WSJT<sup>3</sup>. JT65 is designed to enable EME contacts between moderate-sized amateur VHF/UHF stations. Its high efficiency is due in part to its use of time-synchronized transmissions, compact, structured messages, and strong forward error correction. The most important difference between MAP65 and WSJT (when the latter is running in JT65B mode) is that WSJT receives a single 2 – 4 kHz bandwidth and decodes one signal at a time. In contrast, MAP65 works with dual-polarization antennas and accepts a full 90 kHz bandwidth. MAP65 scans the entire received passband, automatically determining the frequency, drift rate, time offset, and polarization state of every detectable JT65 signal, and decoding each one.

I have been testing various versions of MAP65 on the air since May 2007 — first in receive-only mode and more recently, over the interval July 3 to August 9, 2007, to make more than 160 EME QSOs on 144 MHz. MAP65 still needs polishing and will surely continue to evolve, but already at version 0.8 r502 it is stable, reasonably mature, and a pleasure to use. It's very exciting to have the whole 144 MHz digital EME band (144.070 – 144.160) available on one's computer screen simultaneously — including the contents of all messages being sent and received. If the moon is up, and especially if it has not yet set in Europe, I generally see ten to twenty EME signals on MAP65's waterfall at any time. They originate from anywhere in the world where the moon is above the horizon, and the program decodes them all. When a new station shows up and calls CQ, I see his signal immediately and can respond after his first transmission. No advance knowledge, schedules or internet liaison is required.

---

<sup>1</sup> Linrad Home Page: [www.nitehawk.com/sm5bsz/linuxdsp/linrad.htm](http://www.nitehawk.com/sm5bsz/linuxdsp/linrad.htm)

<sup>2</sup> J. Taylor, K1JT, "The JT65 Communications Protocol", *QEX*, September-October 2005, pp. 3–12.

<sup>3</sup> This paper assumes some basic familiarity with WSJT. If you need more background, the WSJT Home Page can be found at [physics.princeton.edu/pulsar/K1JT/](http://physics.princeton.edu/pulsar/K1JT/)

To exhibit and advertise the power of MAP65, I have had some fun playing radio hide-and-seek with other stations. I ask them to transmit arbitrary messages at random frequencies in the range 144.100 to 144.160, using either JT65 sequence (that is, transmitting in either the odd or even UTC minute) and any polarization. I believe that MAP65 has found and copied *all* of the resulting test messages via the moon. A few operators around the world have accepted the implied challenge and sent me random messages when they knew I was monitoring, but without making their own presence known. As far as I have been able to determine MAP65 copied all of those messages, too.

A screen shot of MAP65 has been posted on the WSJT home page at [physics.princeton.edu/pulsar/K1JT/MAP65\\_5.JPG](http://physics.princeton.edu/pulsar/K1JT/MAP65_5.JPG). The full-screen snapshot does not reproduce well in black and white, so is not included here, but two portions that contain only text are copied below. The snapshot was taken after MAP65 had processed data recorded between 0745 and 0800 UTC on November 11, 2006, during the second weekend of last year's ARRL EME contest. The minutes starting at 07:47, 07:49, 07:51, and 07:53 are absent from the recording because I was transmitting then, working WA8CLT on 144.131. If you were "on the moon" at this time using JT65B on 2 meters, your signal is probably among those found and decoded by MAP65. My antenna at that time was quite modest: a pair of 21-ft cross-polarized yagis stacked side by side, some ten feet above my roof.

To gain some operational understanding of MAP65, I suggest that you read the remainder of this article with the full screen dump in view. Point your browser to the URL given above and be sure to expand the image to full size. Better yet, print a clean copy at full resolution in landscape orientation, and keep it at hand.

The screen shot shows four active MAP65 windows:

1. The main window, at bottom left of the screen, is similar to the main WSJT window. It is used for conducting QSOs in nearly the same way as with WSJT. A MAP65 manual has not yet been written, but many details of the program's operation are identical to WSJT and are described in the *WSJT6 User's Guide and Reference Manual*, available from the "Documentation" link on the WSJT home page, [physics.princeton.edu/pulsar/K1JT/](http://physics.princeton.edu/pulsar/K1JT/).
2. At top right is the Waterfall window, showing two separate panels. The upper panel gives the wideband spectral view, in this case extending from 144.075 to 144.171 MHz (the "144." part of the frequency scale is suppressed). I live in a densely populated region and the birdie situation is usually awful, as you can see: the continuous vertical lines are all birdies of one kind or another. The ones with messy sidebands at 144.091 and 144.140 are especially annoying. Nevertheless, you can see many EME signals in this display. With the help of the decoded text starting on the next page, you should be able to find the transmissions from DK5EW, EA3DXU, and W3SZ at 144.103, LX/PA3FPQ, IW4ARD, AA7A, and W0HP at 110, HB9Q and LZ1DP at 111, IK3MAC at 114, DL8EBW and UA9HK at 116, RA3AQ and DJ9CZ at 118, RK3WWF, I1ANP, SV8CS, and N5KDA at 123, K7MAC at 124, YO9FRJ and EB1DNK at 125, K6MYC and RN4AT at 126, KB8RQ, SP2JYR, and UA9SL at 127, AA1YN at 128, S52LM, WA8CLT, and F6HVK at 131, EA6VQ at 139, DH7FB at 140—yes, right in the middle of all that garbage! — and DF2ZC at 152. There are more signals in there, too—and MAP65 sniffs them out and decodes

them. Nearly 50 callsigns are decoded in this 11-minute data segment, about which there is nothing special: it just represents a time that I remembered to turn on Linrad's recording feature during the EME contest, so as to save the raw data.

The lower waterfall panel gives a “zoomed” view around the operator’s selected QSO frequency — in this instance 144.128 MHz, where AA1YN is calling CQ. AA1YN is the signal at frequency offset  $DF = 220$ . At  $DF = -660$  Hz you can see the strong synchronizing tone of the “big gun” KB8RQ, who was running EME contest QSOs on 144.127. During the displayed time interval he finishes a QSO with someone (you can see the dual tones of his shorthand RRR and 73 messages near the bottom of the waterfall, at 07:48 and 0750 UTC). Then he comes back to SP2JYR and works him; and finally at 0759 he is called by UA9SL.

- At bottom right of the full-screen picture, the “Messages” window lists the results of all decoded transmissions over a time interval set by the user. Messages received in the most recent two minutes are displayed in red, while progressively older ones are indicated with yellow and then diminishing shades of gray before they time out and vanish from the screen. Each message is preceded by numbers giving the nominal frequency in kHz above the band edge (101 means 144.101, etc.), the additional frequency offset  $DF$  in Hz, the measured polarization angle in degrees, the UTC, and the signal level in dB relative to the noise in 2500 Hz bandwidth. The full list of messages is sorted by frequency and then by UTC, and  $DF$  is used to group together all transmissions from the same station. The scrolling Message window’s contents for the 11 recorded minutes look like this:

Freq	DF	Pol	UTC	dB	Message
101	-220	0	0746	-20	RRR
	-21	90	0745	-18	RRR
103	-178	135	0746	-19	RO
	-178	137	0748	-18	CQ EA3DXU JN11
	-178	135	0750	-21	73
	-70	140	0745	-24	EA3DXU DK5EW JN47 OOO
	-70	138	0755	-27	CQ DK5EW JN47
	36	142	0746	-4	DK5EW W3SZ FN20
	141	63	0746	-22	DK5EW W3SZ FN20
110	-53	165	0752	-18	LX/PA3FPQ IW4ARD
	-53	168	0754	-18	LX/PA3FPQ IW4ARD
	-50	165	0756	-19	FPQ ARD RO
	-50	162	0758	-19	FPQ ARD 73
	-12	7	0745	-20	KDA FPQ RRR
	-9	64	0746	-19	LX/PA3FPQ W0HP
	-15	103	0755	-23	IW4ARD LX/PA3FPQ OOO
	-15	99	0759	-22	AA7A LX/PA3FPQ OOO
	155	0	0746	-17	73
	243	95	0756	-20	LX/PA3FPQ AA7A
111	-350	90	0746	-19	RRR
	-98	135	0745	-19	RRR
	-101	135	0755	-18	RRR
	-104	135	0757	-19	73
	-101	139	0759	-14	CQ HB9Q JN47
	-25	0	0750	-24	HB9Q LZ1DP KN22

Freq	DF	Pol	UTC	dB	Message
114	-69	0	0745	-22	73
	31	135	0746	-21	73
	34	153	0748	-9	CQ IK3MAC JN55
	28	152	0750	-9	RA4HCN IK3MAC JN55 OOO
	19	135	0752	-22	RRR
	16	135	0754	-21	73
	25	151	0756	-8	CQ IK3MAC JN55
	19	153	0758	-9	CQ IK3MAC JN55
116	-115	167	0746	-23	DL8EBW UA9HK MO99
	-115	169	0748	-22	DL8EBW UA9HK MO99
	-115	167	0750	-24	DL8EBW UA9HK MO99
	-112	177	0752	-23	DL8EBW UA9HK MO99
	-112	168	0754	-21	DL8EBW UA9HK MO99
	-109	168	0756	-21	DL8EBW UA9HK MO99
	-109	169	0758	-21	DL8EBW UA9HK MO99
	-44	104	0757	-25	UA9HK DL8EBW JO31 OOO
118	-76	137	0745	-13	DJ9CZ RA3AQ KO85 OOO
	-76	140	0755	-10	QRZ RA3AQ
	-76	143	0757	-11	QRZ RA3AQ
	-79	145	0759	-12	OH6KTL RA3AQ KO85 OOO
	-26	90	0746	-19	RO
	-29	90	0748	-20	73
123	-491	156	0758	-21	RK3WWF I1ANP JN44
	-309	168	0746	-17	RK3WWF SV8CS KM07
	-309	166	0748	-20	RK3WWF SV8CS KM07
	-309	171	0750	-20	RK3WWF SV8CS KM07
	-309	167	0752	-20	RK3WWF SV8CS KM07
	-309	173	0754	-19	RK3WWF SV8CS KM07
	-189	0	0745	-22	RRR
	-189	175	0755	-20	CQ RK3WWF KO72
	-189	175	0757	-20	CQ RK3WWF KO72
	-189	172	0759	-18	CQ RK3WWF KO72
	139	164	0758	-19	RK3WWF N5KDA EM41
124	244	75	0754	-17	CQ K7MAC DN13
	250	71	0756	-16	CQ K7MAC DN13
	247	72	0758	-17	CQ K7MAC DN13
125	-255	87	0752	-21	YO9FRJ EB1DNK IN62
	-255	89	0754	-24	YO9FRJ EB1DNK IN62
	-255	91	0756	-21	YO9FRJ EB1DNK IN62
	-255	88	0758	-20	YO9FRJ EB1DNK IN62
	55	178	0745	-13	CQ YO9FRJ KN34
	108	73	0754	-24	YO9FRJ W1FKF FN42
126	-221	3	0755	-18	K6MYC RN4AT LN29
	-224	1	0757	-21	K6MYC RN4AT LN29
	-230	0	0759	-19	RO
	-42	164	0759	-22	KB8RQ UA9FAD LO88
	289	179	0746	-14	WA8RJF K6MYC DM07 OOO
	283	0	0748	-21	RRR
	289	179	0750	-15	UA9FAD K6MYC DM07 OOO
	289	2	0752	-15	UA9FAD K6MYC DM07 OOO
	292	3	0754	-15	F6APE K6MYC DM07 OOO
	289	0	0756	-19	RRR
	292	179	0758	-14	RN4AT K6MYC DM07 OOO

Freq	DF	Pol	UTC	dB	Message
127	-99	175	0759	-18	KB8RQ UA9SL LO71
	340	90	0746	-18	RRR
	337	90	0748	-19	RRR
	340	90	0750	-19	RRR
	340	110	0752	-13	SP2JYR KB8RQ EM79 OOO
	340	115	0754	-14	SP2JYR KB8RQ EM79 OOO
	335	135	0756	-22	RRR
	332	135	0758	-23	73
128	222	77	0746	-22	CQ AA1YN FN43
	219	68	0748	-24	CQ AA1YN FN43
	219	76	0750	-23	QRZ AA1YN FN43
	219	72	0752	-25	QRZ AA1YN FN43
	216	70	0754	-22	CQ AA1YN FN43
	216	76	0756	-24	CQ AA1YN FN43
	216	64	0758	-23	CQ AA1YN FN43
130	27	41	0755	-15	CQ IK1UWL JN33
	18	42	0757	-18	CQ IK1UWL JN33
	1	46	0759	-16	CQ IK1UWL JN33
131	44	119	0754	-21	K1JT F6HVK JN27
	44	114	0756	-19	K1JT F6HVK JN27
	105	160	0745	-17	WA8CLT S52LM JN65 OOO
	111	159	0755	-21	CQ S52LM JN65
	111	155	0757	-17	CQ S52LM JN65
	111	153	0759	-17	CQ S52LM JN65
	313	90	0746	-19	RO
	313	90	0748	-19	73
	319	96	0750	-19	K1JT WA8CLT EN80 OOO
	322	90	0752	-21	RRR
	325	90	0754	-19	73
139	88	148	0745	-16	CQ EA6VQ JM19
	74	0	0755	-18	RRR
	71	135	0757	-18	73
	71	150	0759	-15	CQ EA6VQ JM19
140	-91	95	0752	-25	EA/DJ4UF DH7F
	-94	90	0756	-26	RO
	-68	90	0746	-21	RO
	-71	90	0748	-21	RRR
	-71	90	0750	-22	73
141	174	141	0755	-19	CQ EA3DXU JN11
	171	135	0757	-17	CQ EA3DXU JN11
	169	140	0759	-19	CQ EA3DXU JN11
152	-27	96	0757	-21	KA1VHF DF2ZC JO30
	-30	98	0759	-17	KA1VHF DF2ZC JO30
	193	119	0750	-25	CQ KA1VHF EM89
155	111	0	0755	-18	73
	454	59	0746	-24	CQ N0AKC EN44
	451	57	0748	-24	CQ N0AKC EN44
	454	60	0750	-26	CQ N0AKC EN44
	454	51	0752	-26	N5KDA N0AKC EN44 OOO
	454	45	0756	-21	73
	457	42	0758	-26	TK5JJ N0AKC EN44 OOO
156	-221	103	0755	-6	N0AKC W3SZ FN20
	-215	104	0757	-5	N0AKC W3SZ FN20

4. The window labeled “Band Map,” at top left in the full-screen picture, presents a summary list by frequency of all stations that MAP65 has decoded in the specified time interval. Again, color codes are used to indicate aging. At the time of the screen dump, the full contents of the Band Map were as shown below. You can see that EA3DXU, DK5EW, and W3SZ were operating on 144.103; IW4ARD, W0HP, LX/PA3FPQ, and AA7A were on 144.110; HB9Q and LZ1DP on 144.111; and so on.
- 5.

103	EA3DXU	123	SV8CS	131	F6HVK
103	DK5EW	123	RK3WWF	131	S52LM
103	W3SZ	123	N5KDA	131	WA8CLT
110	IW4ARD	124	K7MAC	139	EA6VQ
110	W0HP	125	EB1DNK	140	DH7F
110	LX/PA3	125	YO9FRJ	141	EA3DXU
110	AA7A	125	W1FKF	152	DF2ZC
111	HB9Q	126	RN4AT	152	KA1VHF
111	LZ1DP	126	UA9FAD	155	N0AKC
114	IK3MAC	126	K6MYC	156	W3SZ
116	UA9HK	127	UA9SL		
116	DL8EBW	127	KB8RQ		
118	RA3AQ	128	AA1YN		
123	I1ANP	130	IK1UWL		

The 2.5 pages of un-edited EME traffic reproduced above contain *no* decoding errors, and such performance is typical. JT65 signals contain powerful forward error correction in the form of a Reed Solomon (63, 12) code. As a consequence, messages are nearly always decoded exactly as sent, or not at all.

Some amusing peculiarities can be seen in the text copied from the Messages and Band Map windows. At UTC 0746 you can see that W3SZ was decoded twice at 144.103, with frequency offsets DF that differ by 105 Hz. Roger is located only 70 miles from my home; the lower frequency is his tropospheric signal, and the higher one his Doppler-shifted EME signal, some 18 dB weaker. On 144.110, a DXpedition group signing LX/PA3FPQ is working a contest pile-up. At the time of the snapshot they are working IW4ARD, and the operator is sending messages like “ARD FPQ RRR” (rather than the shorthand RRR without callsigns) to avoid any possible confusion over who is being worked. You can see that W0HP and AA7A are queuing up to work the Luxembourg group next. At 144.140 you can tell that DH7FB is using an old version of WSJT. He is calling EA/DJ4UF, but the older version did not handle add-on DXCC prefixes like “EA/” automatically. Therefore WSJT sent his message as plain text, and the last letter of his callsign (the 14th character in the message) was necessarily truncated since JT65 plain-text messages are limited to 13 characters. Finally, you may notice that the polarization of JT65 shorthand messages is always reported as 0, 45, 90, or 135 degrees. At present, a program shortcut causes these polarizations to be measured only to the nearest 45 degrees. This shortcut is unnecessary, and will be removed.

Like WSJT, MAP65 does a “quick decode” at your specified QSO frequency, starting at  $t = 52$  s in each reception minute. This enables you to change your Tx message to respond to the message received, in time to start your transmission at the top of the minute. Over the next ten seconds or so the program finds and decodes all of the JT65 signals discernible in the 90 kHz passband (or, optionally, some designated portion thereof). The MAP65 decoder is robust and produces very few

garbage decodes, even in the presence of messy QRM. Once set up properly it finds, synchronizes, matches polarization, and decodes JT65 signals entirely on its own — even amidst a jungle of birdies — without operator intervention. It does *not* make QSOs by itself, however. An operator must make all decisions about what message to send and when a QSO has been completed. It should be obvious that operator skill is required in many other ways, as well.

MAP65 is still in the process of development, but is already generating considerable excitement. I shall turn now to answering a few of the many queries I have been receiving about it.

1. MAP65 runs equally well under Windows and Linux. WSJT runs on the FreeBSD and Macintosh platforms, as well, and I expect this will be true of MAP65 — but it has not yet been tested because I do not own machines running those operating systems.
2. The Linrad “front end” of the Linrad-MAP65 wideband receiver can run on the same computer as MAP65, or on another computer connected to the same local area network. The network need be nothing more than an RJ45-style crossover cable between the two computers. If you use a single computer you will probably want to outfit it with two monitors, since there is a lot of information to display.
3. MAP65 is memory hungry: the present version requires about 670 MB of RAM in addition to that used by the operating system. I use a five-year-old 1.4 GHz machine with 1 GB of memory and its performance is acceptable, but a faster machine would be even better. Linrad can be run on a slower computer with 256 MB of RAM or even less. Your monitors (one for Linrad, one for MAP65) should each display at least 1024 × 768 pixels. The sound card on the MAP65 machine is used only for output of your transmit audio. All MAP65 input signals come in the form of ethernet packets sent by Linrad. You can listen to narrow-band output from the receiver via the output sound card on the Linrad computer.
4. The present version of MAP65 assumes that you have a cross-polarized antenna and that both polarizations are available simultaneously on receive. In other words, you should have two tower-mounted preamps and separate Rx feedlines for each polarization. My system uses the WSE converters designed by SM5BSZ, especially for use with Linrad. My Linrad computer runs Linux (the Kubuntu 6.06 distribution) and uses a Delta-44 soundcard to sample a pair of I/Q channels (four analog signals in all) at 96 kHz. With other receiving hardware you could use real rather than complex sampling, with two channels being sampled at 192 kHz.
5. In the future I will probably provide a MAP65 option for single-polarization use. You should note, however, that on the VHF and lower UHF bands where EME conventionally uses linear polarization, some of the power of the Linrad-MAP65 combination will be lost. It’s hard to overstate the advantage gained by having both polarizations available simultaneously for receiving EME signals on any band where linear polarization is the norm. On 1296 MHz and above, where circular polarization generally prevails, a single channel will be fully effective.
6. It should be possible to use the SDR-IQ and SDR-14 receivers from RFspace with the Linrad-MAP65 combination. This will require some modifications in MAP65 to

accommodate sample rates other than 96000 Hz; I hope to make the necessary changes before long. Interfacing to FlexRadio's SDR-1000 and SDR-5000 should also be possible, but I have not yet explored the detailed requirements.

7. Like WSJT, MAP65 is an "open source" program. I hope and expect that others interested in this newly developing area of amateur radio experimentation will contribute to its future evolution. Please let me know if you have an interest! The most important qualifications are enthusiasm and a willingness to learn. I knew essentially nothing about digital communication techniques when I started the WSJT project six years ago. For me, as I think for many of us, learning is a major part of the fun.

In summary, let me point out that many hundreds of operators are now using JT65 for making EME QSOs. The highest levels of activity are on 144 MHz, but JT65 QSOs are being made regularly on all of the worldwide amateur bands from 50 MHz through at least 2.3 GHz. Most stations use conventional SSB transceivers with bandwidths around 3 kHz, and for them the narrow-band WSJT program is suitable for transmission and reception of JT65. However, broadband software-defined receivers are becoming easier to build and more readily available commercially. Together with software like the Linrad-MAP65 combination, they open a wide and very exciting range of new possibilities for amateur communication.

The MAP65 program is available for free download on the WSJT Home Page, [physics.princeton.edu/pulsar/K1JT/](http://physics.princeton.edu/pulsar/K1JT/). Its source code is available at [developer.berlios.de/projects/wsjt/](http://developer.berlios.de/projects/wsjt/).