

EME Fundamentals

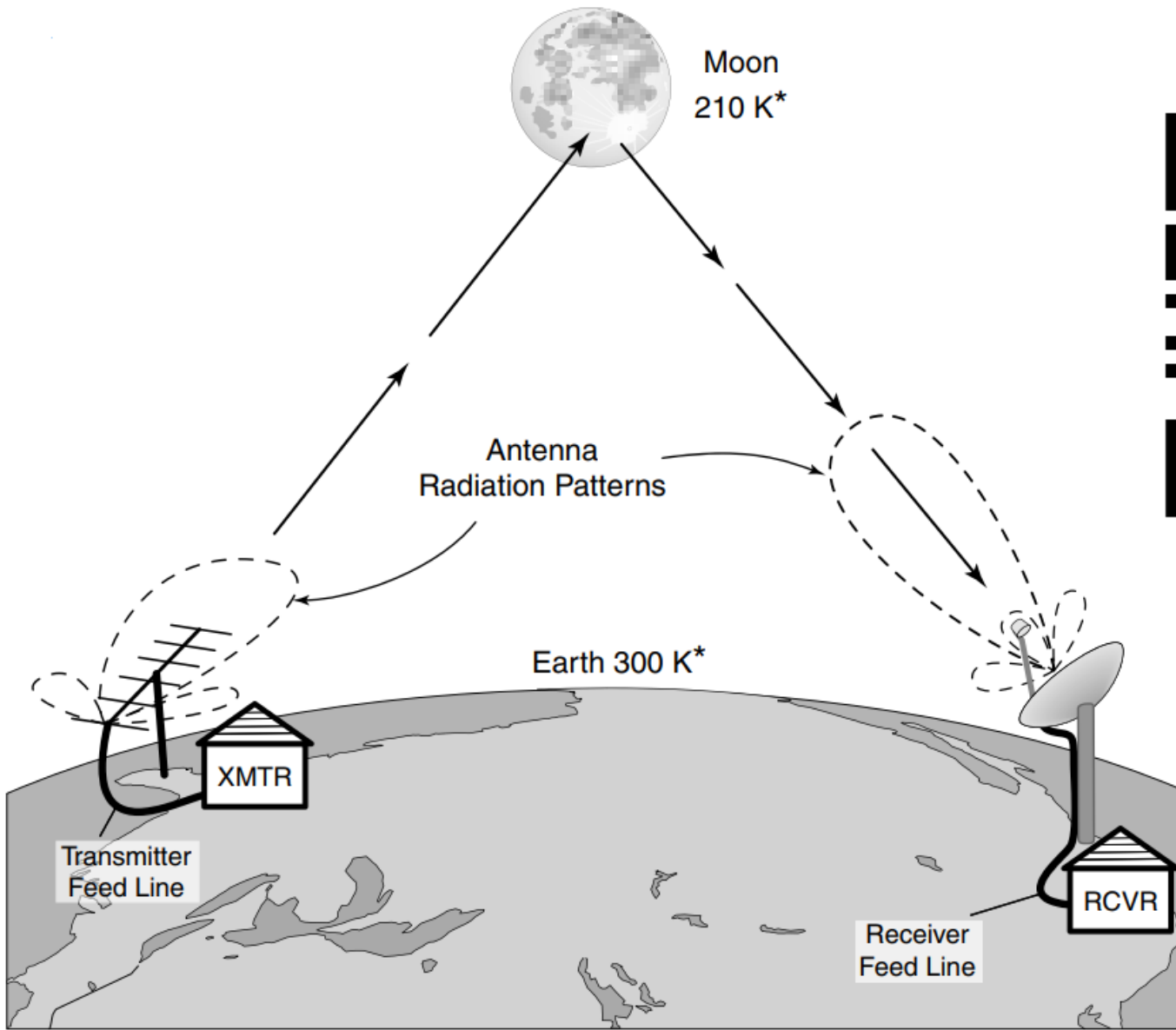
... from basic physics to digi-modes...



Joe Taylor
K1JT

Overview

- EME fundamentals and limits
- Tweaking your setup
- Software and Digi-modes for EME



* Noise temperature, Kelvins

https://wsjt.sourceforge.io/Hbk_2010_Ch30_EME.pdf

EME Path Loss

$$p_r = p_t g_t g_r l$$

$$l = \frac{\eta \lambda^2 r^2}{64 \pi^2 d^4}$$

Two-Way EME Path Loss with Isotropic Antennas

<i>Frequency (MHz)</i>	<i>Average Path Loss (dB)</i>
50	-242.9
144	-252.1
222	-255.8
432	-261.6
902	-268.0
1296	-271.2
2304	-276.2
3456	-279.7
5760	-284.1
10368	-289.2
24048	-293.5

Signal-to-Noise Ratio

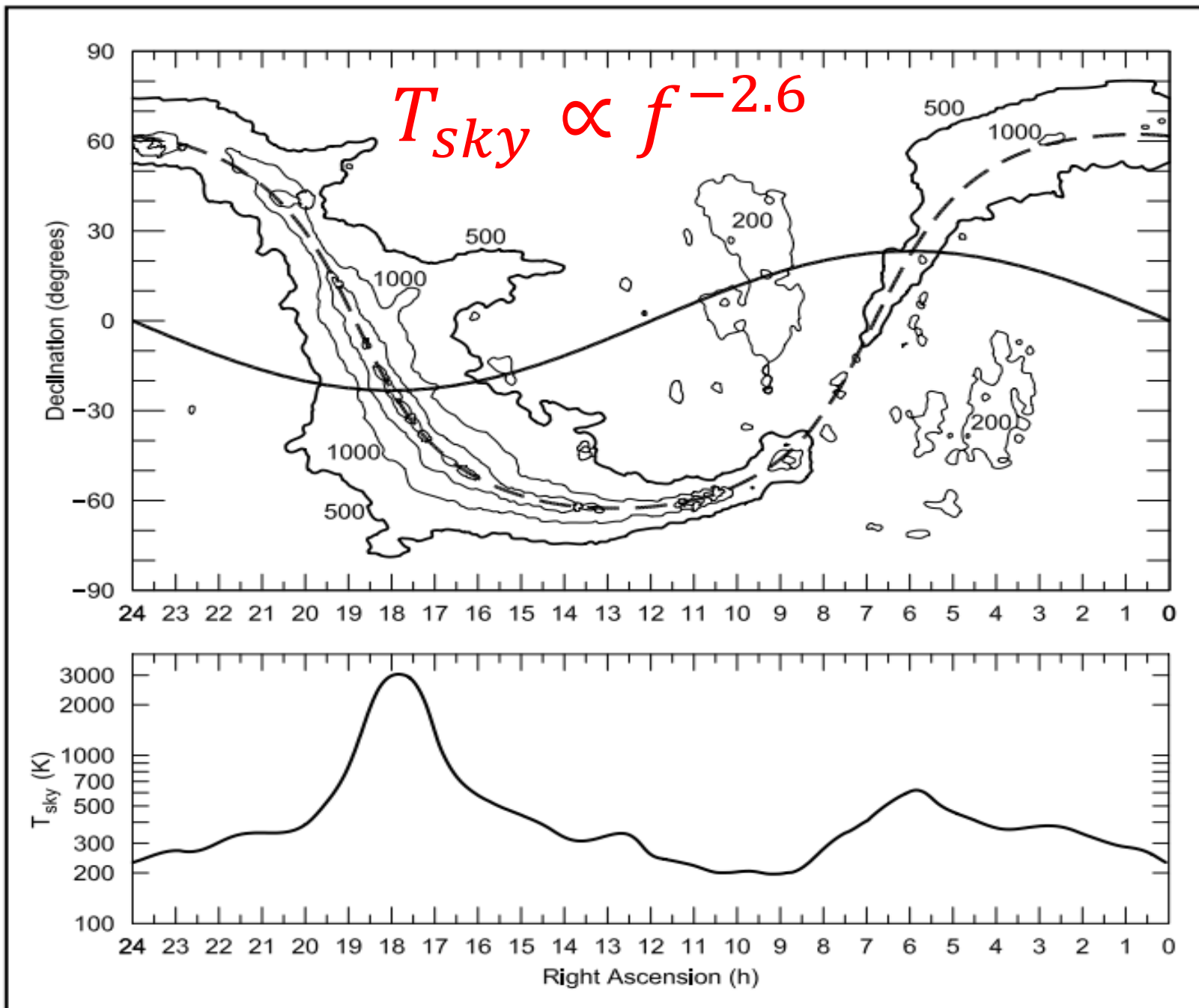
$$\frac{S}{N} = \frac{p_r}{p_n} = \frac{p_t g_t g_r l}{kT_s B}$$

System noise temperature

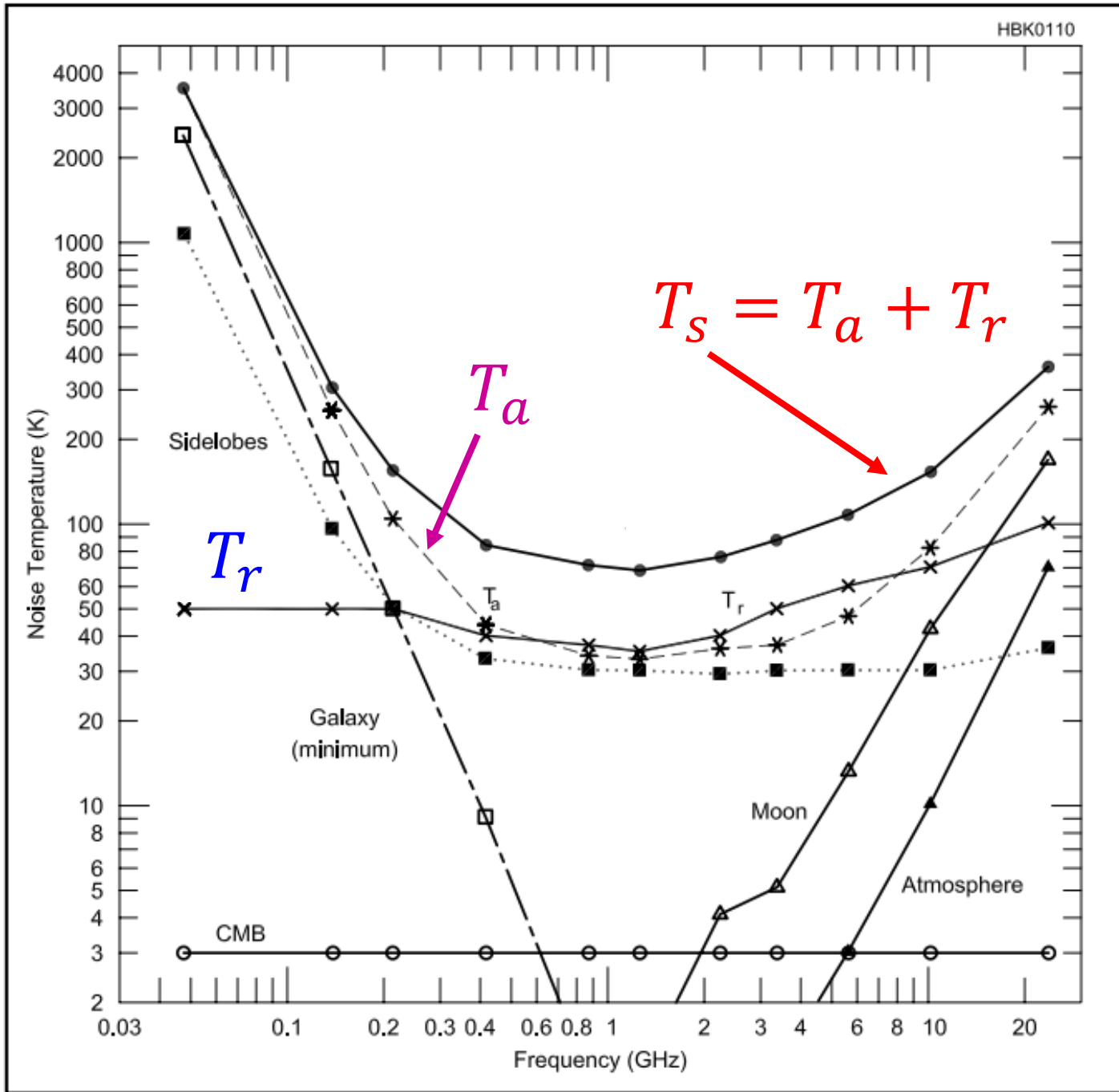
$$T_s = T_a + T_r$$

Received bandwidth

Galactic
Noise
144 MHz



System
Noise
Temperature
 T_s



Signal-to-Noise Ratio

$$\frac{S}{N} = \frac{p_r}{p_n} = \frac{p_t g_t g_r l}{k T_s B}$$

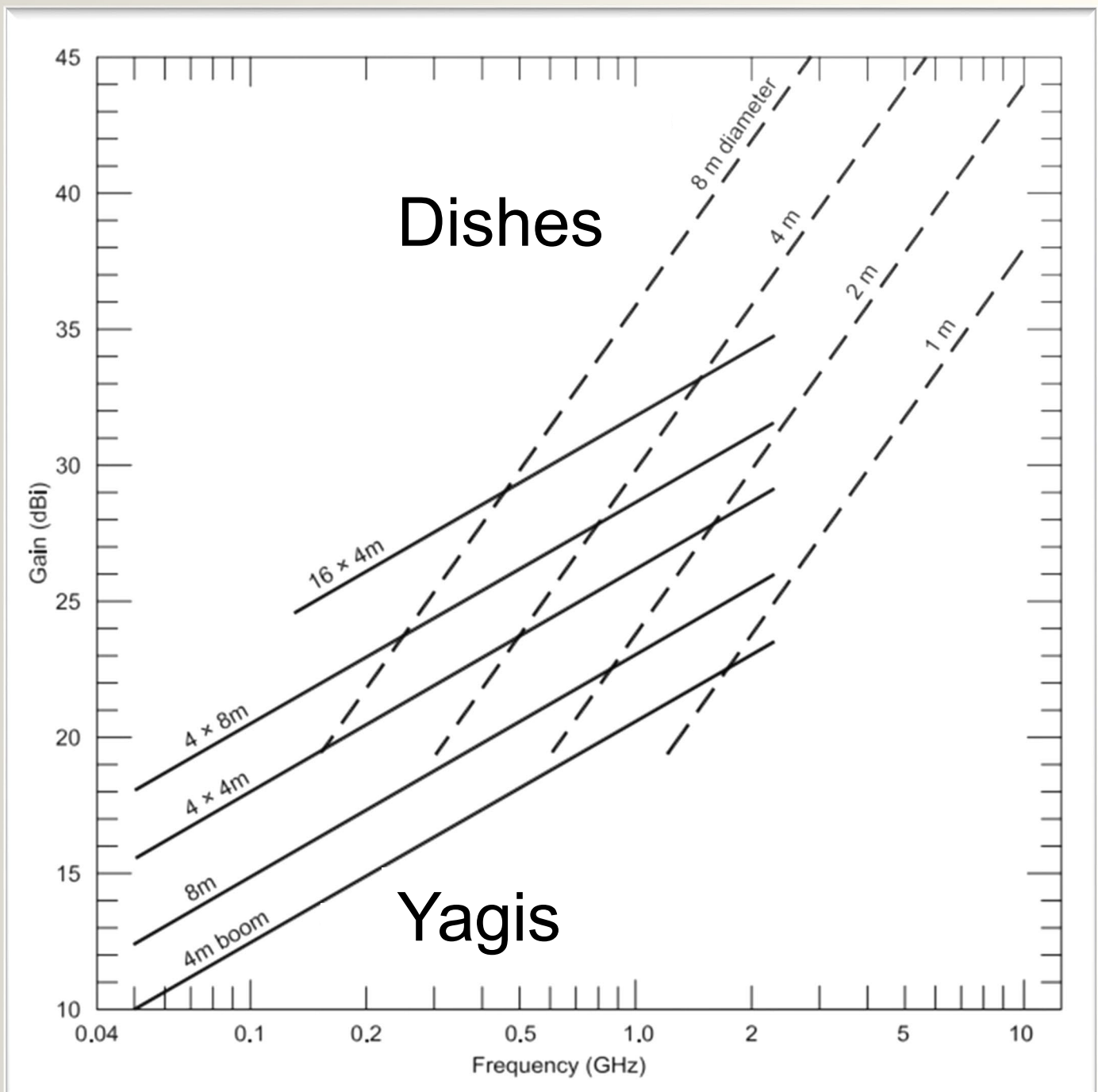
System noise temperature

$$T_s = T_a + T_r$$

Received bandwidth

Q: What can I control ??

What type
of antenna
??



How much power ??

(Assume S/N = 0 dB, B = 100 Hz)

<i>Freq</i> (MHz)	<i>Ant</i> <i>Type</i> ¹	<i>G</i> (dBi)	<i>HPBW</i> (deg)	<i>TxPwr</i> (W)
50	4x12 m	19.7	18.8	1200
144	4x6 m	21.0	15.4	500
432	4x6 m	25.0	10.5	250
1296	3 m	29.5	5.5	160
2304	3 m	34.5	3.1	60
3456	2 m	34.8	3.0	120
5760	2 m	39.2	1.8	60
10368	2 m	44.3	1.0	25



0 dB



-15 dB

EMECalc by VK3UM

<https://www.vk5dj.com/doug.html>

Tx A (Home Station) W22Q_1296

1296 MHz	270.51 dB	10 K	Rx Bw 2500 Hz	Diam 3.00 mm	Mesh 10.00 mm	Spacing 10.00 mm	H ¹ 10.00 mm	Sys Sensitivity -145.3 dBm	Echo SN -12.93 dB
Frequency	Path Loss	Aqu or Leo		Circ 0.27 %				Effective ground 258 K	

Your last sfu data record has been loaded.

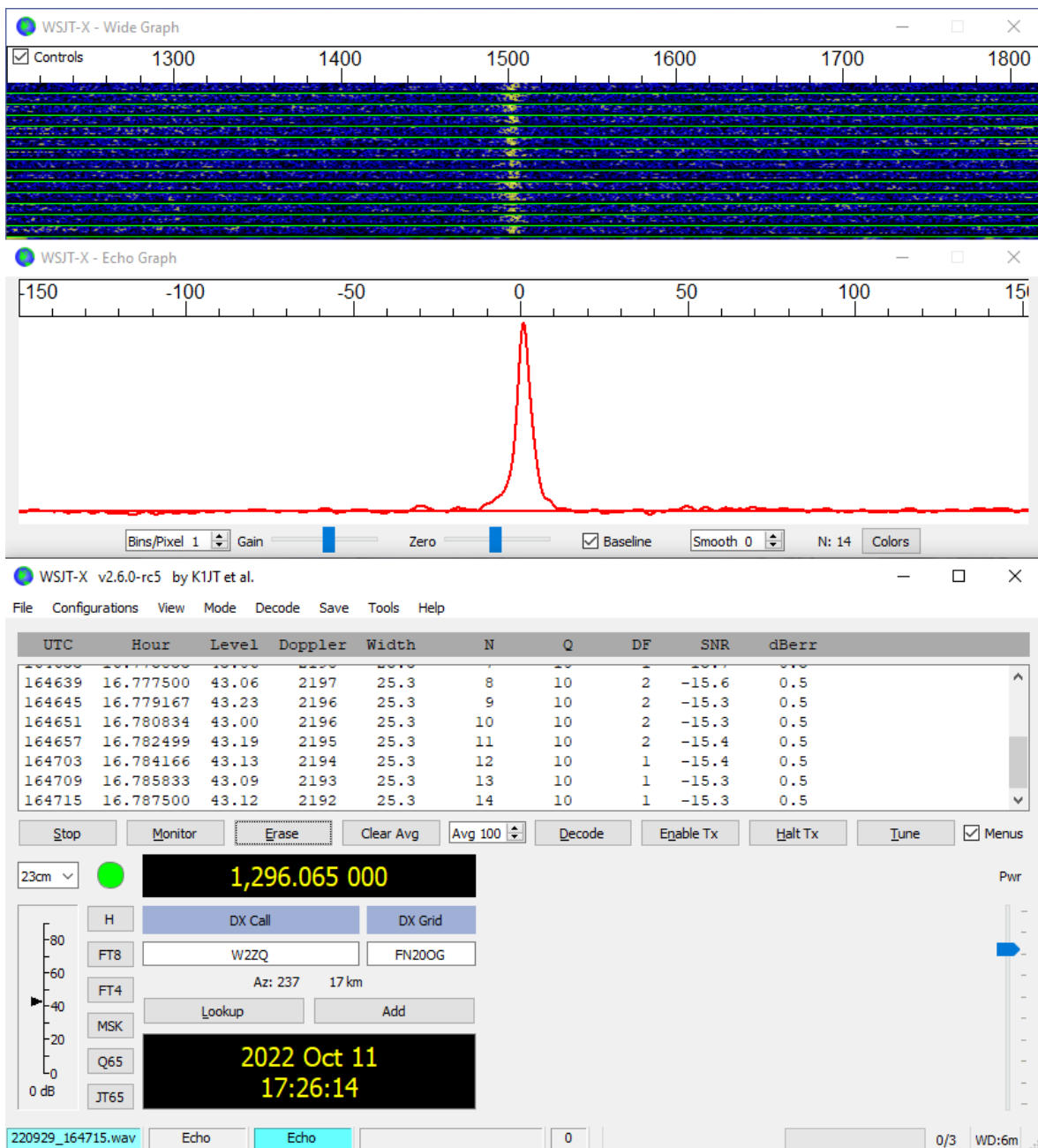
10.7cm	7.55 K	24.34 K	Loss 0.012 dB			Mesh <input checked="" type="checkbox"/>	Gnd to Cold Sky : 5.66 dB	
75	0.10 dB	0.35 dB	30.0 dB	12.6 dB	6.0 dB	21.16 K	0.41 K	12.01 dB
<input type="button" value="Get sfu"/>	LNA Loss	LNA Nf	LNA Gair	Coax Loss	Rx Nf	Spillover	Feedthrough derived from Mesh size	Sun Y 0.06 dB
	Tx A Output Power	Transmission Loss	Power at Feed					Moon Y
	250 Watts	23.98 dBW	0.9 dB	203 Watts	23.08 dBW			185,868 W EIRP

RxTK 53.27 K = 0.73 dB
Receiver Noise Temperature

Ground Temperature
300 K 27 °C

TSys 84.84 K = 1.11 dB
System Noise Temperature

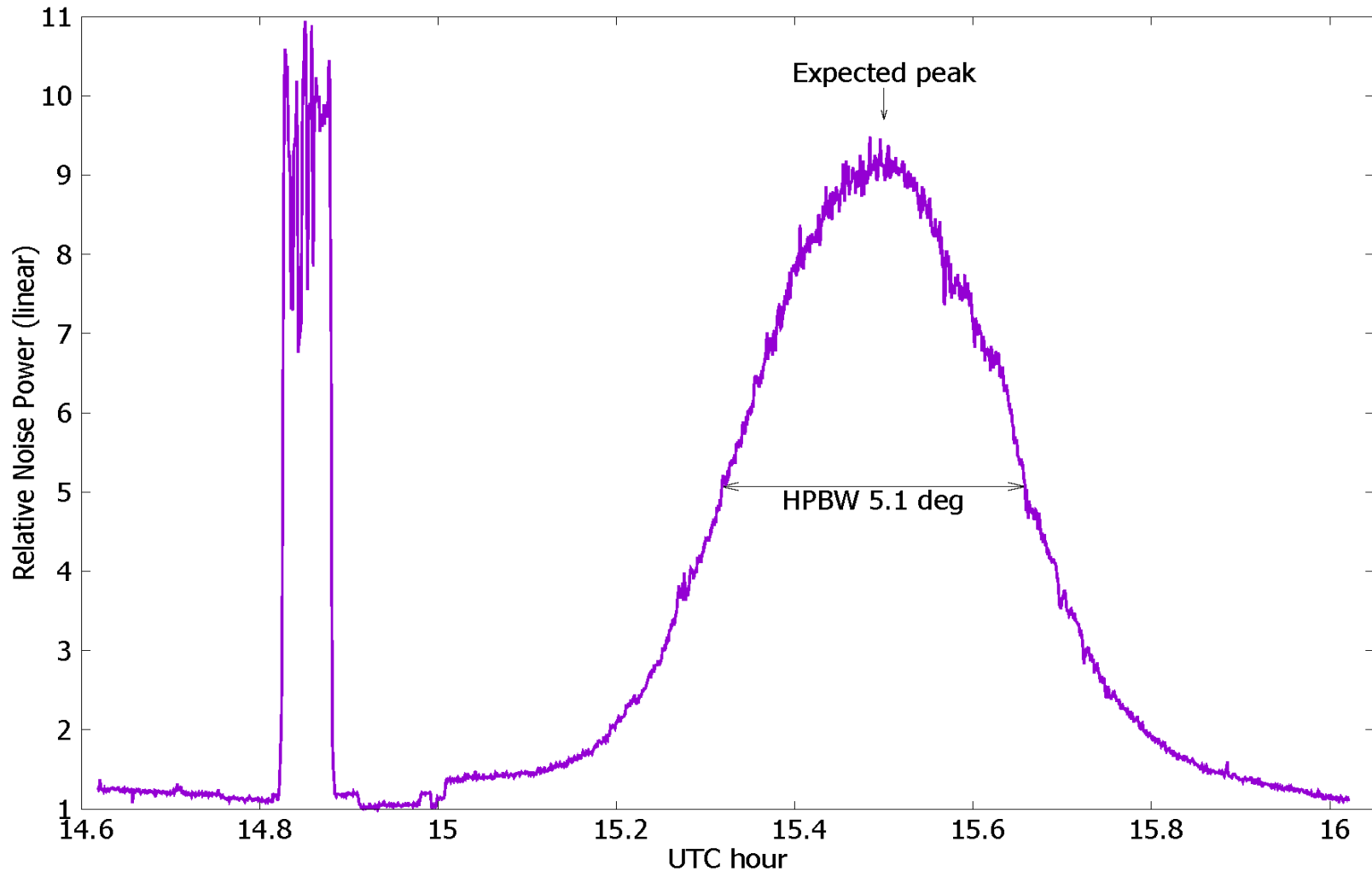
W2ZQ
EME echoes
SNR = -15.3 dB



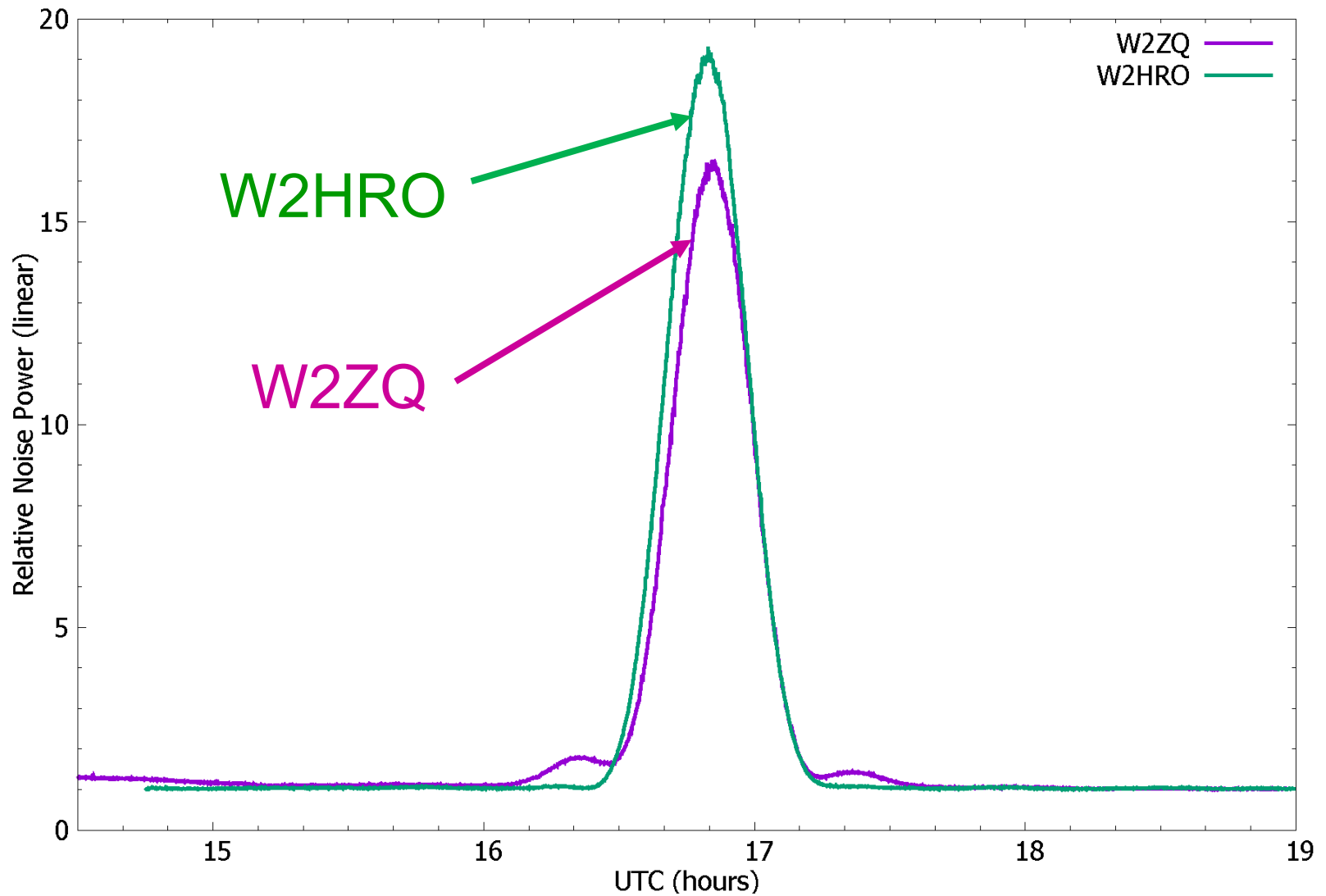
<https://wsjt.sourceforge.io/wsjt.html>

Testing your setup...

W2ZQ: Sun Noise, 1296 MHz

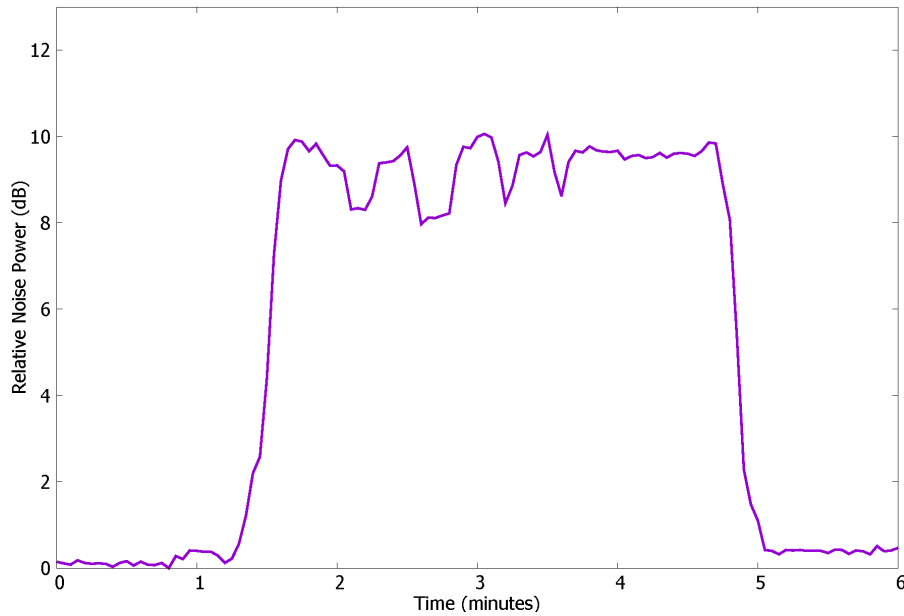


Antenna Pattern

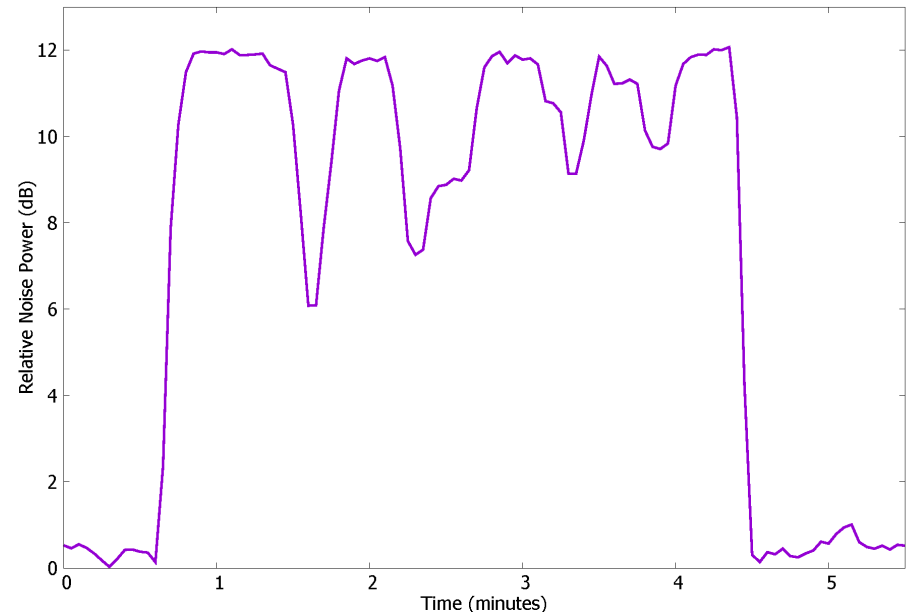


Focus Adjustment

Before: $Y_{\text{sun}} = 10 \text{ dB}$



After: $Y_{\text{sun}} = 12 \text{ dB}$



Software and Digi-Modes

WSJT-X

QMAP

Q65

WSJT-X

The screenshot displays the WSJT-X software interface. At the top is a 'Wide Graph' window showing a spectrogram of a 50 MHz EME test session. The graph shows a signal at approximately 144.116 MHz with a drift rate of 1.13. Below the graph is a control panel with various settings like 'Bins/Pixel 4', 'Start 300 Hz', 'Split 2500 Hz', 'N Avg 8', 'Scope', 'Q65_Sync', 'Flatten', 'Ref Spec', 'Spec 15%', and 'Smooth 1'.

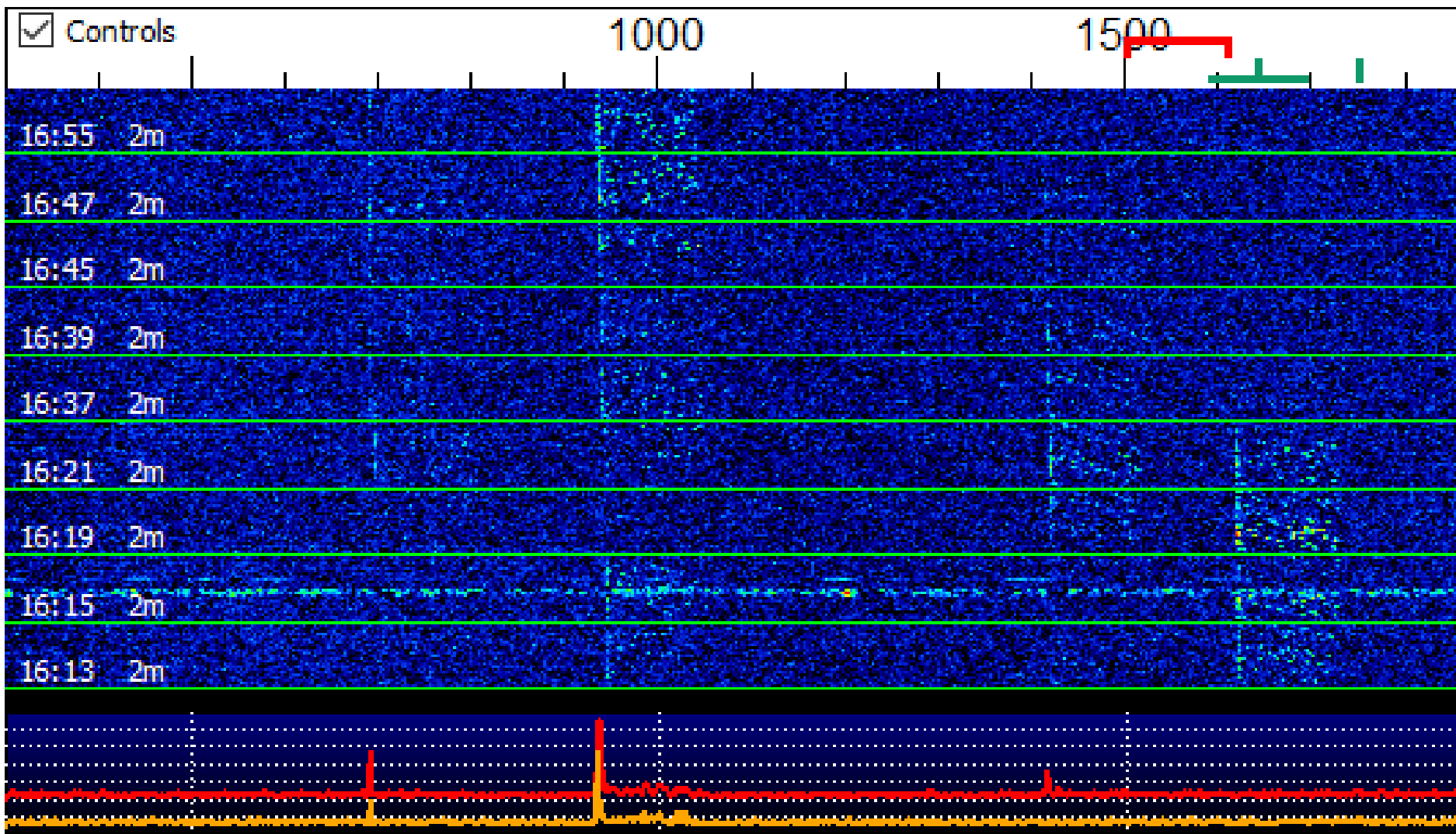
The main window is titled 'WSJT-X v2.7.0-rc5 by K1JT et al.' and has a menu bar with 'File', 'Configurations', 'View', 'Mode', 'Decode', 'Save', 'Tools', and 'Help'. It features two tables for decoding results:

Single-Period Decodes						Average Decodes				
UTC	dB	DT	Freq	Message		UTC	dB	DT	Freq	Message
1613	-19	2.8	1622	: W7GJ VE1JF -18	q0					
1613	-23	2.8	945	: W7GJ NOTB -15	q0					
1615	-19	2.8	1622	: W7GJ VE1JF -18	q0					
1615	-21	2.9	945	: W7GJ NOTB -15	q0					
1619	-14	2.8	1622	: W7GJ VE1JF -18	q0					
1621	-19	2.8	1620	: W7GJ VE1JF RRR	q0					
1621	-24	2.8	697	: W7GJ N8JX EN73	q0					
1621	-20	2.8	1420	: W7GJ W1VD FN31	q0					
1637	-21	2.9	940	: W7GJ NOTB -15	q0					
1637	-22	2.8	1417	: W7GJ W1VD R-24	q0					
1639	-21	2.9	940	: W7GJ NOTB -15	q0					
1639	-24	2.8	1417	: W7GJ W1VD 73	q0					
1647	-27	2.9	692	: W7GJ N8JX EN73	q0					
1647	-21	2.9	938	: W7GJ NOTB 73	q0					
1655	-21	2.9	938	: W7GJ NOTB -24	q0					

The 'Average Decodes' table is currently empty. A large red text overlay in the center of the interface reads '50 MHz EME W7GJ test session'. Below the tables is a control panel with buttons for 'Log QSO', 'Stop', 'Monitor', 'Erase', 'Clear Avg', 'Decode', 'Enable Tx', 'Halt Tx', 'Tune', and 'Menus'. The frequency is set to 144.116 000 MHz. The mode is Q65, and the date and time are 2024 Jul 15 15:57:34. The interface also shows a 'Generate Std Msgs' section with a list of messages and a 'Tx' button.

WSJT-X Waterfall

 WSJT-X - Wide Graph



W7GJ works an EME pileup

UTC	dB	DT	Freq	Message
1613	-19	2.8	1622	: W7GJ VE1JF -18
1613	-23	2.8	945	: W7GJ NOTB -15
1615	-19	2.8	1622	: W7GJ VE1JF -18
1615	-21	2.9	945	: W7GJ NOTB -15
1619	-14	2.8	1622	: W7GJ VE1JF -18
1621	-19	2.8	1620	: W7GJ VE1JF RRR
1621	-24	2.8	697	: W7GJ N8JX EN73
1621	-20	2.8	1420	: W7GJ W1VD FN31
1637	-21	2.9	940	: W7GJ NOTB -15
1637	-22	2.8	1417	: W7GJ W1VD R-24
1639	-21	2.9	940	: W7GJ NOTB -15
1639	-24	2.8	1417	: W7GJ W1VD 73
1647	-27	2.9	692	: W7GJ N8JX EN73
1647	-21	2.9	938	: W7GJ NOTB 73
1655	-21	2.9	938	: W7GJ NOTB -24

WSJT-X Doppler Tracking

WSJT-X - Astronomical Data

2024 Jul 15
UTC: 16:05:35
Az: 86.1
El: -34.2
SelfDop: 2821
Width: 13
Delay: 2.68
DxAz: 0.0
DxEl: 0.0
DxDop: 0
DxWid: 0
Dec: -18.7
SunAz: 141.7
SunEl: 67.2
Freq: 1296.1
Tsky: 4
Dpol: -49.8
MNR: 0.0
Dist: 401078
Dgrd: -2.2

Doppler tracking

Doppler tracking

Full Doppler to DX Grid
 Own Echo
 Constant frequency on Moon
 On DX Echo
 Call DX
 None

Sked frequency

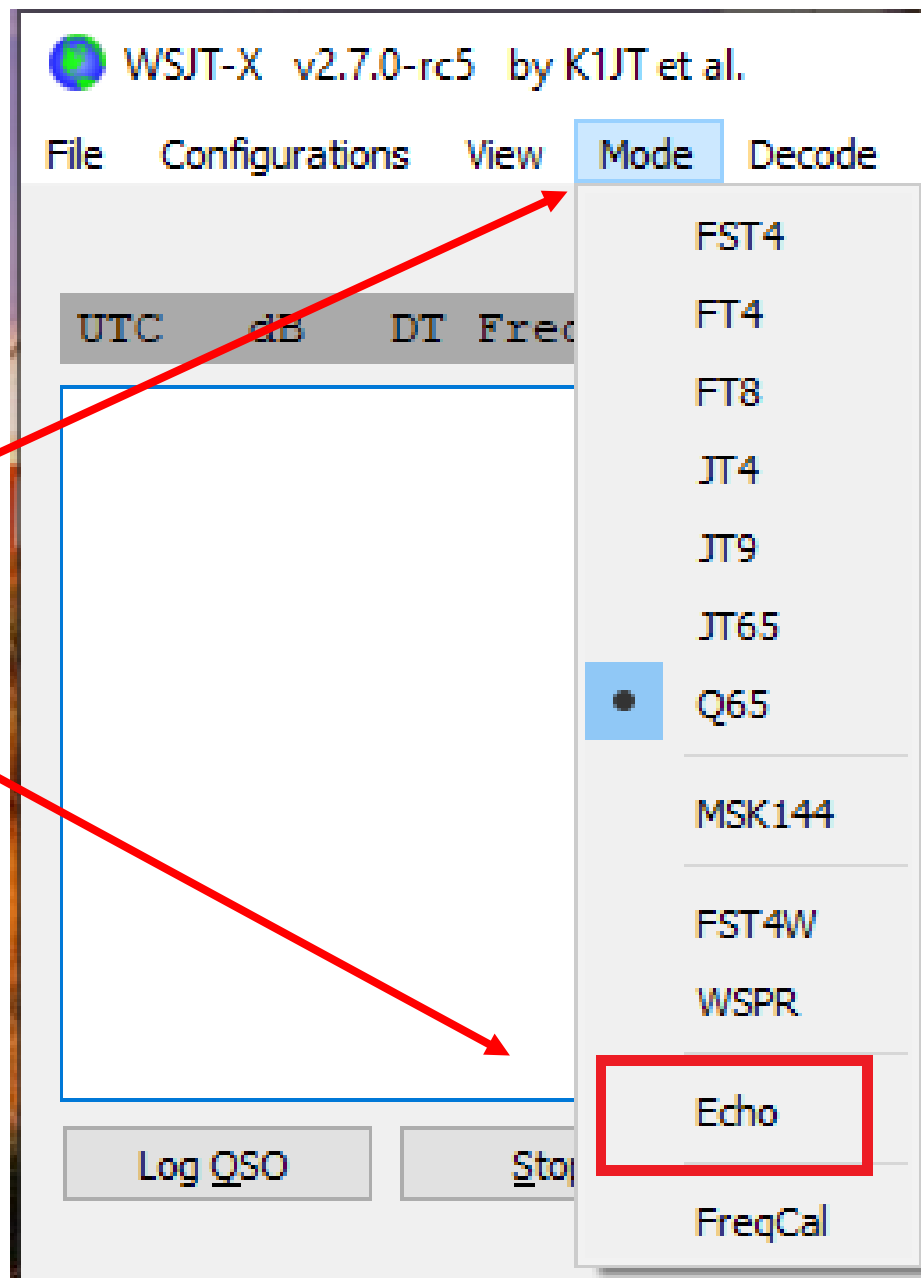
Rx: 1,296.065 000
Tx: 1,296.065 000

Press and hold the CTRL key to adjust the sked frequency manually with the rig's VFO dial or enter frequency directly into the band entry field on the main window.

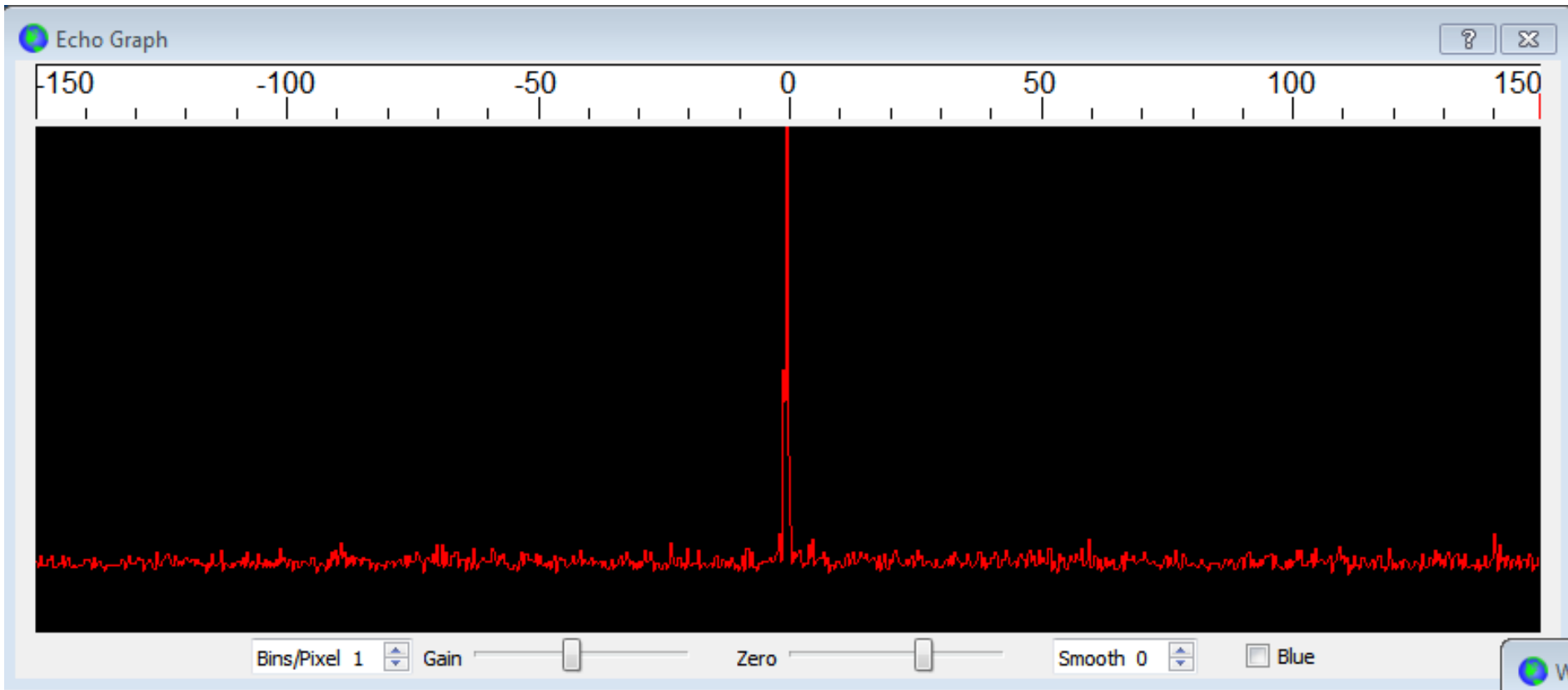
Echo Mode

RIT 0 Hz Dither

WSJT-X Echo Mode

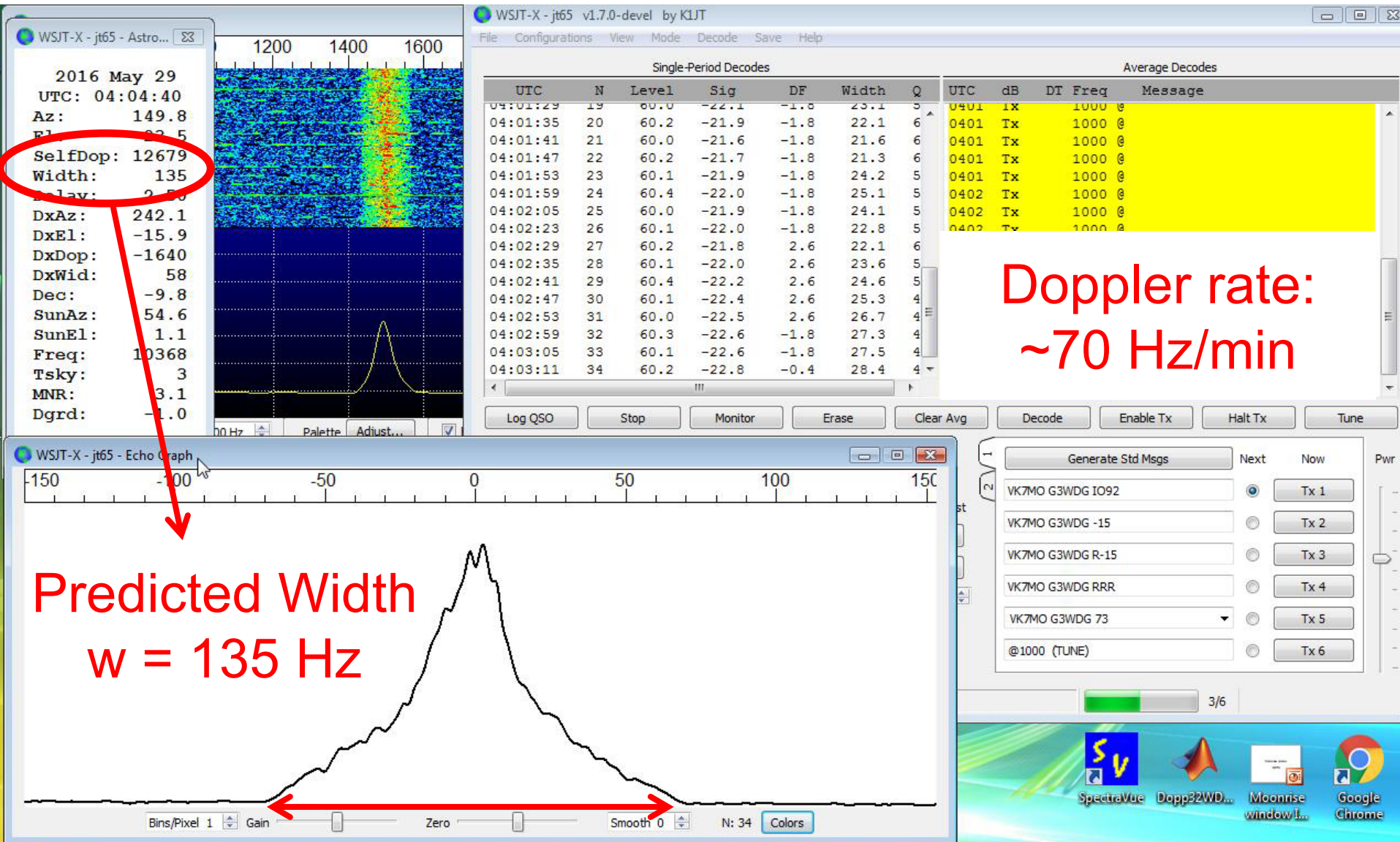


Echo Mode: K1JT, 144 MHz

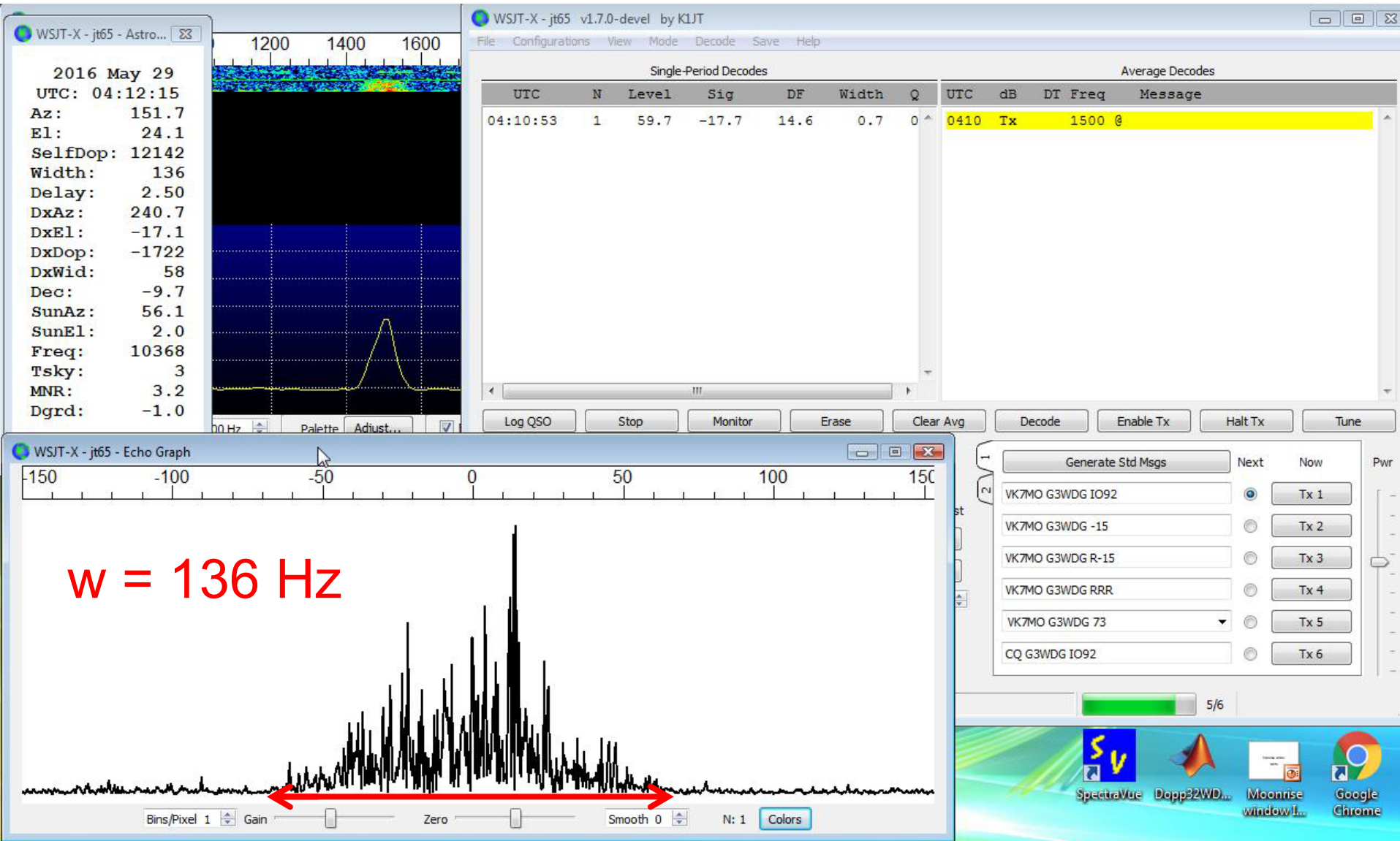


Doppler corrected; predicted spread 2.6 Hz

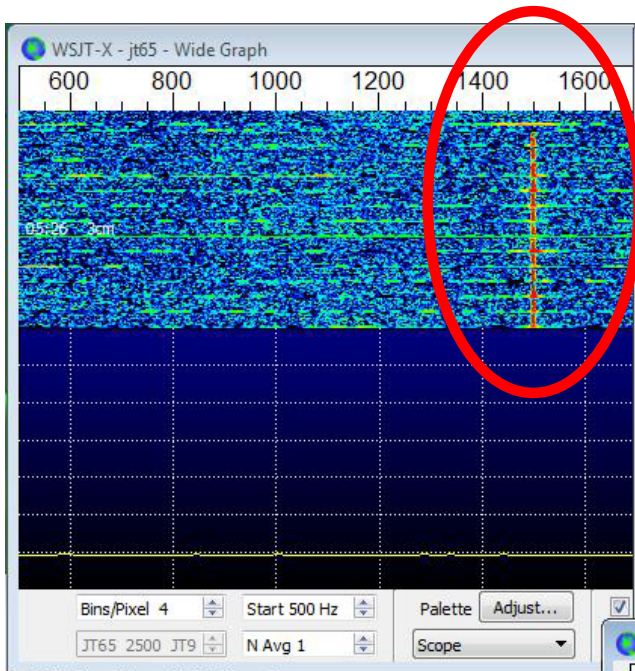
Echo Mode: G3WDG, 10 GHz



Single-pulse Echo, 10 GHz



10 GHz echo at libration minimum

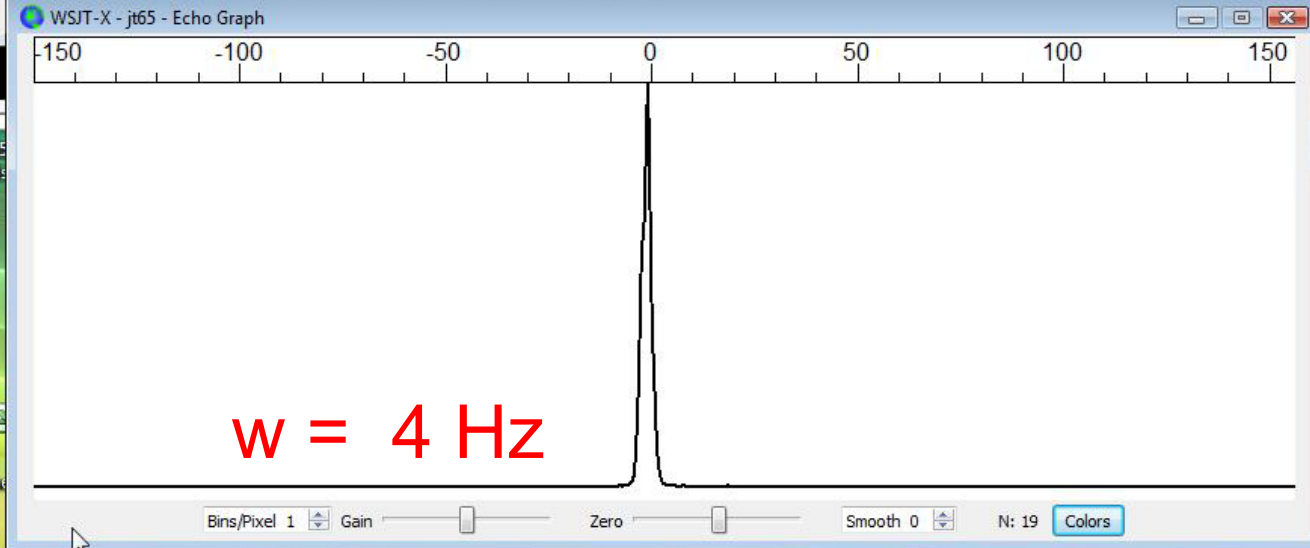


WSJT-X - jt65 v1.7.0-devel by K1JT

File Configurations View Mode Decode Save Help

Single-Period Decodes							Average Decodes				
UTC	N	Level	Sig	DF	Width	Q	UTC	dB	DT	Freq	Message
05:25:02	1	47.9	-5.5	557.0	0.7	0	0525	Tx		1000	@
05:25:05	2	48.3	-5.6	556.3	0.4	10	0525	Tx		1000	@
05:25:11	3	60.1	-2.6	555.2	0.4	10	0525	Tx		1000	@
05:25:17	4	59.4	-5.7	0.0	1.0	10	0525	Tx		1000	@
05:25:23	5	59.8	-5.5	0.0	1.0	10	0525	Tx		1000	@
05:25:29	6	59.5	-6.6	0.0	1.3	10	0525	Tx		1000	@
05:25:35	7	60.1	-6.7	0.0	1.3	10	0525	Tx		1000	@
05:25:41	8	59.6	-7.2	0.0	1.5	10	0525	Tx		1000	@
05:25:47	9	59.6	-7.8	0.0	1.7	10	0525	Tx		1000	@
05:25:53	10	60.3	-7.3	0.0	1.7	10	0525	Tx		1000	@
05:25:59	11	59.9	-7.7	0.0	1.9	10	0525	Tx		1000	@
05:26:05	12	59.5	-8.1	0.0	2.0	10	0526	Tx		1000	@
05:26:11	13	59.7	-7.9	0.0	1.9	10	0526	Tx		1000	@
05:26:17	14	60.0	-8.1	0.0	2.2	10	0526	Tx		1000	@
05:26:23	15	60.4	-7.6	-0.4	2.0	10	0526	Tx		1000	@
05:26:29	16	60.2	-7.2	-0.4	1.9	10	0526	Tx		1000	@
05:26:35	17	60.0	-7.2	-0.4	1.9	10	0526	Tx		1000	@
05:26:41	18	59.6	-7.4	-0.4	1.9	10	0526	Tx		1000	@
05:26:47	19	51.4	-7.4	-0.4	1.9	10	0526	Tx		1000	@

UTC: 05:27:05
Az: 110.6
El: 25.1
SelfDop: 17802
Width: 4
Delay: 2.40
DxEl: -31.5
DxDop: 8192
DxWid: 104
Dec: 8.0
SunAz: 69.8
SunEl: 12.6
Freq: 10368
Tsky: 3
MNR: 0.0
Dgrd: -0.3



QMAP: Wideband Decoding

The screenshot displays the QMAP v0.4 interface, which is used for wideband decoding of digital signals. The top portion is a waterfall plot showing frequency (MHz) on the x-axis (35 to 120) and time on the y-axis (00:42 to 00:52). The plot shows a dense spectrum of signals, with a prominent signal around 117 MHz. Below the waterfall plot, there are control buttons for 'Span 90 kHz', 'N Avg 12', 'Gain 5', 'Zero 22', 'Auto Zero', and '2D Spectrum'. The center frequency is set to 1296.118.000.

The bottom section of the interface is divided into three main panels:

- Left Panel (QMAP v0.4):** Displays a table of decoded messages. The table has columns for UTC, Frx, Fsked, DT, dB, Q65, and Message. The current message is: UTC: 005030, Frx: 117.723, Fsked: 115.4, DT: 2.66, dB: -13, Q65: 30B, Message: OK1DFC OM4XA JN98.
- Middle Panel (WSJT-X - Active Stations):** Displays a table of active stations. The table has columns for N, Frx, Fsked, S/N, Q65, Call, Grid, Tx, and Age. The current station is: N: 13, Frx: 117.289, Fsked: 115.0, S/N: -14, Q65: 30B, Call: N9HF, Grid: EL99, Tx: 0, Age: 4.
- Right Panel (WSJT-X v2.7.0-rc5):** Displays the 'Single-Period Decodes' and 'Average Decodes' sections. The current decode is: UTC: 005030, dB: -13, DT: 2.66, Freq: 117.723, Message: OK1DFC OM4XA JN98.

At the bottom of the interface, there are various control buttons and indicators, including 'Monitor', 'Erase', 'Decode', 'Log QSO', 'Stop', 'Monitor', 'Erase', 'Clear Avg', 'Decode', 'Enable Tx', 'Halt Tx', 'Tune', and 'Menus'. The current frequency is 145.058 700, and the time is 2024 Jul 15 13:46:31.

QMAP: Wideband Decoding

The image displays a Wideband Waterfall plot and the QMAP v0.4 interface. The waterfall plot shows frequency (MHz) on the x-axis (35 to 120) and time on the y-axis (00:42 to 00:52). A red box highlights a signal at approximately 117.7 MHz. A red arrow points from this box to the QMAP interface.

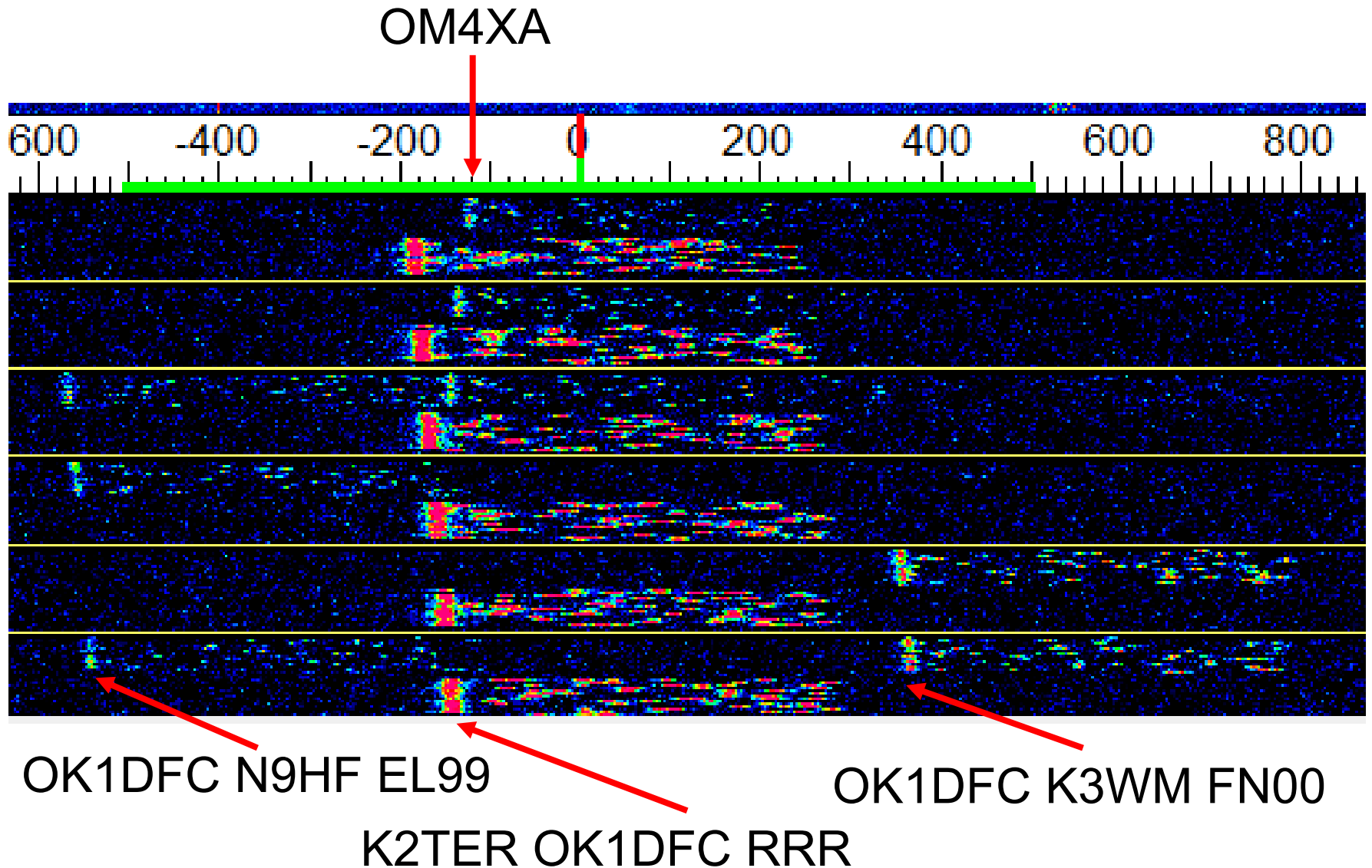
The QMAP v0.4 interface shows the following data:

UTC	Frq	Fsked	DT	dB	Q65-	Message
005000	97.637	95.3	2.78	-15	60C	ACORA PA3HDG R-17
005000	84.184	81.9	2.62	-17	60C	CQ G7TZZ IO92
005030	117.723	115.4	2.66	-13	30B	OK1DFC OM4XA JN98
005200	117.673	115.4	2.59	-1	30B	SP3YDE OK1DFC RRR
005200	57.673	55.4	2.62	-7	60C	W3SZ K3WM 73
005200	58.133	55.8	2.62	-12	60C	W3SZ UA9FAD LO88
005200	63.676	61.4	3.08	-12	60C	PA3FXB SP5GDM -09
005200	72.772	70.5	2.62	-15	60C	W2ZQ LU8ENU GF05
005200	84.175	81.9	2.62	-18	60C	CQ G7TZZ IO92
005200	87.257	84.9	3.23	-6	60C	WA3GFZ UA5Y RRR
005200	97.625	95.3	2.78	-15	60C	ACORA PA3HDG 73
005230	117.734	115.4	2.74	-15	30B	OK1DFC OM4XA JN98

The interface also displays a frequency display showing 1296.080 MHz and the date/time 2024 Jul 15 13:46:31. The WSJT-X Active Stations table is also visible:

N	Frq	Fsked	S/N	Q65	Call	Grid	Tx	Age
1.	57.649	55.3	-17	60C	RX6AIA	...	1	6 #
2.	57.673	55.4	-07	60C	K3WM	FN00	1	0 #
3.	58.133	55.8	-12	60C	UA9FAD	LO88	1	0 #
4.	60.216	57.9	-12	60C	YO2LAM	KN05	1	8 #
5.	60.942	58.6	-14	60C	YU1SAN	KN03	1	2 #
6.	63.676	61.4	-12	60C	SP5GDM	...	1	0 #
7.	72.772	70.5	-15	60C	LU8ENU	GF05	1	0 #
8.	84.175	81.9	-18	60C	G7TZZ	IO92	1	0 #*
9.	87.257	84.9	-06	60C	UA5Y	K072	1	0 #
10.	97.625	95.3	-15	60C	PA3HDG	JO31	1	0 #
11.	97.988	95.7	-16	60C	PA0TBR	JO21	1	4 #
12.	107.205	104.9	-18	60C	O21CTZ	...	1	10 #
13.	117.289	115.0	-14	30B	N9HF	EL99	0	4 #
14.	117.734	115.4	-15	30B	OM4XA	JN98	0	0 #
15.	117.673	115.4	-01	30B	OK1DFC	...	1	0 #

QMAP: High-resolution Waterfall



QMAP main window

The screenshot displays the QMAP v0.4 software interface. At the top, the title bar reads "QMAP v0.4 by K1JT et al." with standard window controls. Below is a menu bar with "File", "View", "Mode", "Save", and "Help".

The main display area contains a table of decoded messages with the following columns: UTC, Frx, Fsked, DT, dB, Q65-, and Message. The messages are as follows:

UTC	Frx	Fsked	DT	dB	Q65-	Message
010000	117.635	115.0	2.59	0	30B	WA3GFZ OK1DFC RRR
010000	63.641	61.0	3.23	-11	60C	KB2SA SP5GDM R-12
010000	72.228	69.6	3.08	-5	60C	W2ZQ UA5Y KO72
010000	72.898	70.2	2.62	-14	60C	W2ZQ YU1SAN 73
010000	87.658	85.0	2.62	-12	60C	K5QE PA3FXB R-09
010000	61.625	59.0	2.93	-17	60C	W3HMS OK2AQ JN89
010000	84.140	81.5	2.62	-18	60C	CQ G7TZZ IO92
010030	117.644	115.0	2.66	-16	30B	OK1DFC W3HZU FN10

Below the table is a control panel. On the left, a vertical scale shows a signal level of 24 dB. Two large black boxes display "1296.080" and "2024 Jul 15 14:54:43". To the right are buttons for "Monitor", "Erase", and "Decode". Further right are input fields for "100" (with a dropdown), "Tol", "Max Drift 0" (with a dropdown), and "Offset 1500 Hz" (with a dropdown). At the bottom right, there is a checkbox for "NB" and a slider.

The status bar at the bottom shows: "231028_0100.iq", "Rx: 24.3 0.0 %", "Q65-60C", "58.5 s 8/10", and a yellow "Save decoded" button.

WSJT-X: Active Stations

Click to
work a
station

N	Frq	Fsked	S/N	Q65	Call	Grid	Tx	Age
1.	57.813	55.4	-07	60C	K3WM	FN00	1	0 #
2.	57.789	55.4	-17	60C	RX6AIA	...	1	6 #
3.	58.273	55.9	-12	60C	UA9FAD	LO88	1	0 #
4.	60.356	58.0	-12	60C	YO2LAM	KN05	1	8 #
5.	61.082	58.7	-14	60C	YU1SAN	KN03	1	2 #
6.	63.816	61.4	-12	60C	SP5GDM	...	1	0 #
7.	72.912	70.5	-15	60C	LU8ENU	GF05	1	0 #
8.	84.315	81.9	-18	60C	G7TZZ	IO92	1	0 #*
9.	87.397	85.0	-06	60C	UA5Y	KO72	1	0 #
10.	97.765	95.4	-15	60C	PA3HDG	JO31	1	0 #
11.	98.128	95.7	-16	60C	PA0TBR	JO21	1	4 #
12.	107.345	105.0	-18	60C	OZ1CTZ	...	1	10 #
13.	117.429	115.0	-14	30B	N9HF	EL99	0	4 #
14.	117.813	115.4	-01	30B	OK1DFC	...	1	0 #
15.	117.874	115.5	-15	30B	OM4XA	JN98	0	0 #

Max Age 10 # Wanted only * CQ only QSOs: 5

EME Digi-modes

- 50 MHz: Q65-60A
- 144 MHz: Q65-60B, JT65B
- 222, 432 MHz: Q65-60B
- 1296 MHz: Q65-60C Q65-30B
- 2.3+ GHz (depends on Doppler spread)
Q65-60C, -60D, -60E

Programming Details

- User interface: C++ and Qt
- Number crunching: Fortran
- Core developers: K1JT, G3WJS (SK),
K9AN, IV3NWV, DG2YCB, N9ADG,
G3WDG
- Open source: GPLv3 license
- Version control with git:

```
$ git clone https://git.code.sf.net/p/wsjt/wsjtx
```