10 GHz EME QSO with 64 cm (~2 ft) Dish and 8 Watts

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We report on completing a QSO on 10 GHz EME with at one end a small portable station as would be used on field days. This result was achieved by taking advantage of predicted low libration spreading so that the narrow bandwidth mode JT65c could be employed, by using a program to automatically correct for Doppler and by using the Deep Search averaging function of WSJT. A feature of 10 GHz signals on EME is that while they vary significantly on a short term basis with glints of a second or so the average signal to noise (S/N) varies only a dB or so between periods (over several periods) and this steady S/N is useful for signal averaging.

Equipment

VK3XPD
Antenna: 10 ft Dish linear horizontal polarisation
TX: TWT with power 80 watts to the feed
RX: DB6NT pre-amp
Transverter, Multiplier & GPS Locked Oscillator; totally Aussie design by Graham - VK3XDK.
IF: FT817 GPS locked to VK3HZ design
Computer: Dell Hardware running Windows 7

VK7MO
Antenna: 64 cm TVRO offset Dish linear horizontal polarisation
TX: DB6NT amp with 8 watts to the feed
RX: DB6NT pre-amp
Transverter: DB6NT
IF: IC-910-H
Computer: Toshiba
Transverter and IF GPS locked with automatic Doppler Correction of IF by VK1XX's program to produce an essentially stable signal.

Doppler Correction

Glen English VK1XX kindly produced a program that takes the Doppler calculated by WSJT and automatically tunes the IC-910-H to correct for Doppler. It can be set to also tune the IC-910-H to transmit with the opposite amount of Doppler so that the receiving station also sees the signal at a constant frequency. The waterfall display (Fig 1) demonstrates the stability of VK3XPD's signal after Doppler correction. From Fig 2 it can be seen that the frequency (Df) varied from only -27 to -22 Hz over a period of 45 minutes.

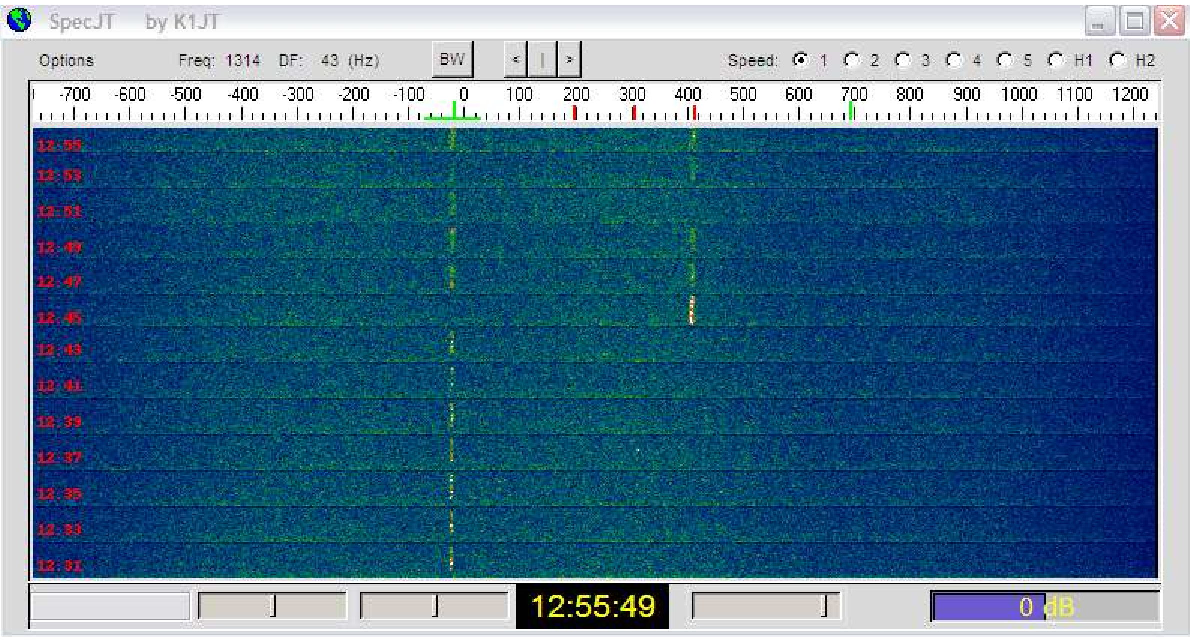

Fig 1: Stability of VK3XPD's signal after Doppler correction. The JT65c sync tones are at around -20 Hz and at the top of the figure a second tone representing 73 is seen. (there is a stronger single tone 73 at 12:45 which will be discussed later)

Performance of JT65c with Libration Spreading

JT65c uses groups of 4 bins of 2.7 Hz or a total of 10.8 Hz to detect the individual tones. Accordingly one might expect that it would fail if the spreading is greater than 10.8 Hz. We have found, however, that on strong signals such as are received from VK3XPD it is possible to get good decodes with spreading of up to 100 Hz. We put this down to firstly the fact that the spreading is most likely in the form of a Bell curve so most of the energy is constrained to much less than the predicted spreading and secondly the Deep Search function of WSJT is able to resolve a signal with some tones outside the correct bins. It is interesting to note that even at time of low libration spreading and strong signals of -21 and -22 db it is rare to achieve a decode on the Kotter-Vardy decoder – pointing to a significant advantage of the Deep Search decoder. Fig 2 is a list of decodes of VK3XPD's signal with the libration spreading Highlighted in Yellow.

Time		S/N	Dt	Df	W						Spreading (Hz)
115700	1	-28	1.5	-27	10	*	VK7MO VK3XPD QF22		0	10	37
115900	0	-28	1.4	-27	8	*	VK7MO VK3XPD QF22		0	10	34
120100	0	-31	1.5	-27	22	*	VK7MO VK3XPD QF22		0	8	32
120300	1	-28	1.6	-24	9	*	VK7MO VK3XPD QF22	?	0	2	30
120500	1	-28	1.5	-24	11	*	VK7MO VK3XPD QF22		0	10	29
120700	1	-27	1.6	-27	6	*	VK7MO VK3XPD QF22		0	8	27
120900	2	-26	1.5	-27	9	*	VK7MO VK3XPD QF22		0	10	25
121100	1	-27	1.5	-27	8	*	VK7MO VK3XPD QF22		0	10	23
121300	2	-24	1.5	-24	8	*	VK7MO VK3XPD QF22		0	10	21
121500	2	-25	1.5	-24	10	*	VK7MO VK3XPD QF22		0	10	19

121700	3	-23	1.5	-24	8	*	VK7MO VK3XPD QF22	0	10	17
121859	3	-22	2.1	-24	8	*	VK7MO VK3XPD QF22	0	10	16
122059	5	-22	2.1	-24	8	*	VK7MO VK3XPD QF22	0	10	14
122259	5	-23	2.1	-24	7	*	VK7MO VK3XPD QF22	0	10	12
122459	2	-23	2.1	-22	7	*	VK7MO VK3XPD QF22	0	10	10
122659	4	-23	2.1	-22	6	*	VK7MO VK3XPD QF22	0	10	9
122859	3	-22	2.1	-24	5	*	VK7MO VK3XPD QF22	1	10	7
123059	4	-21	2.1	-24	6	*	VK7MO VK3XPD QF22	0	10	6
123259	4	-22	2.1	-22	6	*	VK7MO VK3XPD QF22	0	10	5
123459	3	-22	2.1	-22	6	*	VK7MO VK3XPD QF22	0	10	5
123659	6	-23	2.1	-22	6	*	VK7MO VK3XPD QF22	0	10	6
123859	4	-22	2.1	-22	5	*	VK7MO VK3XPD QF22	1	10	7
124059	1	-24	2.3	-22	5	*	VK7MO VK3XPD QF22	0	10	8
124259	4	-22	2.1	-22	6	*	VK7MO VK3XPD R-30	0	10	10

Fig 2: Examples of Decodes with Libration Spreading (highlighted in Yellow)

From Fig 2 it is seen that the WSJT reported Signal to Noise ratio does reduce significantly with spreading and this is graphed in Fig 3. This is to be expected as JT65c finds the single 2.7 Hz bin with the strongest signal which it reports – thus with spreading much of the energy of the signal is outside any single 2.7 Hz bin and not included in the reported signal to noise.

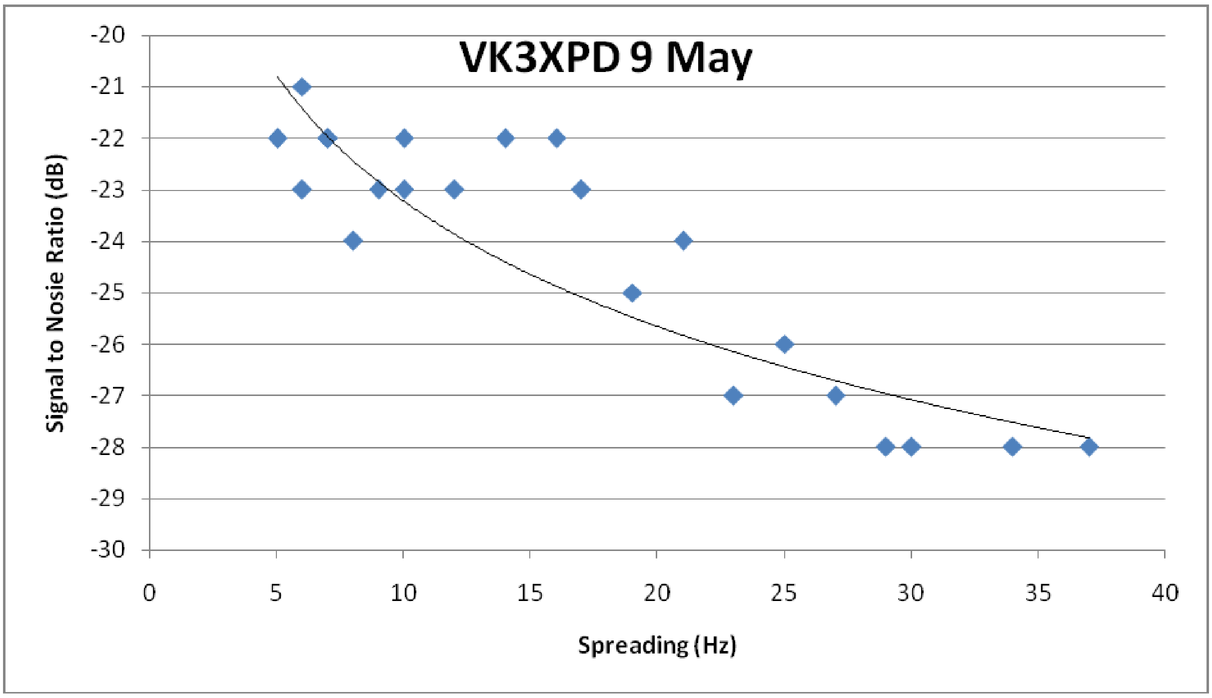

Fig 3: Reduction in Reported Signal to Noise Ratio with Spreading

Prediction of Spreading

K1JT has added a real time calculation of spreading to WSJT and both VK3UM and GM4JJJ have added spreading calculations to their EME programs. Fig 4 is an example extracted from the GM4JJJ program for the day of the successful QSO.

Time	VK7MO Az	VK7MO El	VK3XPD Az	VK3XPD El	Spreading
10:30	114°	+4°	115°	+0°	118 Hz
10:40	112°	+6°	114°	+2°	109 Hz
10:50	111°	+7°	113°	+4°	99 Hz
11:00	109°	+9°	111°	+6°	90 Hz
11:10	108°	+11°	110°	+7°	81 Hz
11:20	106°	+12°	108°	+9°	71 Hz
11:30	105°	+14°	107°	+11°	62 Hz
11:40	103°	+16°	106°	+13°	52 Hz
11:50	101°	+17°	104°	+15°	43 Hz
12:00	100°	+19°	103°	+16°	33 Hz
12:10	098°	+21°	102°	+18°	24 Hz
12:20	097°	+23°	100°	+20°	15 Hz
12:30	095°	+24°	099°	+22°	6 Hz
12:40	094°	+26°	098°	+24°	8 Hz
12:50	092°	+28°	096°	+26°	15 Hz
13:00	091°	+30°	095°	+28°	24 Hz
13:10	089°	+31°	093°	+30°	33 Hz
13:20	087°	+33°	092°	+31°	42 Hz
13:30	085°	+35°	090°	+33°	50 Hz
13:40	084°	+37°	089°	+35°	59 Hz
13:50	082°	+38°	087°	+37°	67 Hz
14:00	080°	+40°	086°	+39°	75 Hz
14:10	078°	+42°	084°	+41°	83 Hz
14:20	076°	+44°	082°	+43°	91 Hz
14:30	074°	+45°	081°	+45°	99 Hz
14:40	072°	+47°	079°	+47°	106 Hz
14:50	069°	+49°	077°	+49°	113 Hz
15:00	067°	+50°	075°	+50°	120 Hz

Fig 4: Extract from GM4JJJ program used for planning the successful QSO. Note that the Spreading is below 15 Hz as shown by the Yellow highlighted area for a total of 30 minutes.

System Performance

VK3UM's EME calc can be used to estimate the possibility of a QSO. Applying our equipment parameters to EME calc suggests that the signal received by VK3XPD would be -29 dB on the WSJT scale and that received by VK7MO would be -16 dB. This is a difference of 13 dB even though the TX power is only 10 dB greater. The main reason is that VK3XPD's larger antenna is almost entirely filled with moon noise where as this has negligible effect on the small antenna of VK7MO. In practice the best signals received by VK3XPD are consistent with EME calc but those by VK7MO around 4 dB less than calculated – (something else we need to understand). One issue is that in applying WSJT reported S/N to EME calc it is only valid if the signal remains within one 2.7 Hz bin for the full TX period and thus with spreading of 5 Hz the WSJT reported S/N is likely to be under-reported.

Procedure for QSO

As the signals will be well above the noise at the VK7MO end the key problem is the VK3XPD end. In practice VK7MO receives the signals well before the time of minimum libration and can send a report in the form of "VK3XPD VK7MO -26". VK3XPD must pick up this signal for a sufficient amount of time to get a Deep Search Average. Once he picks up the signal he can send a report in the form VK7MO VK3XPD R-30 which will quickly be picked up by VK7MO*. In order to complete a valid QSO VK3XPD must receive a valid RRR. As the libration spreading will most likely have increased sending RRR with both callsigns is unlikely to be successful as this would require a number of periods to obtain a good average. The traditional solution is the use the two tone RRRs provide with WSJT which can be decoded by eye down to around -32 dB. However, as the frequency is stable, because of the Doppler correction, we have adopted the approach of sending RRR as a single tone on 1593 Hz and 73 as a single tone on 1701 Hz which gives around 3 to 4 dB# more energy in the tone and makes it clearly visible (see example of the 1701 Hz tone in Fig 1). The procedure is to click on the sync tone on the waterfall which then sets the three red lines for RO, RRR and 73. The tone being sent can then be easily read of the waterfall. While the single tone method is a significant advantage (it is also used by WSJT's FSK441) this method is only practical if the frequency is stable as in this case due to the use of Doppler correction. Single tones can be sent in WSJT with the format "@1593" in any TX line - where the 1593 represents the frequency.

> * It is possible with weak spreading signals for WSJT to report a valid sync at below -30 dB. The way that WSJT is set up it does not send reports below -30 dB so for signals below this value we recommend that the report be inserted manually at -30 dB and that this be interpreted as -30 dB or below – or an extremely weak signal.
>
> *# While it is easy to see that a single tone would have 3 dB more energy than one of two tones, measurements suggest that it is around 3.8 dB better. The explanation for the additional 0.8 db might be the energy that is lost in the switching sidebands when using the two tone method.*

It is useful to set sync on WSJT to zero (or -1 to make sure)## as this gives the best chance of finding a valid sync even though it increases the chance of a false decode – false decodes are still rare on 10 GHz where there are few birdies or noise sources and in any case can usually be rejected.

> ## It is noted that even in running with Sync at -1 neither of us received a single false decode in several hours of testing.

The QSO of 9 May

For the day in question VK7MO was receiving solid decodes as shown in Fig 2 above and VK3XPD could see a slight smear as evidence of signal at about the same Df (ie -27 Hz). However it was not until the libration spreading dropped to 15 Hz that VK3XPD got a Sync as evidenced by the * (Fig 5). Note that there was also a * at 121000 but as the Dt was 3.3 seconds this was rejected and excluded from the average. The average was based only on those with a red spreading figure.

	Spreading (Hz)
121000 0 -29 3.3 -27 41 *	24
121200 0 -33 1.6 -48 33	22
121400 0 -33 6.3 -27 10	20
121600 0 -33 2.7 -24 2	18
121800 0 -33 2.2 -30 32	17
122000 0 -30 2.2 -24 5 *	15
122200 0 -33 4.8 57 2	13
122400 0 -33 2.2 -27 75	11
122600 0 -33 10.0 48 48	10
122800 0 -31 2.1 -24 36 *	8
123000 0 -33 6.5 -54 29	6
123200 0 -29 2.3 -24 28 *	5
123400 0 -30 2.2 -24 2 *	5
123600 0 -33 3.6 -70 41	6
123800 0 -28 2.2 -24 5 *	7
124000 0 -32 2.0 -24 33 *	8
124000 1 6/11 VK3XPD VK7MO -27 ? 0 1	Deep Search Av decode
124105 Transmitting: JT65C VK7MO VK3XPD R-27	
124123 Transmitting: JT65C VK7MO VK3XPD QF22	
124200 0 -33 -1.2 11 52	9
124200 1 6/12 VK3XPD VK7MO -27 ? 0 1	
124300 Transmitting: JT65C VK7MO VK3XPD R-30	
124400 0 -33 2.0 161 46	10
124400 1 6/13 VK3XPD VK7MO -27 ? 0 1	
124500 Transmitting: JT65C	
124400 0 -27 5.9 299 29 #	10 RRR single tone at -27 dB
124600 0 -33 3.3 -78 17	12
124700 Transmitting: JT65C 73 (Shorthand)	

Fig 5: ALL.TEXT at VK3XPD's end

The single tone RRR shows up at 124400 at DF 299 Hz which is the 1593 Hz less 1270 Hz less the earlier Df error of -23 Hz. The reason the 124400 shows up earlier as well is that VK3XPD had set his tolerance around zero Hz and had to re-click up on the water fall to decode it. After VK3XPD received the RRR he sent 73 as a single tone which shows up in Fig 1 and then sent 73s in two tone form which also show up in Fig 1, but are much weaker.

Variations in Doppler correction

While the Doppler correction is excellent and stable within a few Hz on any one day we have seen it vary up to +/- 40 Hz from day to day as shown in Fig 6. This is not significant in terms of a QSO but it will be interesting to understand the reasons for this variation. We don't see this as due to frequency stability at either end as the errors are similar in magnitude and sign at each end – if one station was off frequency we think the errors would be reciprocal. Fig 5 compares the variation of Df from day to day with Declination, Elevation and Azimuth but there is no obvious correlation.

Date UTC	Time UTC	Df (Hz)	Declination (Deg)	El (Deg)	Az (Deg)
2 May	0621	-27	0	26	62
3 May	0715	+48	-5	23	74
6 May	1015	+13	-19	32	86
7 May	1117	-22	-21	34	87
8 May	1203	-35	-22	29	95
9 May	1234	-24	-21	23	98
10 May	1302	0	-18	16	100

Fig 6: Variation of Df from day to day of the tests

Acknowledgements

Joe Taylor K1JT for WSJT and helping us with the Deep Search Averaging function and Glen English VK1XX for his Doppler correction program.

Conclusions

We have demonstrated that it is possible to complete an EME QSO with a small portable 10 GHz system at one end by taking advantage of low libration, the narrow bandwidth mode JT65c, the use of Deep Search Averaging and using Doppler correction. The use of single tones to send RRR and 73 is a useful advantage. Total system GPS locking of both stations is essential.