Predicting Libration Fading on the EME Path
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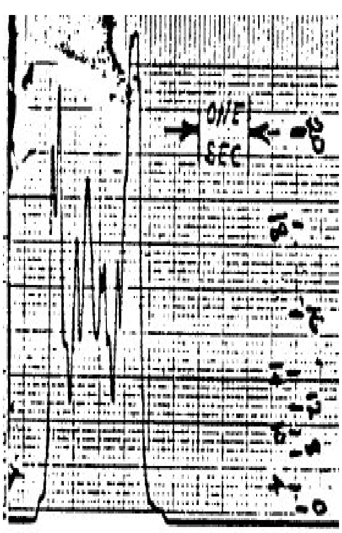
Introduction

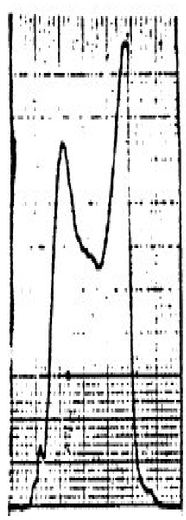
All EME operators will be very familiar with the effects of libration fading. A very detailed and informative paper was written on the subject some 36 years ago, by Dick Turrin, W2IMU (ref 1). At lower frequencies, the main effect of libration fading is noticed as fluctuating signal amplitudes, which frequently "chops" up Morse code characters such that dots may be missing or dashes broken up into several dots. When signals are weak, it is possible that only the peaks of the signal can be copied, which makes cw extremely difficult or impossible to copy.

At higher frequencies, the amplitude fading can no longer be distinguished by ear, and the signal becomes "smeared out" in the frequency domain so that it no longer sounds like a pure tone, but more like a musical "hiss". The more severe the libration is at any particular time, the weaker the signal appears to sound, since the energy is spread out over a wider bandwidth and is thus more difficult to decipher against the background noise.

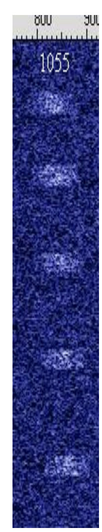
Most operators will also have observed that the fading rate (or amount of spreading) varies with moon position in the sky, being generally less with the moon near the horizon and worst with the moon at transit. It has also been observed that on some occasions the fading becomes very slow (and signals very narrow). EME operators sometimes report "good conditions", which I believe may sometimes be attributable to low libration fading rates. Examples of some signals with differing fading rates and spreading are shown below.



1630z



1130z



1055z

0815z

W2NFA 26 July 1973 1.3GHz

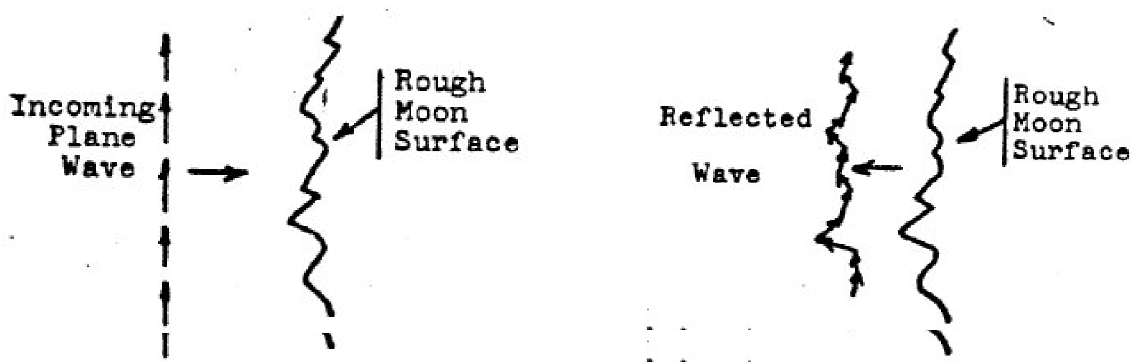
W2NFA 12 July 1973 1.3GHz

G3WDG/G4KGC 19 March 2010 10GHz

I recently became interested to see if it would be possible to predict when low libration "events" would occur, since it might be possible at such times to make contacts which might otherwise be too difficult under average conditions. At lower frequencies, signals might exist for long enough on peaks of fading to be copied, while at higher frequencies the signal energy would be more concentrated, and thus possibly easier to distinguish from the noise. This could be especially valuable for EME experiments on bands above 24GHz. It is also possible that certain weak-signal data modes might be able to operate at such times, on bands where they cannot normally be used. This has yet to be tried experimentally. Being able to predict libration fading could also help to avoid particularly bad times for skeds.

Predicting Libration

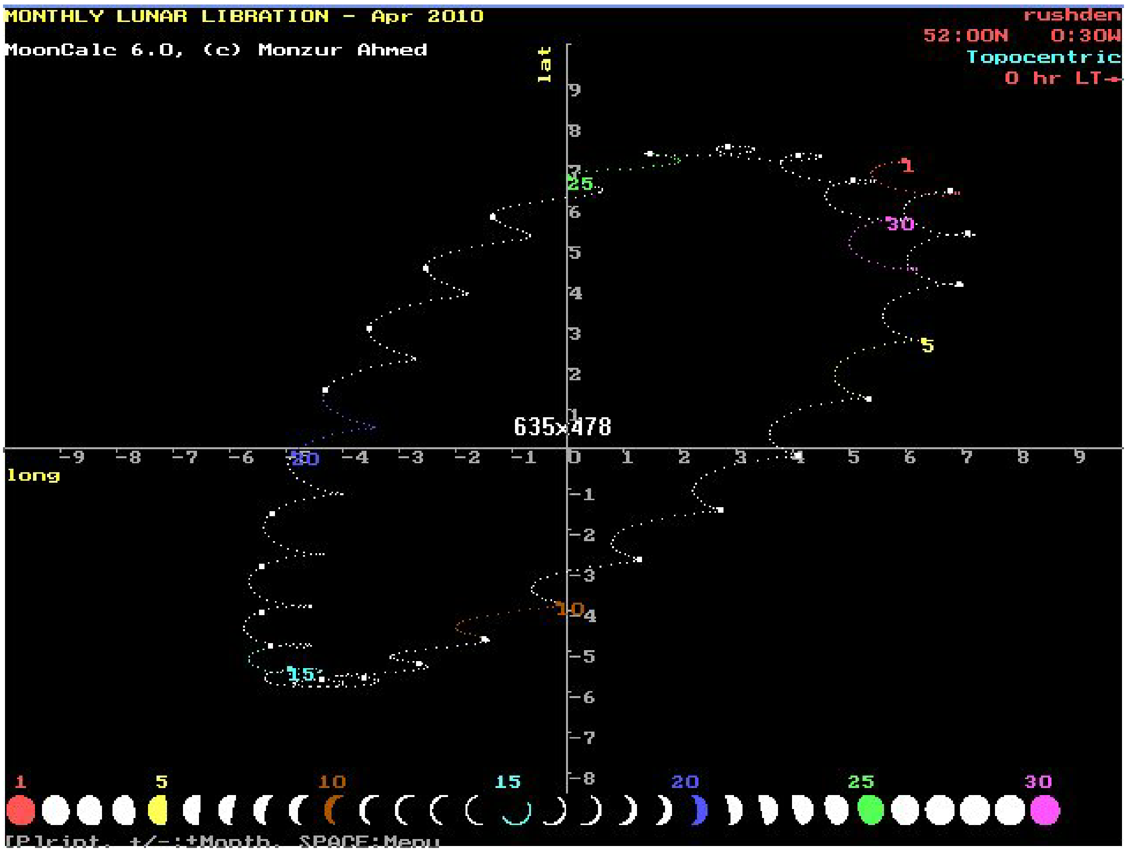
Briefly, the fading is caused by multipath propagation from the rough surface, as illustrated very clearly by Turrin:



The reflected wave that is received on Earth is a combination of all the individual reflections from points on the moon's surface, and since there is almost always some degree of relative motion of the moon's surface as observed from earth (referred to as libration), the individual reflections combine to give a fluctuating signal. Libration minimum events occur when the relative motion is at a minimum, so to predict these events it is necessary to predict when the relative motion is at a minimum.

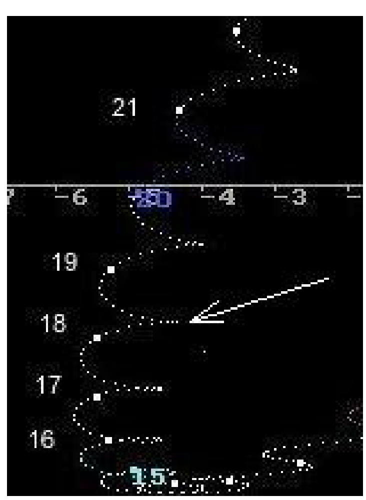
Moon libration is of great interest to astronomers, as the cyclic wobble of the moon allows approximately 59% of the moon's surface to be observed from Earth, over a period of time. According to Ref 2 , there are four separate components to libration, which together contribute to moon's total libration motion. These are libration of latitude, libration of longitude, diurnal libration and physical libration. These are described in relatively simple terms in the reference. Fortunately it was not necessary to delve too deeply into all this, as astronomers have already written excellent software to predict the libration relative to the centre of the Earth (geocentric) and relative to an observer on the Earth's surface (topocentric). The latter is the one that interests us, since it applies to an observer on the surface of the earth, and includes the all-important rotation of the earth velocity component tangential to the moon's surface.

I found two programs which could display topocentric libration over a whole month, Lunar Phase Pro (ref 3) and MoonCalc v6.0 (ref 4). Below is a screen capture from MoonCalc for my QTH for April 2010:



Topocentric Libration prediction for IO92RG for April 2010

The calculated lunar latitude and longitude points (dots) are spaced at 1 hour intervals, and the days of the month are indicated on days 1, 5, 10, 15, 20, 25 and 30. The larger dots indicate 0000z. The libration minimum would occur simply when the topocentric lunar latitude and longitude (indicated by the dots) change at the slowest rate, and this can be estimated with reasonable accuracy by eye. For example, look at days around the middle of the month, as shown below.



Looking at the 18th, and counting the one hour dots towards the 19th, it can be seen that minimum libration will occur at about 0900-1000, since this is where the dots are most closely spaced (ie lunar latitude and longitude are changing at the lowest rate). The diagram does not show whether the moon is above the horizon, of course, so this needs to be checked with an ephemeris program to see if it is observable.

A means of getting greater precision was sought, and further investigations found a spreadsheet (Ref 5) , which amongst other things can predict topocentric lunar latitude (Bo) and longitude (Lo) at any given time, as the screenshot below shows:

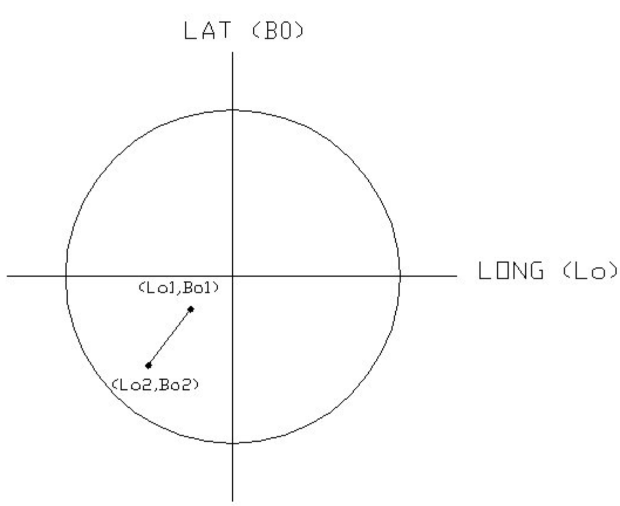
Circumstances of the moon

Re-worked from a BASIC program by George Rosenberg (ALPC

Date and station			
Parameter	User value		
Year	2010		
Month	3		
Day (UT)	20		
Hour (UT)	11		
Minute	30		
Longitude	-0.5000	-0.009	C
Latitude	52.0000	0.908	

Numerical Results	Geocentric	Topocentric
Co-longitude of Sun	329.55	
Libration in latitude (Bo)	-5.4	-4.727
Libration in longitude (Lo)	-6.1	-5.819
Sub solar point (Ls)	120.5	

While this spreadsheet predicts Bo and Lo at a given time, it does not calculate the rate of change, which is required to predict the libration rate. I modified the spreadsheet by adding an Excel Macro to calculate Bo and Lo 1 minute before and one minute after the entered time, giving values Lo1, Bo1 at T-1min and Lo2, Bo2 at T+1min, as shown in the diagram below (note: the change in Lo and Bo was been grossly exaggerated for clarity).

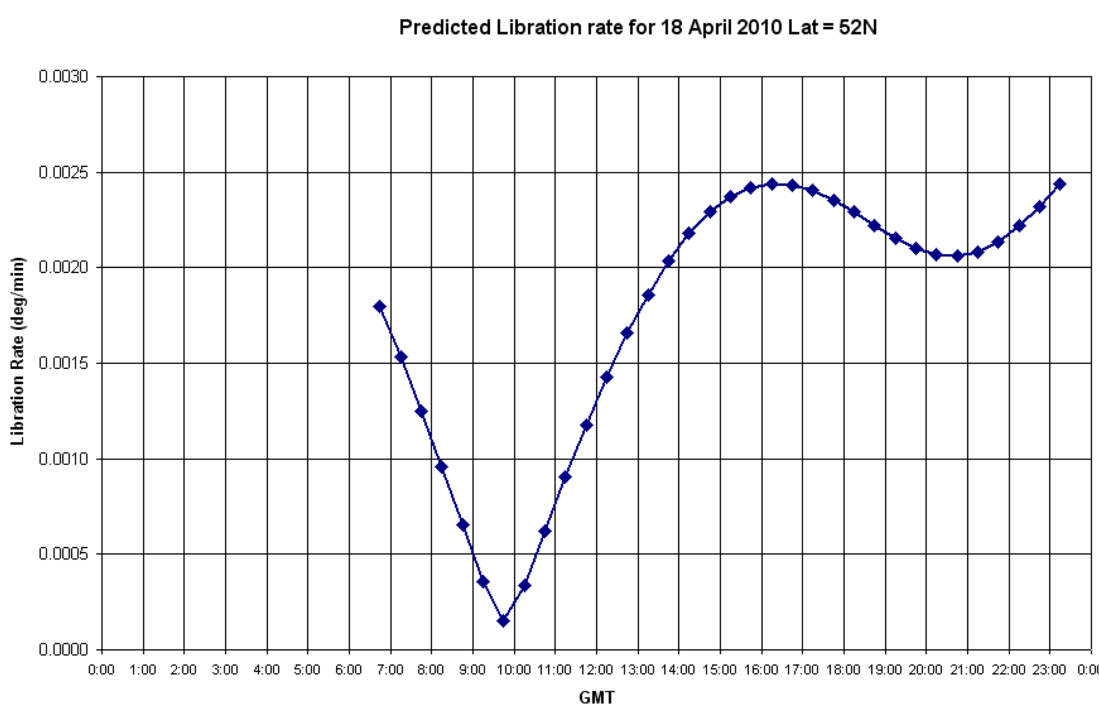


The libration rate was then calculated by working out the distance between the two calculated points using Pythagoras, and dividing by the time interval (2 mins), using the formula Libration Rate at time T (deg/min) = (SQRT ((Bo2-Bo1)**2 + (Lo2-Lo1)**2))/2. . This is a linear interpolation of what are really spherical changes, but the errors are negligible over such a short time interval.

A screenshot of part of the modified spreadsheet is shown below:

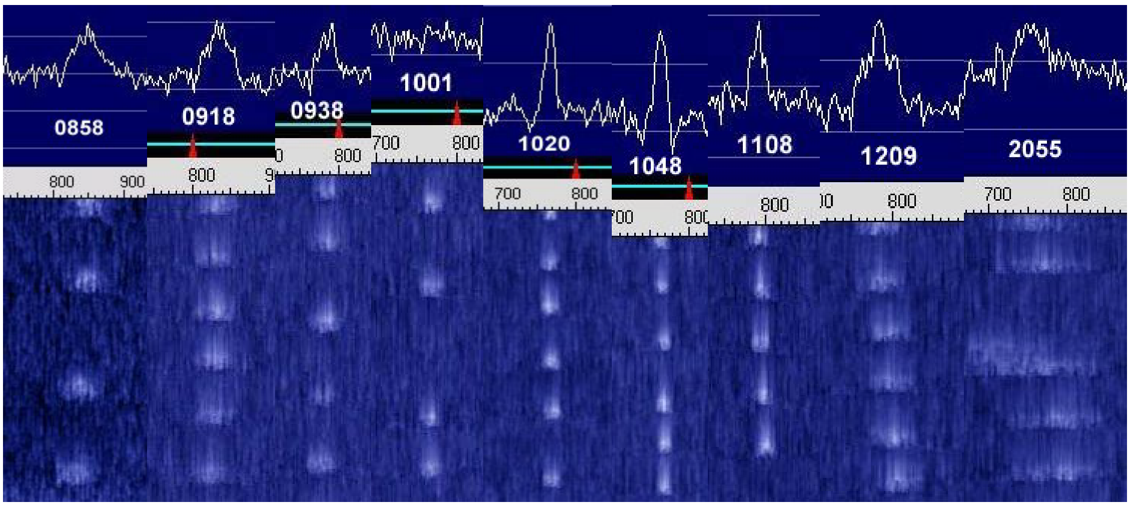
Circumstances of the moon									
Re-worked from a BASIC program by George Rosenberg (ALPO), with topocentric corrections from Meeus and other formulas fron									
Original Spreadsheet by Keith Burnett, Macros by Charles Suckling G3WDG									
Date and station									
Parameter	User value	Input user data in blue cells, press ENTER and run macro "Onetime" (ALT-F8, clic							
Year	2010								
Month	5								
Day (UT)	20						Bo	Lo	Libration Rate
Hour (UT)	21			43	43		5.643	-0.144	deg/min
Minute	44			44	44				0.001742218
Longitude (E +ve)	-1.4600	-0.025		45	45		5.647	-0.145	
Latitude (N +ve)	51.2700	0.895							
User Frequency	0.432	GHz							
Numerical Results	Geocentric	Topocentric							
Co-longitude of Sun	358.92								
Libration in latitude (Bo)	4.8	5.645							
Libration in longitude (Lo)	0.1	-0.144							
Sub solar point (Ls)	91.1								

A new macro was then written, to predict the rate of libration every 30 minutes over a 24 hour period so that predictions for one day could be made easily. A graph of the output is shown below for 18 April, showing that minimum libration occurs at about 0940z, which agrees well with the timing interpreted by eye from MoonCalc above.



Testing the Predictions

Predictions were then made for the next available libration minimum (21 March 2010) and echoes were recorded on 10GHz by G3WDG/G4KGC and on 3.4GHz by G3LTF. Below are the Spectran captures for the 10GHz echoes, taken before, during and after the predicted minimum.

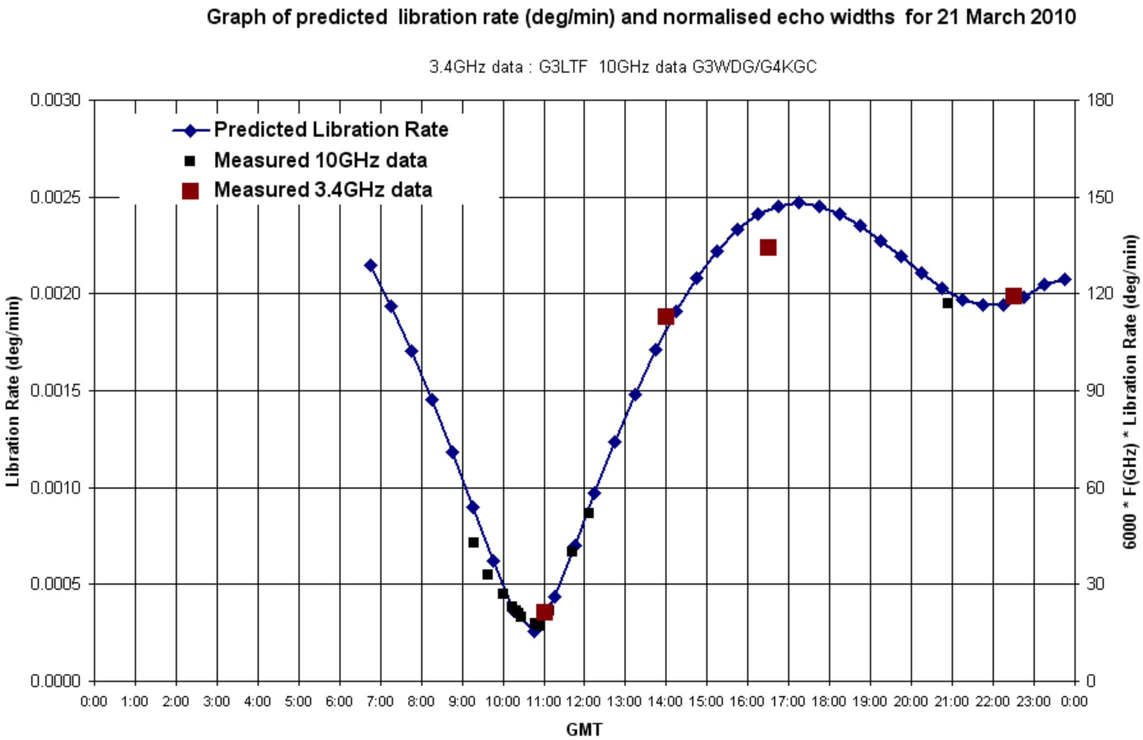


It can be seen that the signal started off fairly wide at the first observation at 0858, which was just after moonrise, became progressively narrower over the next two hours or so, reached a minimum at 1048 and then became progressively broader again. The third echo in the 2055 waterfall appears broader than the other echoes, and was caused by another station on the same frequency trying to attract our attention!

The timing of the point of minimum echo width also corresponds closely to when the Doppler shift reaches its maximum amount , ie the time when it briefly stops changing (thanks to G3LTF for this observation). The changing Doppler can be seen in the above plots in the waterfall traces, as a horizontal displacement from echo to echo. At 0858, for example, the echoes are moving progressively higher in frequency while at 1209 they are moving lower. At 1048 the echoes are practically all on the same frequency.

It can also be seen that the distribution of energy in the echoes changes from echo to echo. Some "fine structure" appears to be present in many of the echoes, which is not the same from echo to echo (eg look at the 1108 set).

The width of the echoes over the observation period were then measured (visually from the Spectran plots), and are plotted below, together with results obtained on the same day by G3LTF on 3.4GHz, on the same graph as the predicted libration rate. The scale of the right hand axis was adjusted so that the 10GHz echo width data fitted the predictions as closely as possible around the minimum region.



The timing of the 10GHz results matched the predictions very closely. The width of the signals also tracked the predictions well, both for the data points not only around the minimum (where the fitting was done) but also later in the day well away from the minimum (2055z). G3LTF's 3.4GHz results also fit the predictions well, if his observed signal widths are multiplied by the ratio of the operating frequencies (10.4/3.4).

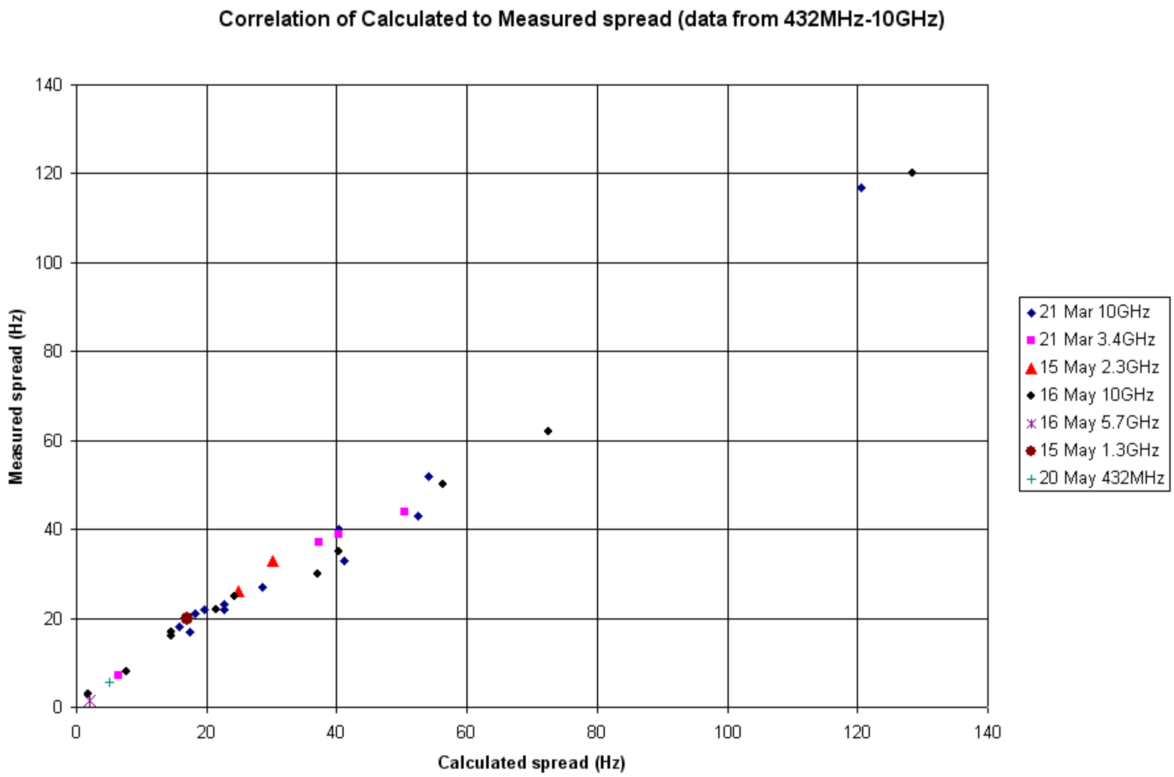
A formula for predicting signal width from this experimental data was thus derived to be:

Echo width (Hz) = 6000 * F(GHz) * Libration Rate (deg/min)

This agrees within 10% with recent theoretical predictions by GM4JJJ (Ref 6), which are higher than the experimentally derived values. It should be noted that the 6000 factor is likely to apply to systems where the antenna beamwidth is larger than the moon's diameter. Observed libration is lower when the antenna puts a "spot" on the moon.

Further Observations

Since the initial observations were made a lot more data has been collected. Thanks go especially to G3LTF, who has provided recordings of his echoes on 432MHz, 1.3, 2.3, 3.4 and 5.7GHz for analysis. The graph below shows how the measured echo widths compare to those predicted by the simple formula above. The data falls on a straight line (within experimental error) showing that the formula above works well, at least down to 432MHz, for predicting echo width. The slope of the best straight line fit is not exactly 1 however, and it is possible that the initially chosen 6000 factor may need to be modified slightly in the light of the extra data. This will be looked again at once more data has been collected. Please watch the website version of this paper for more details.

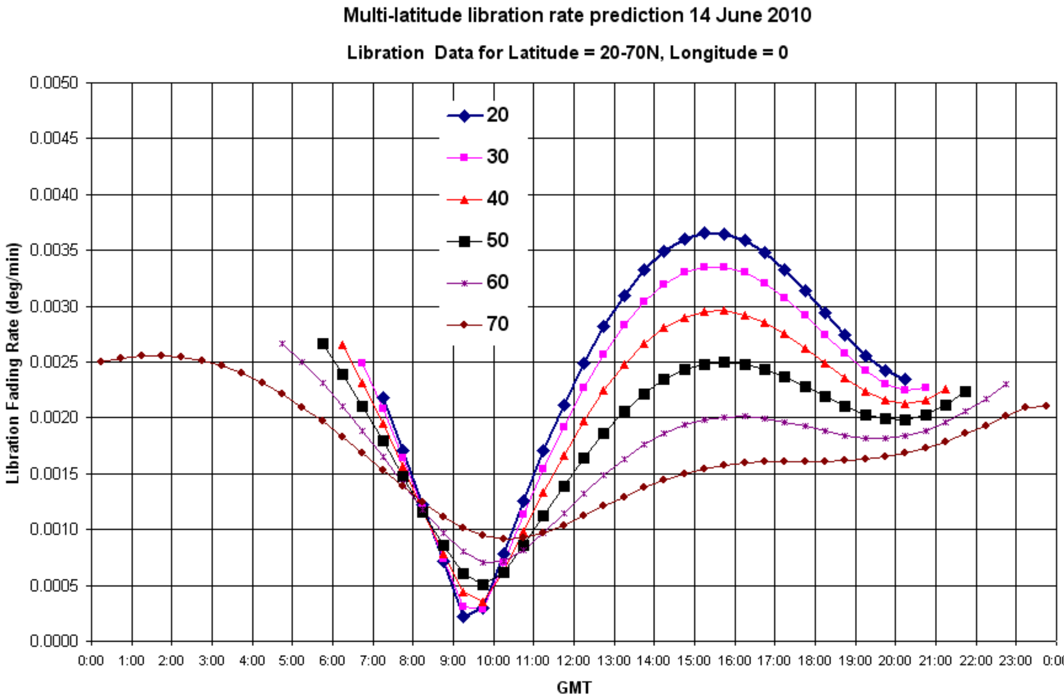


Variations in Libration - Geographical

The spreadsheet was modified further to produce daily graphs of libration rate at a number of different latitudes. It became immediately apparent that the libration rate varies considerably with the latitude of the observing station.. These effects can be seen in the following graph, which shows the predicted fading rates for 14 June 2010 for latitudes of 20 to 70 degrees, with longitude = 0.

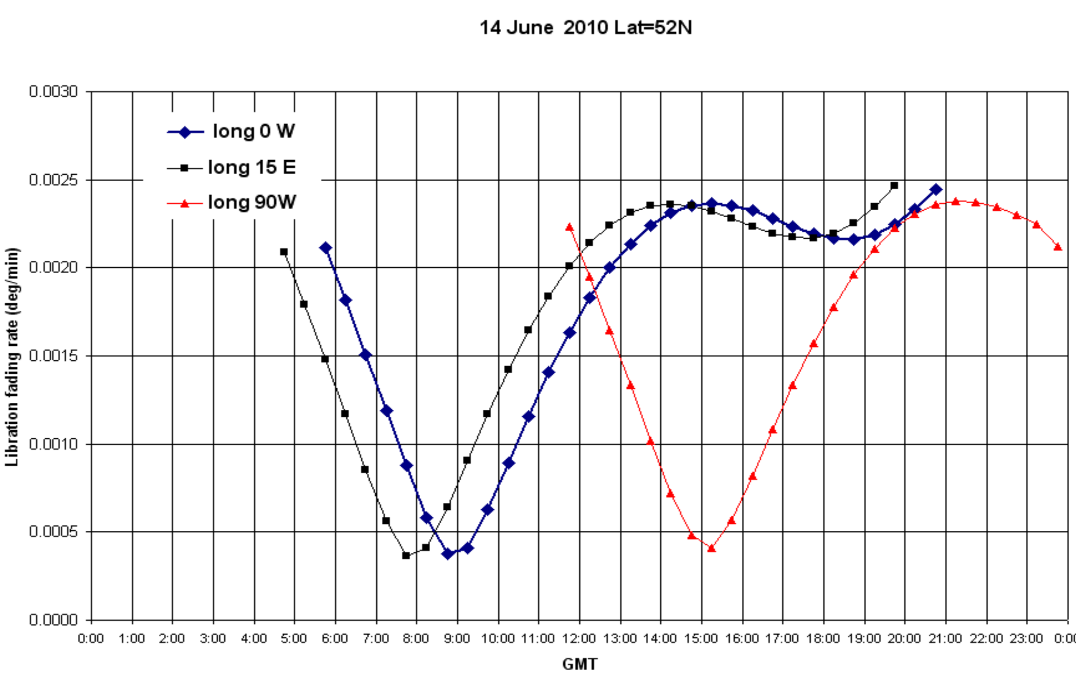
Stations nearer to the equator observe more rapid libration fading (and hence wider signals) near transit (~1400z in this case). In the region where the libration goes to minimum, the libration rate depends on the latitude of the station, and in this case stations between 30 and 40 degrees latitude will experience near zero libration rates, at around 0845z.

The time at which the minimum occurs varies by up to one hour for stations at the same longitude, but different latitudes.



The spreadsheet was also used to look at the effect of station longitude, for constant station latitude. . The graph below shows the predictions for stations located at lat=52N and longitudes of 0, 15E and 90W for the same day as above. Stations further east experience the minimum earlier than those to the west, by approximately 4 mins/degree longitude.

The depth of the minimum is almost the same for all three stations. The small differences in depth are attributed to the declination of the moon changing by a small amount between the times the stations experience the minimum, which changes the geometry slightly.



Variations in Libration during the Lunar Month

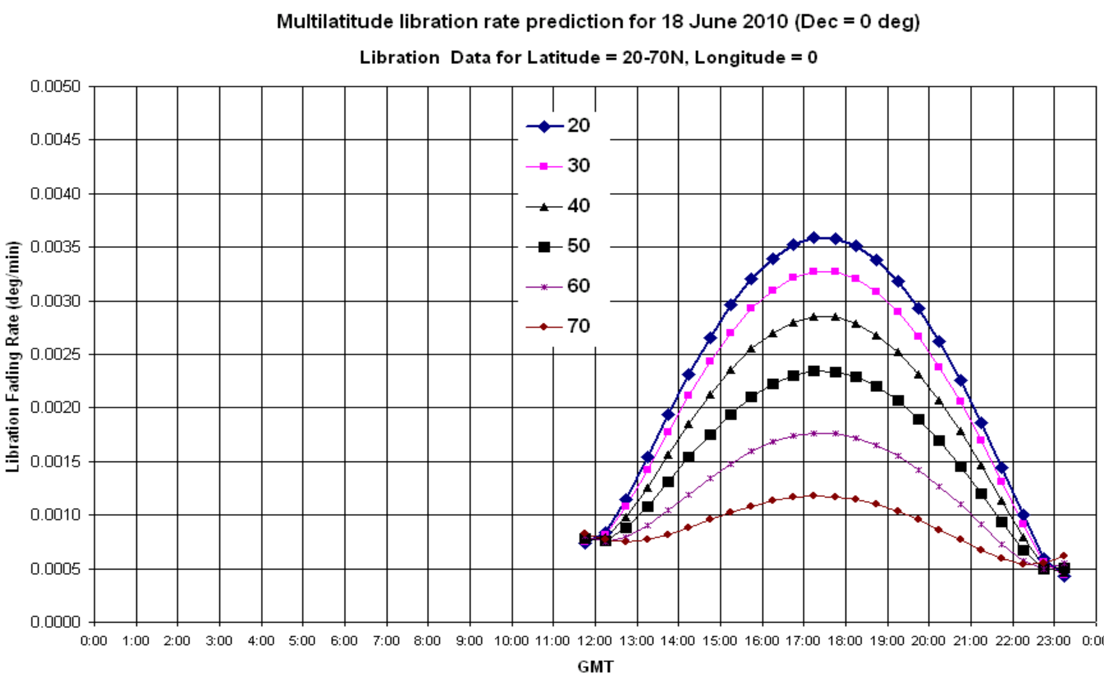
A set of predictions was run for 28 days during June, to see how the libration rate changes from day to day. The results are given in the web version of this paper. The following conclusions were drawn:

1. On all days, libration is lower near moonrise and moonset compared to values at transit, for all latitudes.

2. Libration minima are only observed with the moon above the horizon for 11 days in the month

3. For days where there is a minimum, there are only one or two days when the minimum is "deep", and these are not the same days for stations at different latitudes.

4. An interesting case occurs on 18 June, with the moon near zero declination, when stations at all latitudes see both the same amount of fading, and also at the same local times ie at local moonrise and moonset.



The geometry in this case is interesting. With the moon at 0 deg declination, it is located perpendicular to the spin axis of the earth, so that at moonrise (and moonset) stations on the Earth are moving directly towards (or away) from the moon, with no component of their earth rotation velocity being tangential to the moon. (It is this velocity component that is responsible for most of the observed libration). Thus the libration component due to Earth rotation at these times is zero and the observed libration rate (0.0075 deg/min) at the minimum is due to the other (much smaller) libration components.

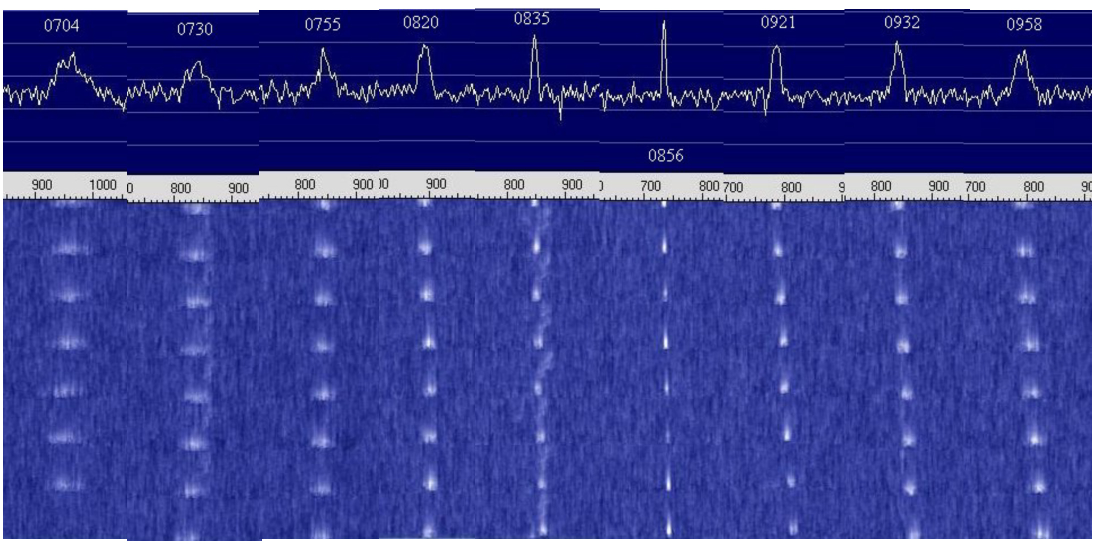
This example also help us to understand how "deep" minima occur. It has been seen above that deep minima usually occur some time after local moonrise. At these times the component of the station's Earth rotation velocity tangential to the moon's surface will, for a short time, cancel the sum of the other three libration components such that there little net libration. The fact that deep minima occur on different days for different Earth latitudes can be understood in the same way, as the geometry depends on both station latitude, moon declination and what the other librations are doing at that time.

A Libration "Zero" Event - May 16, 2010

The spreadsheet showed a minimum for our location on 16 May when the libration rate went to practically zero (predicted 10GHz signal width 2Hz). This provided a good opportunity to test to the accuracy of the predictions. G3WDG/G4KGC tested on 10GHz during the event and the following sequence of Spectra captures shows the results from 0704z to 0958z.

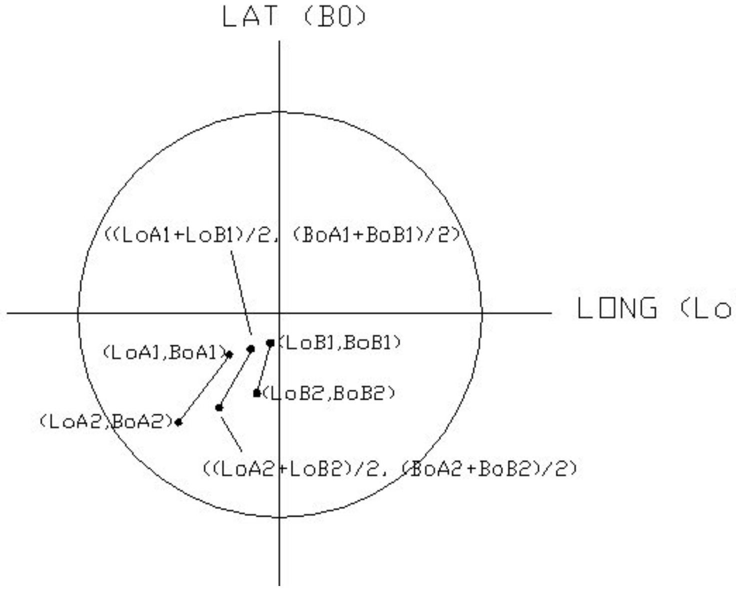
The signal width went to nearly zero width at 0856 and we observed a corresponding very slow fading fate, such that some echoes in the sequence are barely visible, having been knocked out by deep slow fades. This variation in echo strength on such a long timescale has not been observed before to my knowledge on 10GHz, and it not visible in the other traces.

As expected, the signal amplitude peaked at the libration minimum - this effect had been used on 21 March to observe echoes with Spectran with only 1-2W TX power into a 3m dish, on 10GHz:.



Predicting Libration Fading between two stations

A simple model has been produced to calculate the libration fading rate between two stations. This is of interest, as it would allow skeds to be arranged at times when libration is at a minimum between two stations, if the contact is likely to be marginal or to experiment with narrowband data modes. The model has been implemented as a spreadsheet, where the lunar longitude and latitude are calculated in the same way (ie two minutes apart) for the two stations separately. For station A the spreadsheet calculates (LoA1, BoA1) at T-1 and (LoA2, BoA2) at T+1, and for station B (LoB1, BoB1) and (LoB2, BoB2) for the same times. New points are then derived which are the averages of the lunar latitudes and longitudes observed by the two stations at T-1 and T+1 as shown in the diagram below: The distance between them is then calculated as was done for the single station case, and divided by 2 to obtain the “mutual” libration fading rate in deg/min.



Circumstances of the moon(two station case)

Re-worked from a BASIC program by George Rosenberg (ALPO), with topocentric corrections from Meeus and other formulas from Duffett-Smith

Original Spreadsheet by Keith Burnett, Macros by Charles Suckling G3WDG

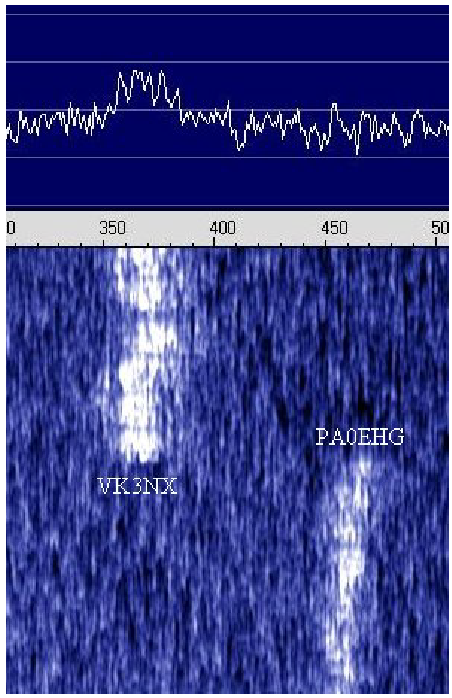
Date and station													User value
Parameter	User value	Input user data in blue cells with thick borders, press ENTER											Station A
Year	2010	and run macro "twostats" (ALT-F8, click "twostats", Click RUN)											G3WDG
Month	6									one station		Long	-0.5000
Day (UT)	13						Bo	Lo	Libration Rate	signal width		Lat	52.0000
Hour (UT)	7			14	14	T1	-0.483584	-3.139	deg/min	Hz			
Minute	15			15	15				0.000559254	34			
Longitude (E +ve)	26.7000	0.466		16	16	T2	-0.482797	-3.139					
Latitude (N +ve)	58.4000	1.019								**one station**			User value
User Frequency	10.0	GHz								**signal width**			Station B
Numerical Results	Geocentric	Topocentric			Station A	@ T1	-0.452721	-2.966		**Hz**			ES5PC
Co-longitude of Sun	284.66								0.000554338	**33**	Station A	Long	26.7000
Libration in latitude (Bo)	-1.1	-0.483			Station A	@ T2	-0.452548	-2.965			G3WDG	Lat	58.4000
Libration in longitude (Lo)	-3.6	-3.139								**one station**			
Sub solar point (Ls)	165.3									**signal width**			
Sub solar point (Bs)	0.5				Station B	@ T1	-0.483584	-3.139		**Hz**			
Longitude of terminator (+ Crisium)	75.3								0.000559254	**34**	Station B		
Nature of terminator	sunrise				Station B	@ T2	-0.482797	-3.139			ES5PC		
Illuminated Fraction	0.009												
PA of bright limb	267									**two station**			
Parallactic angle	-34						Bo av 1	Lo av 1		**signal width**			
PA of axis	0						-0.468152	-3.052226		**Hz**			
RA	6.237								0.000251440	**15**	Station A to Station B		
Dec	24.279						Bo av 2	Lo av 2			G3WDG	ES5PC	
							-0.467672	-3.052076					

A limited amount of data has been collected at the time of writing to verify whether this simple model works. A test between G3WDG (Station A) and JA6CZD (station B) was made on 16 May 2010 specifically to test the two station model. Both stations echo tested for 2 minute periods each between 0700 and 0800z and recordings were made.

At the start of the test, the model predicted a two way signal width of 64Hz and at the end 73Hz. Measurements of JA6CZD's signal as received by G3WDG gave values of 55Hz at the start and 60Hz at the end. G3WDG's signal received at JA6CZD measured slightly wider at 70Hz. Given the different signal levels and difficulty in estimating echo widths with high precision, the agreement between the model predictions and the measurements seems to be quite close.

Since that test, some further results have been obtained, as shown below.

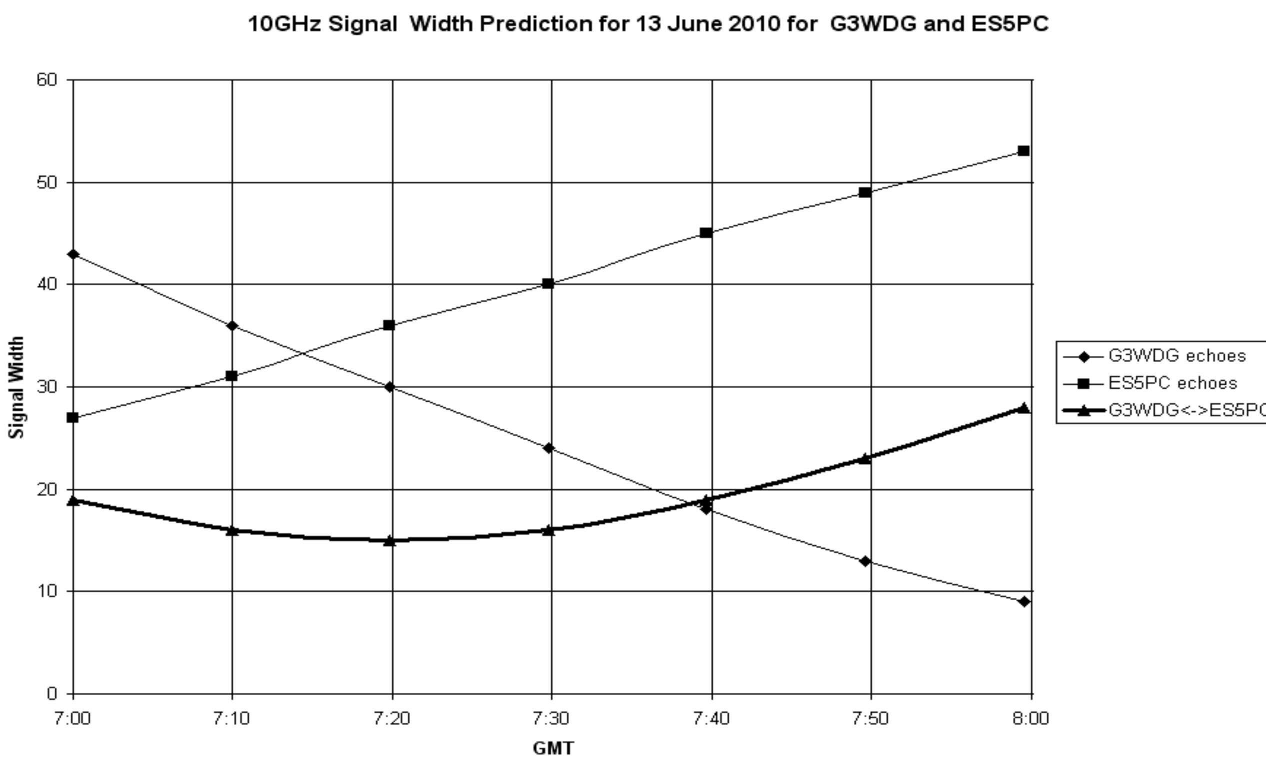
Date	Time	Station A	Station B	Predicted width	Measured width	Band	Comment
16 May	0930	G3WDG	SP7JSG	44Hz	35Hz	10GHz	Weak signal
16 May	0741	G3LTF	VK3NX	38Hz	35Hz	5.7GHz	see figure below
16 May	0741	G3LTF	PA0EHG	25Hz	20Hz	5.7GHz	see figure below



PA0EHG and VK3NX received by G3LTF on 5.7GHz at 0741z 16 May 2010, illustrating differing signal widths for two widely separated stations

Using WSJT modes during Libration Minima

10GHz tests between G3WDG/G4KGC and ES5PC were carried out on 13 June, to investigate whether some of the WSJT modes could be used on 10GHz EME, during periods of low libration. The test was planned to take place when the mutual spreading was at its lowest (approx 15Hz). The two station spreadsheet was used to predict the signal widths, and the results are shown below:



In line with the predictions above, the sked was arranged to start at 0700z, just before the minimum signal width would occur. It is interesting to note that the mutual signal width (ie the width of one station received by the other) is less than either station's own echoes at the time. ES5PC observed this in practice during the test.

Contact was initially established using JT4G (315Hz tone spacing). This had been tested successfully the previous day by G4NNS, ES5PC and G3WDG, and was found to work well during high libration conditions (with ~150Hz signal widths).

At Viljo's suggestion (via JT4G!), we then tried JT4E (78.75Hz tone spacing) with excellent decodes and a quick QSO, followed by JT4C (17.5Hz tone spacing). This proved to be more difficult, as the signals width was starting to increase, but a QSO was completed. By 0745z, with predicted signal widths of 20Hz (exceeding the tone spacing) , there were no more successful JT4C decodes.

Finally we tried JT65C, which also resulted in many successful decodes (of G3WDG by ES5PC) , but no QSO, probably due to inexperience with JT65 at our end! G3WDG's QSO log is shown below:

```
UTC Date: 2010 Jun 13
---------------------
065034  Transmitting: JT4G    ES5PC G3WDG IO92
065100 13  -16  2.6  105  9 *      CQ ES5PC KO38            1   0
065300 12  -17  2.6  179  2 #      G3WDG ES5PC KO38    OOO   1   0
065500  1  -19  1.8  144 25 #
065608  Transmitting: JT4G    ES5PC G3WDG IO92 OOO
065700 15  -17  2.6  118 24 *      RO                       1   0
065810  Transmitting: JT4G    RRR
065900 14  -18  2.5  -20  0 *      73                       1   0
070011  Transmitting: JT4G    73
070100 19  -19  2.5  -53 61 *      PSE JT4E                 1   0
070233  Transmitting: JT4E    ES5PC G3WDG IO92
070300  3  -20  2.6 -339  5 *
070500 12  -17  2.6 -370 31 #      G3WDG ES5PC KO38    OOO   1   0
070606  Transmitting: JT4E    RO
070700 10  -20  2.7 -252 29 *      RRR                      1   0
070804  Transmitting: JT4E    73
070900 17  -19  2.8 -289 29 *      PSE JT4C                 1   0
071009  Transmitting: JT4C    73
071012  Transmitting: JT4C    ES5PC G3WDG IO92
071100  1  -24  2.6 -324 45 #      G3WDG ES5PC KO38    OOO   1   0
071210  Transmitting: JT4C    RO
071300  0  -25  1.9 -378 40
071500  4  -25  2.5 -173 19 *      RRR                      1   0
071605  Transmitting: JT4C    73
071700  2  -25  2.7  -77 36 *      RRR                      1   0
071900  4  -25  2.6 -114 41 *      73                       1   0
```

Conclusions

1. A method has been developed to predict libration fading for one station with high accuracy, which has been tested against measured data on all bands from 432MHz - 10GHz.

2. A model has been produced to calculate libration fading between two stations, and is showing promising results.

3. Libration minimum events can be used to detect echoes with marginal systems.

4. Being able to calculate libration fading allows skeds to be arranged when fading as at a minimum, which can be useful for marginal contacts especially on the higher microwave bands, and for data modes.

5. Recent releases of GM4JJJ's MoonSked program now include provision for predicting signal width, both for own echoes and for two stations. This is available in both the Sked Maker and Moon Track windows.

6. Certain narrow-band WSJT modes can be used on 10GHz EME, given the right libration conditions. JT4G has been shown to work with high levels of libration spreading., and is recommended for initial tests.

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Libration Spreadsheet/software downloads

1. Single station, one time: www.sucklingfamily.free-online.co.uk/downloads/libration1.xls
2. Single station, predictions for 24h : www.sucklingfamily.free-online.co.uk/downloads/libration2.xls
3. One Longitude, multi latitude for 24h : www.sucklingfamily.free-online.co.uk/downloads/libration3.xls
4. Two station, one time : www.sucklingfamily.free-online.co.uk/downloads/libration4.xls
5. MoonSked by GM4JJJ: www.gm4jjj.co.uk/MoonSked/moonsked.htm

References

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http://www.ve1alq.com/W2IMU-K1RQG/Tech Bulletin 16/Tech Bulletin 16 of 20.pdf

2. Physics Forums, "Why Doesn't the Moon Spin?", comment 14 by "Janus"
http://www.physicsforums.com/showthread.php?t=14029

3. "Lunar Phase Pro" by Gary
http://lunarphasepro.nightskyobserver.com/

4. "MoonCalc" by Monzur Ahmed
http://www.ummah.net/ildl/mooncalc.html

5. Excel Spreadsheet "Circumstances of the Moon" by Keith Burnett
http://bodmas.org/kepler/mooneph.html#twig03

6. GM4JJJ, Private Communication May 2010

This article may be viewed on-line at
www.sucklingfamily.free-online.co.uk/Libration%20Paper/moonlibration.htm
including any updates, links to spreadsheets and software downloads