EME 2014 – Parc du Radome, Pleumeur Bodou France

Chapter I : Ionospheric interactions with EME signals

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Synopsis:

Cap. I – 2014
Ionosphere's meteorology: QSB in 2 m.
Building an Excel sheet for 2 m Faraday calculations.
Panoramic of polarity on moon passes

Cap. II - 2016
Spatial offset as function of distance and direction.
Extension of Excel sheet to other V/UHF bands
Analysis of polarity for each band.
Numbers and orders of magnitude
of qualitatively known characteristics.

Date: August 20, 2016

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1 – EME 2016 – Chapter II . Signal Polarity in V/UHF bands

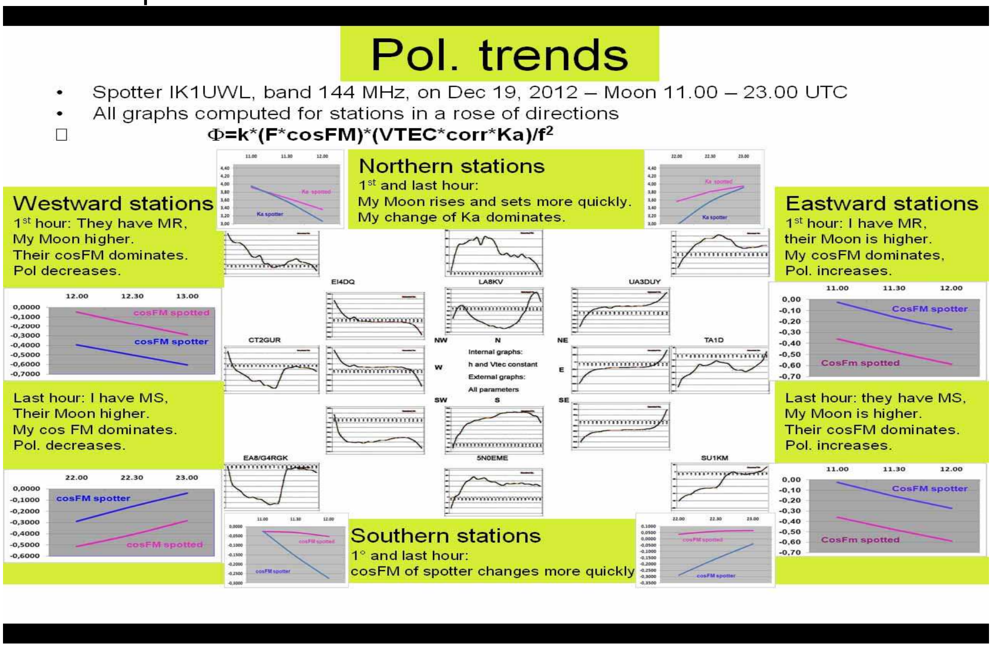
Hello, nice to meet you again. Why Chapter II?

2 – Background, Chapter I

We both operate on the 2 m band, and had decided to investigate Faraday and QSB effects, so common on this band.

In the 2014 France meeting we showed you our studies on what happens in the ionosphere to a 2 m signal.

Specifically: the type of QSB one can expect, and the polarity of the returning wave over a full moon pass.



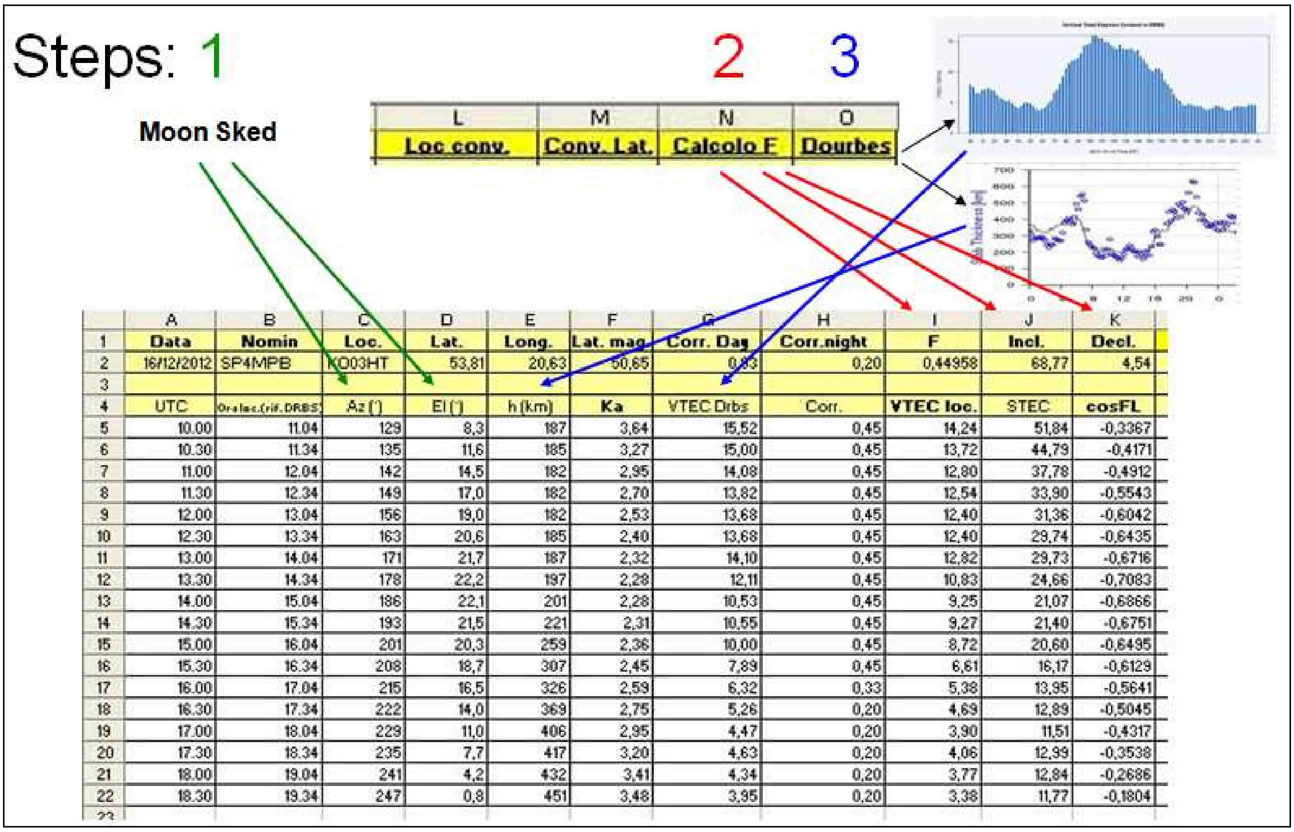
All the polarity calculations were made with an Excel sheet we built.

Data	Nomin	Loc.	Lat.	Long.	Lat. mag	Corr. Day	Corr.night	F	Incl.	Decl.	Loc conv.	Conv. Lat.	Calcolo F	Dourbes
16/12/2012	SP4MPB	KO03HT	53,81	20,63	50,65	0,93	0,20	0,44958	68,77	4,54				
UTC	Ora loc.(rif. DRBS)	Az (°)	El (°)	h (km)	Ka	VTEC Drbs	Corr.	VTEC loc.	STEC	cosFL	Rotaz. (°)	Rotaz.(rad)	Offset P1	P1(0,180)
10:00	11:04	129	8,3	187	3,64	15,52	0,45	14,24	51,84	-0,3367	-57,1	-1,00	61,6	61,6
10:30	11:34	135	11,6	185	3,27	15,00	0,45	13,72	44,79	-0,4171	-61,1	-1,07	64,5	64,5
11:00	12:04	142	14,5	182	2,95	14,08	0,45	12,80	37,78	-0,4912	-60,7	-1,06	68,0	68,0
11:30	12:34	149	17,0	182	2,70	13,82	0,45	12,54	33,90	-0,5543	-61,5	-1,07	71,7	71,7
12:00	13:04	156	19,0	182	2,53	13,68	0,45	12,40	31,36	-0,6042	-62,0	-1,08	75,6	75,6
12:30	13:34	163	20,6	185	2,40	13,68	0,45	12,40	29,74	-0,6435	-62,6	-1,09	79,7	79,7
13:00	14:04	171	21,7	187	2,32	14,10	0,45	12,82	29,73	-0,6716	-65,3	-1,14	84,5	84,5
13:30	14:34	178	22,2	197	2,28	12,11	0,45	10,83	24,66	-0,7083	-57,1	-1,00	88,8	88,8
14:00	15:04	186	22,1	201	2,28	10,53	0,45	9,25	21,07	-0,6866	-47,3	-0,83	-86,4	93,6
14:30	15:34	193	21,5	221	2,31	10,55	0,45	9,27	21,40	-0,6751	-47,3	-0,82	-82,2	97,8
15:00	16:04	201	20,3	259	2,36	10,00	0,45	8,72	20,60	-0,6495	-43,8	-0,76	-77,4	102,6
15:30	16:34	208	18,7	307	2,45	7,89	0,45	6,61	16,17	-0,6129	-32,4	-0,57	-73,4	106,6
16:00	17:04	215	16,5	326	2,59	6,32	0,33	5,38	13,95	-0,5641	-25,7	-0,45	-69,6	110,4
16:30	17:34	222	14,0	369	2,75	5,26	0,20	4,69	12,89	-0,5045	-21,3	-0,37	-66,1	113,9
17:00	18:04	229	11,0	406	2,95	4,47	0,20	3,90	11,51	-0,4317	-16,3	-0,28	-62,8	117,2
17:30	18:34	235	7,7	417	3,20	4,63	0,20	4,06	12,99	-0,3538	-15,0	-0,26	-60,2	119,8
18:00	19:04	241	4,2	432	3,41	4,34	0,20	3,77	12,84	-0,2686	-11,3	-0,20	-58,0	122,0
18:30	19:34	247	0,8	451	3,48	3,95	0,20	3,38	11,77	-0,1804	-6,9	-0,12	-56,1	123,9
Data	Nomin	Loc.	Lat.	Long.	Lat. mag	Corr. Day	Corr.night	F	Incl.	Decl.	Loc conv.	Conv. Lat.	Calcolo F	Dourbes
16/12/2012	PA3FPQ	JO22XE	52,19	5,96	50,61	0,93	0,20	0,43860	66,93	0,23				
UTC	Ora loc.(rif. DRBS)	Az (°)	El (°)	h (km)	Ka	VTEC Drbs	Corr.	VTEC loc.	STEC	cosFL	Rotaz. (°)	Rotaz.(rad)	Offset P2	P2(0,180)
10:00	10:05	116	2,0	192	4,21	14,74	0,45	13,48	56,76	-0,2023	-36,7	-0,64	55,4	55,4
10:30	10:35	122	5,8	187	3,93	16,05	0,45	14,79	58,16	-0,2974	-55,2	-0,96	57,6	57,6
11:00	11:05	128	9,4	187	3,52	15,52	0,45	14,26	50,13	-0,3869	-61,9	-1,08	60,1	60,1
11:30	11:35	135	12,8	185	3,13	15,00	0,45	13,74	42,98	-0,4725	-64,8	-1,13	63,4	63,4
12:00	12:05	141	15,8	182	2,82	14,08	0,45	12,82	36,10	-0,5427	-62,5	-1,09	66,6	66,6
12:30	12:35	148	18,4	182	2,58	13,82	0,45	12,56	32,35	-0,6055	-62,5	-1,09	70,4	70,4
13:00	13:05	155	20,6	182	2,40	13,68	0,45	12,42	29,82	-0,6558	-62,4	-1,09	74,5	74,5
13:30	13:35	163	22,3	185	2,28	13,68	0,45	12,42	28,27	-0,6956	-62,8	-1,10	79,4	79,4
14:00	14:05	170	23,5	187	2,20	14,10	0,45	12,84	28,25	-0,7199	-64,9	-1,13	83,7	83,7
14:30	14:35	178	24,0	187	2,17	12,11	0,45	10,85	23,49	-0,7319	-54,9	-0,96	88,7	88,7
15:00	15:05	186	24,0	201	2,16	10,53	0,45	9,27	19,99	-0,7304	-46,6	-0,81	-86,2	93,8
15:30	15:35	193	23,3	221	2,19	10,53	0,45	9,27	20,29	-0,7151	-46,3	-0,81	-81,9	98,1
16:00	16:05	201	22,0	259	2,25	10,00	0,45	8,74	19,66	-0,6844	-42,9	-0,75	-76,9	103,1
16:30	16:35	208	20,3	307	2,33	7,89	0,45	6,63	15,44	-0,6444	-31,8	-0,55	-72,8	107,2
17:00	17:05	215	18,0	326	2,48	6,32	0,33	5,39	13,37	-0,5905	-25,2	-0,44	-68,8	111,2
17:30	17:35	222	15,4	369	2,64	5,26	0,20	4,70	12,40	-0,5258	-20,8	-0,36	-65,1	114,9
18:00	18:05	229	12,3	406	2,85	4,47	0,20	3,91	11,12	-0,4483	-15,9	-0,28	-61,7	118,3
18:30	18:35	235	8,9	417	3,11	4,63	0,20	4,07	12,64	-0,3655	-14,7	-0,26	-59,0	121,0

Results were checked by comparison with real decodes of the same stations lasting at least one hour. For our research we built a big library of station pairs.

3 – Our Excel sheet

Building the sheet for each pair of stations is a lot of work, due to the amount of data necessary. These are: Moon position during the pass, ionospheric density and thickness for that date, the geomagnetic field above that locator.



	A	B	C	D	E	F	G	H	I	J	K
1	Data	Nomin	Loc.	Lat.	Long.	Lat. mag	Corr. Day	Corr.night	F	Incl.	Decl.
2	16/12/2012	SP4MPB	KO03HT	53,81	20,63	50,65	0,83	0,20	0,44958	68,77	4,54
3											
4	UTC	Ora loc.(rif. DRBS)	Az (°)	El (°)	h (km)	Ka	VTEC Drbs	Corr.	VTEC loc.	STEC	cosFL
5	10.00	11.04	129	8,3	187	3,64	15,52	0,45	14,24	51,84	-0,3367
6	10.30	11.34	135	11,6	185	3,27	15,00	0,45	13,72	44,79	-0,4171
7	11.00	12.04	142	14,5	182	2,95	14,08	0,45	12,80	37,78	-0,4912
8	11.30	12.34	149	17,0	182	2,70	13,82	0,45	12,54	33,90	-0,5543
9	12.00	13.04	156	19,0	182	2,53	13,68	0,45	12,40	31,36	-0,6042
10	12.30	13.34	163	20,6	185	2,40	13,68	0,45	12,40	29,74	-0,6435
11	13.00	14.04	171	21,7	187	2,32	14,10	0,45	12,82	29,73	-0,6716
12	13.30	14.34	178	22,2	197	2,28	12,11	0,45	10,83	24,66	-0,7083
13	14.00	15.04	186	22,1	201	2,28	10,53	0,45	9,25	21,07	-0,6866
14	14.30	15.34	193	21,5	221	2,31	10,55	0,45	9,27	21,40	-0,6751
15	15.00	16.04	201	20,3	259	2,36	10,00	0,45	8,72	20,60	-0,6495
16	15.30	16.34	208	18,7	307	2,45	7,89	0,45	6,61	16,17	-0,6129
17	16.00	17.04	215	16,5	326	2,59	6,32	0,33	5,38	13,95	-0,5641
18	16.30	17.34	222	14,0	369	2,75	5,26	0,20	4,69	12,89	-0,5045
19	17.00	18.04	229	11,0	406	2,95	4,47	0,20	3,90	11,51	-0,4317
20	17.30	18.34	235	7,7	417	3,20	4,63	0,20	4,06	12,99	-0,3538
21	18.00	19.04	241	4,2	432	3,41	4,34	0,20	3,77	12,84	-0,2686
22	18.30	19.34	247	0,8	451	3,48	3,95	0,20	3,38	11,77	-0,1804
23											

The sheet converts the ionospheric data for the station’s location, calculates the increase of ion density due to oblique passage (Ka), and finds the magnetic field component in the wave’s direction (cosFM).

4 – Results for each station

Putting these data in Faraday’s rotation formula and adding the polar offset gives us a table of the rotations of the up going and down going waves.

5 – Final results in 2m

Notwithstanding the choice of two relatively near stations (1000 km), so that the ionospheric density is similar, we see that the two factors, Ka and cosFM, have an important influence in causing different rotations (up right figure).

So, on 2 meters, the rotation varies appreciably, going up and down during the Moon pass.

SP4MPB (tx)

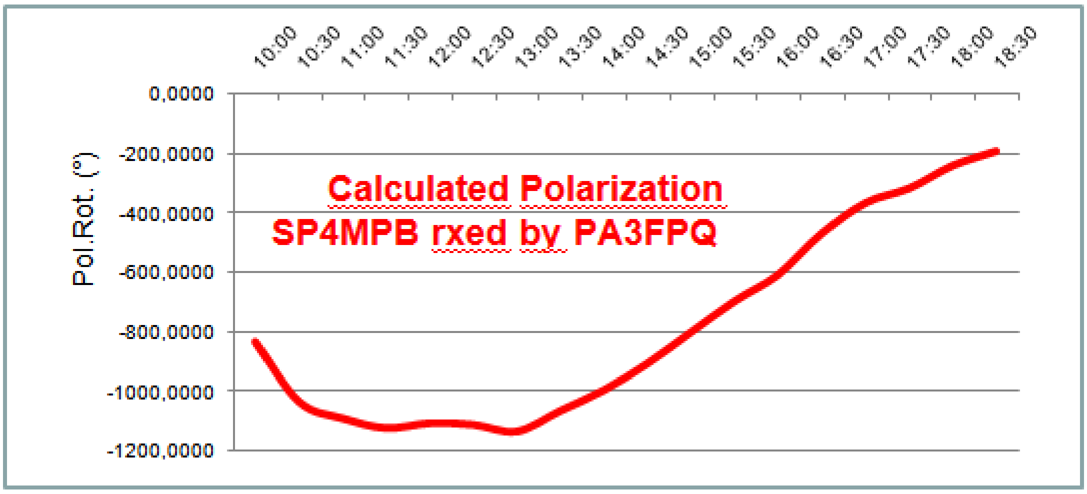
Data	**Nomin**	**Loc.**	**Lat.**	**Long.**	**Lat. mag**	**Corr. Day**	**Corr.night**	**F**	**Incl.**	**Decl.**	**Loc conv.**
16/12/2012	SP4MPB	KO03HT	53,81	20,63	50,65	0,93	0,20	0,44958	68,77	4,54	
UTC	Ora loc.(rif.ORBS)	Az (°)	El (°)	h (km)	**Ka**	VTEC Dbs	Corr.	**VTEC loc.**	STEC	**cosFL**	Rotaz. (°)
10:00	11:04	129	8,3	187	3,64	15,52	0,45	14,24	51,84	-0,3367	-512,6
10:30	11:34	135	11,6	185	3,27	15,00	0,45	13,72	44,79	-0,4171	-548,7
11:00	12:04	142	14,5	182	2,95	14,08	0,45	12,80	37,78	-0,4912	-545,0
11:30	12:34	149	17,0	182	2,70	13,82	0,45	12,54	33,90	-0,5543	-551,9
12:00	13:04	156	19,0	182	2,53	13,68	0,45	12,40	31,36	-0,6042	-556,5
12:30	13:34	163	20,6	185	2,40	13,68	0,45	12,40	29,74	-0,6435	-562,1
13:00	14:04	171	21,7	187	2,32	14,10	0,45	12,82	29,73	-0,6716	-586,4
13:30	14:34	178	22,2	197	2,28	12,11	0,45	10,83	24,66	-0,7083	-512,9
14:00	15:04	186	22,1	201	2,28	10,53	0,45	9,25	21,07	-0,6866	-424,9
14:30	15:34	193	21,5	221	2,31	10,55	0,45	9,27	21,40	-0,6751	-424,2
15:00	16:04	201	20,3	259	2,36	10,00	0,45	8,72	20,60	-0,6495	-393,0
15:30	16:34	208	18,7	307	2,45	7,89	0,45	6,61	16,17	-0,6129	-291,0
16:00	17:04	215	16,5	326	2,59	6,32	0,33	5,38	13,95	-0,5641	-231,1
16:30	17:34	222	14,0	369	2,75	5,26	0,20	4,69	12,89	-0,5045	-191,0
17:00	18:04	229	11,0	406	2,95	4,47	0,20	3,90	11,51	-0,4317	-145,9
17:30	18:34	235	7,7	417	3,20	4,63	0,20	4,06	12,99	-0,3538	-135,0
18:00	19:04	241	4,2	432	3,41	4,34	0,20	3,77	12,84	-0,2686	-101,3
18:30	19:34	247	0,8	451	3,48	3,95	0,20	3,38	11,77	-0,1804	-62,4

Wave going up

PA3FPQ (rx)

Data	**Nomin**	**Loc.**	**Lat.**	**Long.**	**Lat. mag**	**Corr. Day**	**Corr.night**	**F**	**Incl.**	**Decl.**	**Loc conv.**
16/12/2012	PA3FPQ	JO22XE	52,19	5,96	50,61	0,93	0,20	0,43860	66,93	0,23	
UTC	Ora loc.(rif.ORBS)	Az (°)	El (°)	h (km)	**Ka**	VTEC Dbs	Corr.	**VTEC loc.**	STEC	**cosFL**	Rotaz. (°)
10:00	10:05	116	2,0	192	4,21	14,74	0,45	13,48	56,76	-0,2023	-329,0
10:30	10:35	122	5,8	187	3,93	16,05	0,45	14,79	58,16	-0,2974	-495,6
11:00	11:05	128	9,4	187	3,52	15,52	0,45	14,26	50,13	-0,3869	-555,6
11:30	11:35	135	12,8	185	3,13	15,00	0,45	13,74	42,98	-0,4725	-581,9
12:00	12:05	141	15,8	182	2,82	14,08	0,45	12,82	36,10	-0,5427	-561,3
12:30	12:35	148	18,4	182	2,58	13,82	0,45	12,56	32,35	-0,6055	-561,2
13:00	13:05	155	20,6	182	2,40	13,68	0,45	12,42	29,82	-0,6558	-560,2
13:30	13:35	163	22,3	185	2,28	13,68	0,45	12,42	28,27	-0,6956	-563,4
14:00	14:05	170	23,5	187	2,20	14,10	0,45	12,84	28,25	-0,7199	-582,6
14:30	14:35	178	24,0	187	2,17	12,11	0,45	10,85	23,49	-0,7319	-492,6
15:00	15:05	186	24,0	201	2,16	10,53	0,45	9,27	19,99	-0,7304	-418,4
15:30	15:35	193	23,3	221	2,19	10,53	0,45	9,27	20,29	-0,7151	-415,6
16:00	16:05	201	22,0	259	2,25	10,00	0,45	8,74	19,66	-0,6844	-385,4
16:30	16:35	208	20,3	307	2,33	7,89	0,45	6,63	15,44	-0,6444	-285,2
17:00	17:05	215	18,0	326	2,48	6,32	0,33	5,39	13,37	-0,5905	-226,2
17:30	17:35	222	15,4	369	2,64	5,26	0,20	4,70	12,40	-0,5258	-186,8
18:00	18:05	229	12,3	406	2,85	4,47	0,20	3,91	11,12	-0,4483	-142,8
18:30	18:35	235	8,9	417	3,11	4,63	0,20	4,07	12,64	-0,3655	-132,4

Wave coming back



6 – Chapter II

Using this library, we intend to show and expand the polarity issue for the V/UHF bands.

<u>Polarity</u> is the <u>sum of Spatial Offset and Faraday rotation.</u>

Spatial Offset is dependent only on the relative location of the stations..

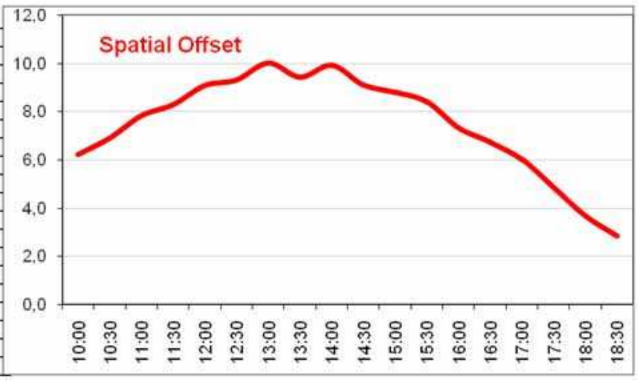
Faraday is dependent on frequency, ionosphere's density, and on Moon's position

7 –From our library: Spatial Offsets

With a simple shift of the field chosen for the polarity graph, we easily obtain from each Excel sheet in our library the graph of Polar Offset.

- **With a simple shift: Spatial Offset between SP4MPB and PA3FPQ**

UTC	Somma rot.(°)	P1-P2 (°)	Pol. Calc.	Reale
10:00	-183,5	6,2	-177,3	
10:30	-53,1	6,9	-46,2	
11:00	10,6	7,8	18,4	
11:30	30,0	8,3	38,3	
12:00	4,8	9,1	13,9	
12:30	-0,9	9,3	8,4	
13:00	-7,0	10,0	3,0	
13:30	50,6	9,4	60,0	
14:00	138,7	9,9	148,6	
14:30	68,4	9,1	77,5	
15:00	25,4	8,8	34,2	
15:30	124,6	8,4	133,0	
16:00	154,3	7,3	161,6	
16:30	94,1	6,7	100,8	
17:00	80,3	6,0	86,3	
17:30	51,9	4,8	56,7	
18:00	41,6	3,7	45,2	
18:30	70,0	2,8	72,9	



Since it is independent from frequency, our library data are valid for all bands.

8 – Spatial Offset

An easy way to calculate the angle between the planes of two antennas in different places of the world is to calculate for each the angle respect earth's polar axis, then make the difference between them.

P=arctg((sin**Lat***cos**El**-cos**Lat***cos**Az***sin**El**)/cos**Lat***sin**Az**)

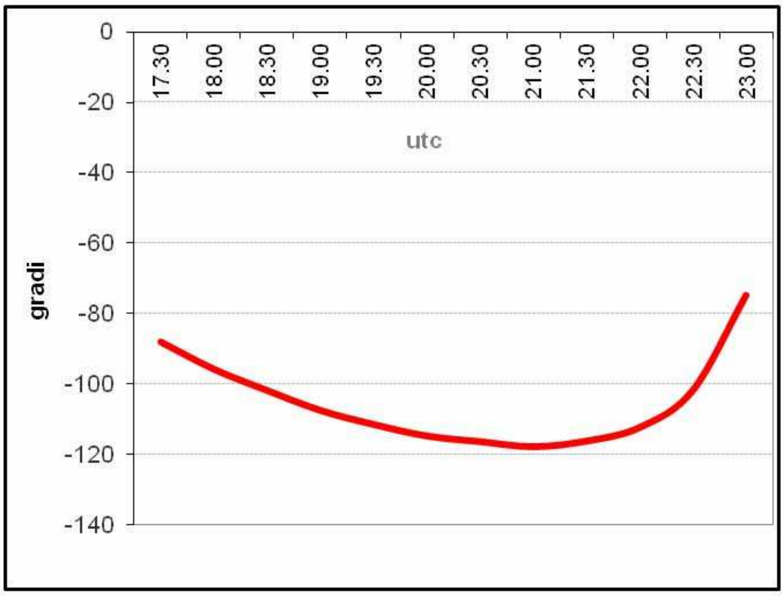
Spatial Offset = P1 – P2

These angles depend on the latitude, and on Moon's direction.

Latitude is a constant, Moon's direction varies during the pass.

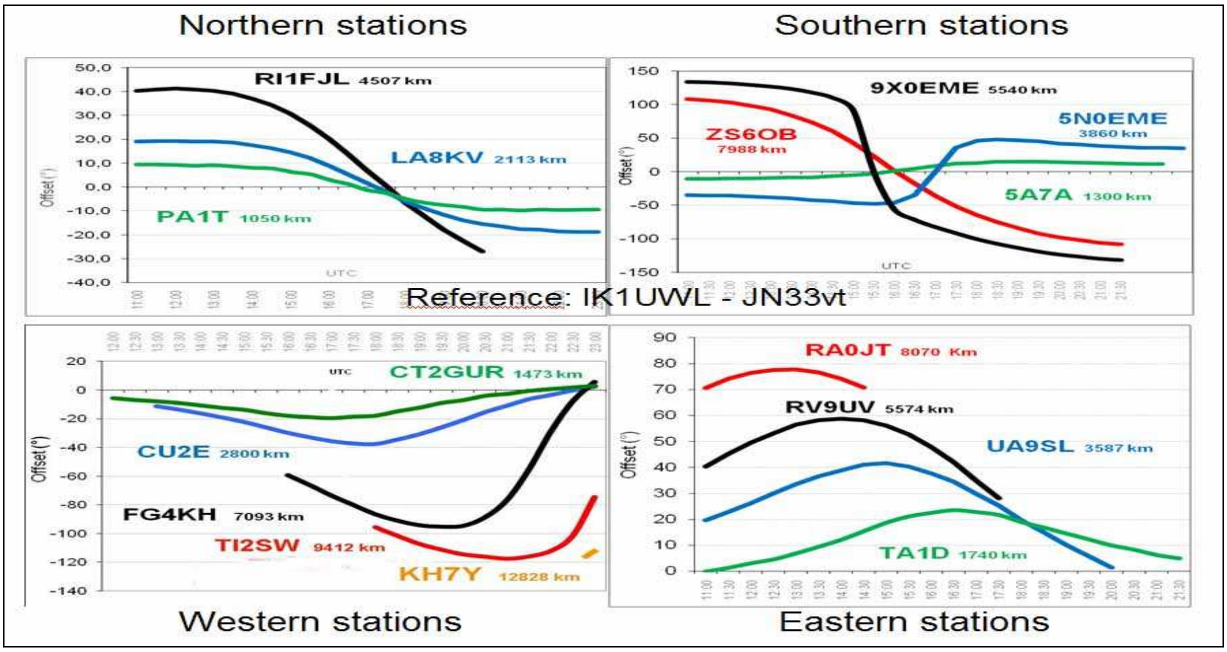
The differences between polar offsets increase with station distance so spatial offset can become an important factor of polarity.

For example TI2SW 9000 km west of IK1UWL



9 – Offset, change with distance and direction

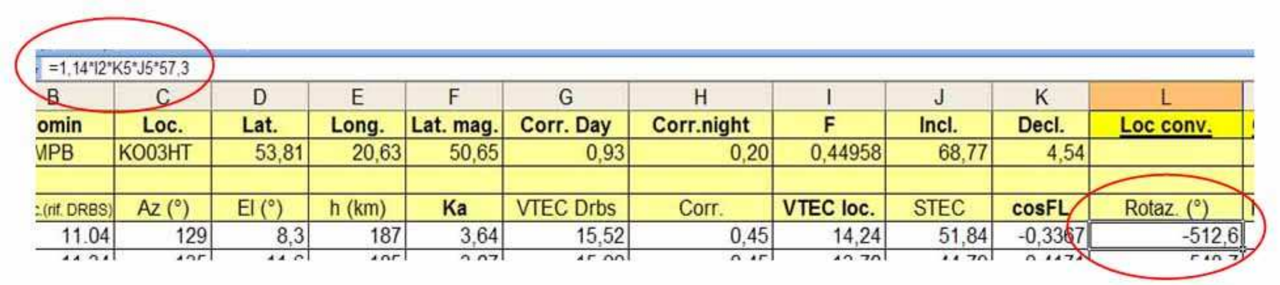
From our big library we have extrapolated graphs for many stations placed in different directions and at different distances.



When the main difference is only in latitude, the graphs have an S shape, and offset tends to zero with Moon in the middle of the pass.
When the difference is mainly longitude, the offset is maximum with Moon in the middle of the pass, and does not change sign.
Offsets can reach and pass 90°. If greater, since the phase is not important, the effective offset is the supplement of the calculated value (but the full value must be used for polarity calculation).

10 – Conversion to other bands

In our sheets we did put in the coefficient k/f^2 which has a value for 2 m of 1,14.



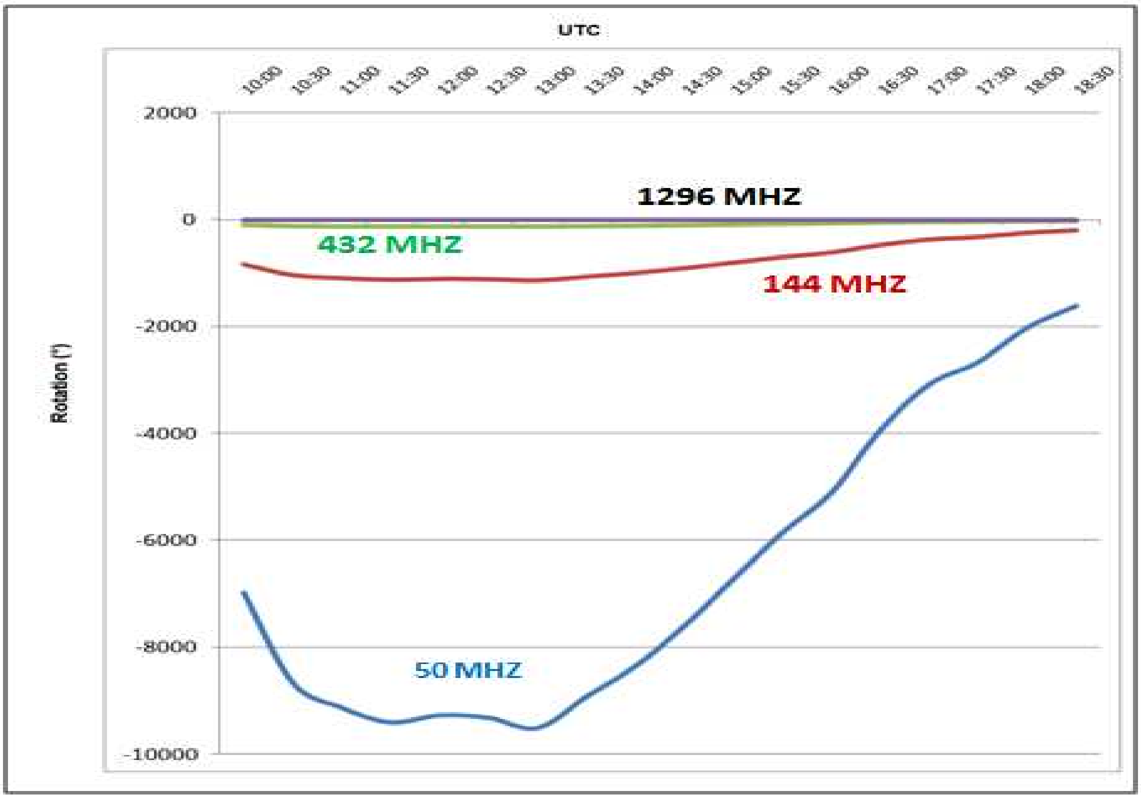
=1,14*I2*K5*J5*57,3

B	C	D	E	F	G	H	I	J	K	L
omin	Loc.	Lat.	Long.	Lat. mag.	Corr. Day	Corr.night	F	Incl.	Decl.	Loc conv.
MPB	KO03HT	53,81	20,63	50,65	0,93	0,20	0,44958	68,77	4,54	
:(rif. DRBS)	Az (°)	El (°)	h (km)	Ka	VTEC Drbs	Corr.	VTEC loc.	STEC	cosFL	Rotaz. (°)
11.04	129	8,3	187	3,64	15,52	0,45	14,24	51,84	-0,3367	-512,6

These are the different values for the other VHF and UHF bands:
6m – 9,46; 70cm – 0,127; 23cm – 0,0123
Changing the coefficient in the formula transforms the sheet to what would happen if the two stations were operating on this different band. Our library can be easily transformed to show what would happen on different bands for the same pair and in the same conditions.

11 – 4 bands (6m, 2m, 70 cm, 23 cm)

Using the same pair, SP4MPB by PA3FPQ, we show you the superimposed graphs of polarity rotation when operating on these four bands.



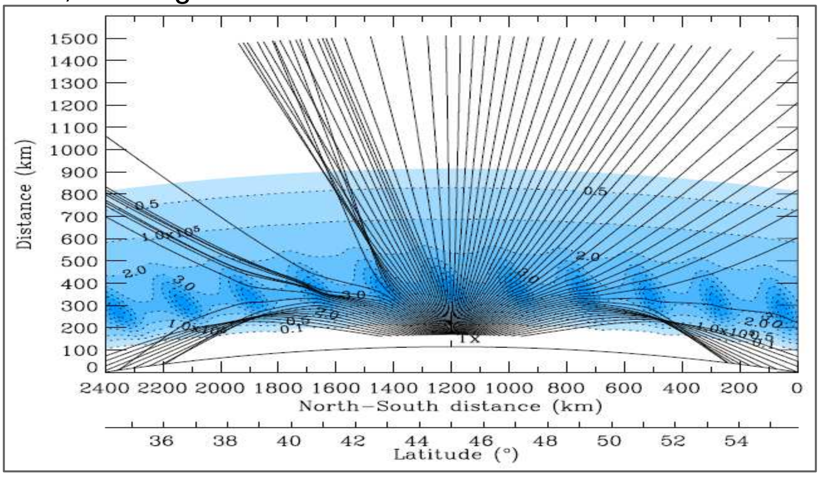
Rotation due to Faraday is enormous on the lower band, and gradually becomes smaller with decreasing frequency. There is a factor 9 for each jump.
These graphs use Faraday calculated for an unperturbed ionosphere.
Lets see in more detail what happens on each band.

12 – VHF bands, unperturbed ionosphere

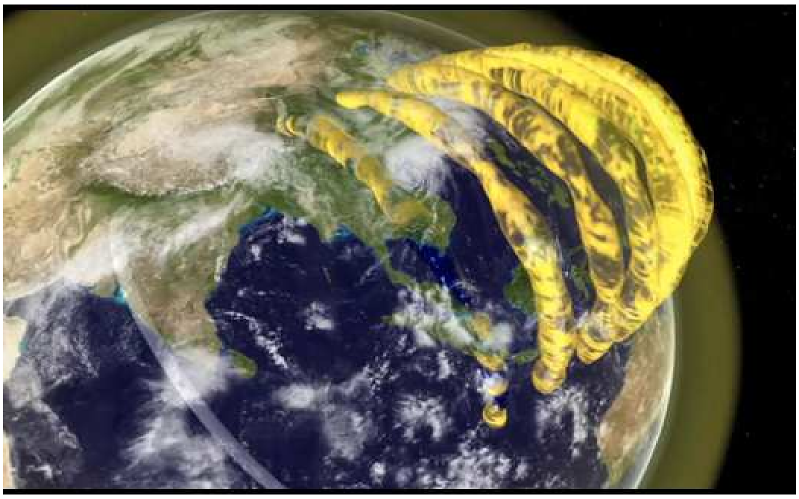
In VHF, polarity is determined mainly by Faraday rotation, which is much bigger than spatial offset.
Faraday rotation is obtained multiplying a frequency dependent coefficient, the geomagnetic field component in the wave's direction, and the ionosphere's electron content encountered. In order of importance, parameters influencing Faraday, for an unperturbed ionosphere, are:
-- the angle between the Geomagnetic field and Moon's direction which can vary from very small values to almost 90°
-- the obliquity coefficient which measures the increase of length of the passage through the ionosphere, function of moon's elevation
-- the electron density of the ionosphere

13 – VHF bands, turbulent ionosphere

Superimposed on the average evolution of Faraday rotation during a Moon pass, there can be a more quicker fluctuation due to the effect of ionospheric winds.
Winds cause undulations and waves (TIDs), so free electron density varies in space and time, causing rotation fluctuations.



Australian scientist of the University of Sydney , Cleo Loi, has made the very interesting discovery of plasma tubes in Earth's magnetosphere. These structures are important because they cause signal distortions that could affect trans-ionospheric communication.



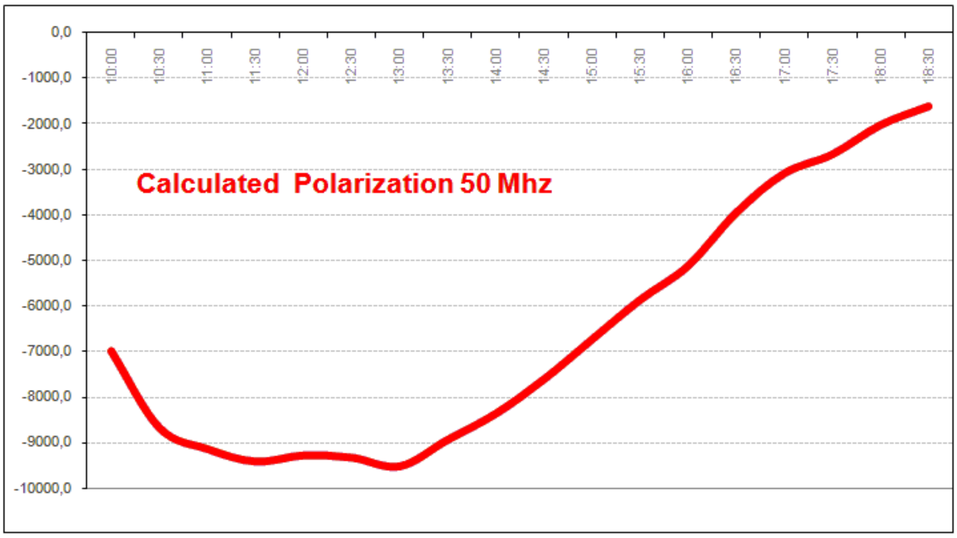
The complex plasma ducts are created in the atmosphere when this is ionized by sunlight. The plasma interacts with the earth's magnetic field, creating field-aligned ducts of plasma. These structures of plasma are at about 600 km above the Earth's surface, in the upper ionosphere.

14,15 – 50 MHz band

Typical sky noise temperature is 3600 °K (very high).

On this band Faraday rotates with high speed many thousands of degrees over a Moon pass. So there is a quick shift between horizontal and vertical polarization.

Spatial offset is absolutely irrelevant.



16 – Effect of rotation speed on a JT65 qso

JT65 alternates 1’ periods of transmission and reception.

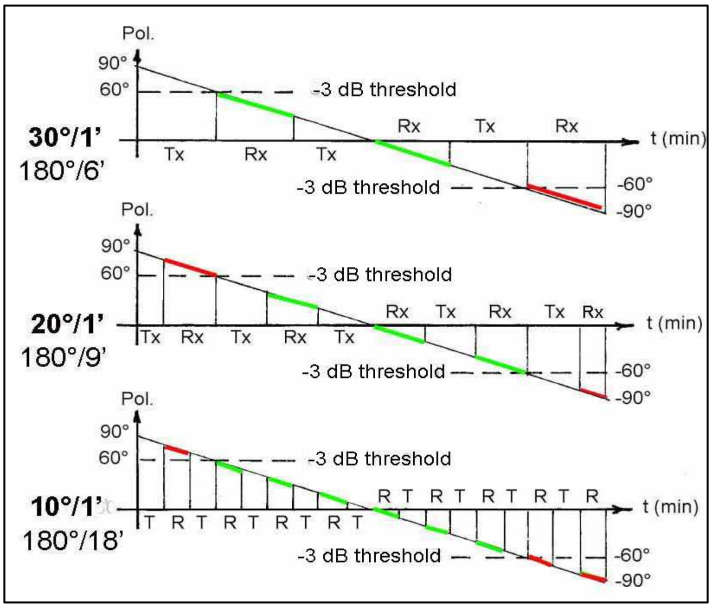
We are considering a case in which the received signal, when polarity is optimum, is 3 dB above the minimum decoding limit.

3 dB is the attenuation when the polarity is +-60°.

So, during the time that polarity is between 60° and -60°, decodes are possible.

Beyond -60° through 90° till the successive 60°, there are no decodes.

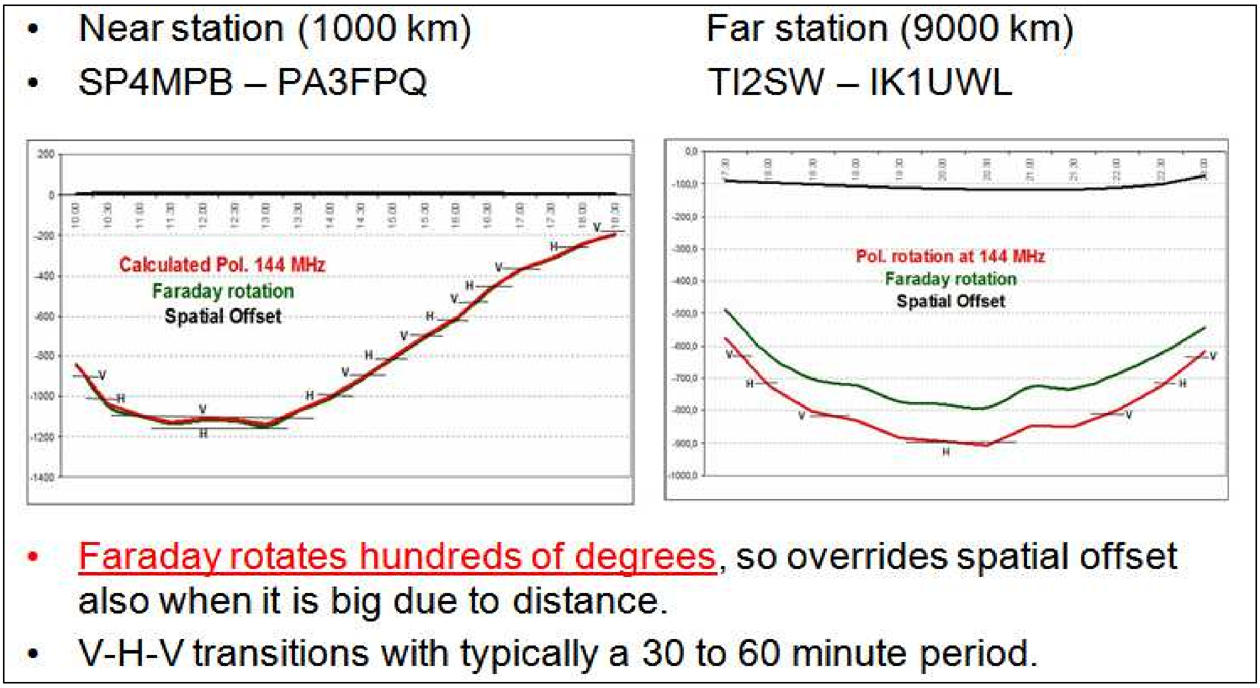
Part of the favourable period is occupied by transmission, so the number of consecutive periods favourable for decodes decreases to half.



In this graph we show the effect of rotation speed for three typical cases.
A JT65 qso takes 5-6 minutes overall if decodes happen consecutively, rare case.
On this band this condition is very rare, so a qso can take a much longer time.

17 – 144 MHz band

Typical sky noise temperature is 300 °K (moderate).



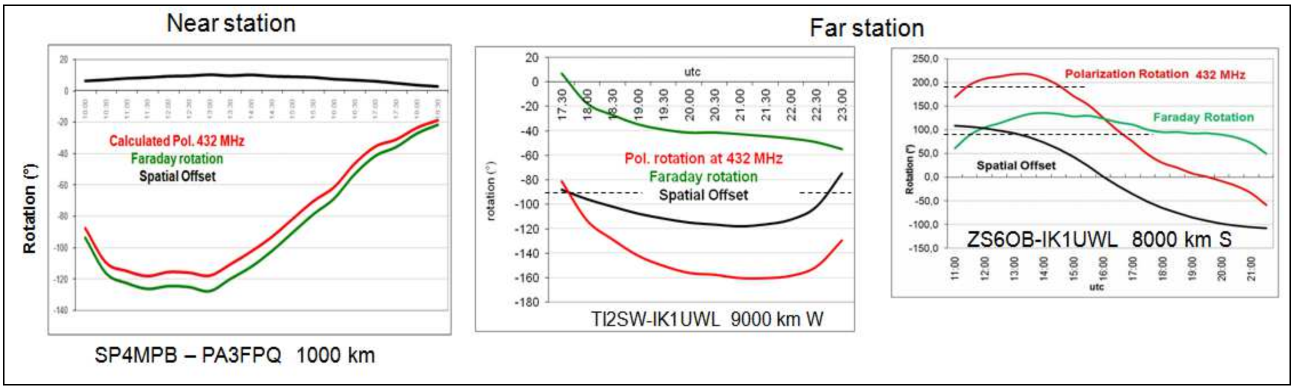
On this band there are typically <u>overall rotations of hundreds of degrees</u>, so spatial offset can influence the time when polarity is favourable, but is overridden by Faraday, both for near and for distant stations.
Speed of rotation change is much lower, of the order of 90°/30', so during a Moon pass, there are tens of favourable periods followed by tens of unfavourable periods.
On this band cross yagis are possible, and it is a trend to overcome Faraday.

18 – UHF bands

In the UHF bands the dominant factor becomes spatial offset, which can reach and pass half turn, in which case the supplement counts since phase does not count .
So distance between stations has the biggest influence.

19 – 432 MHz band

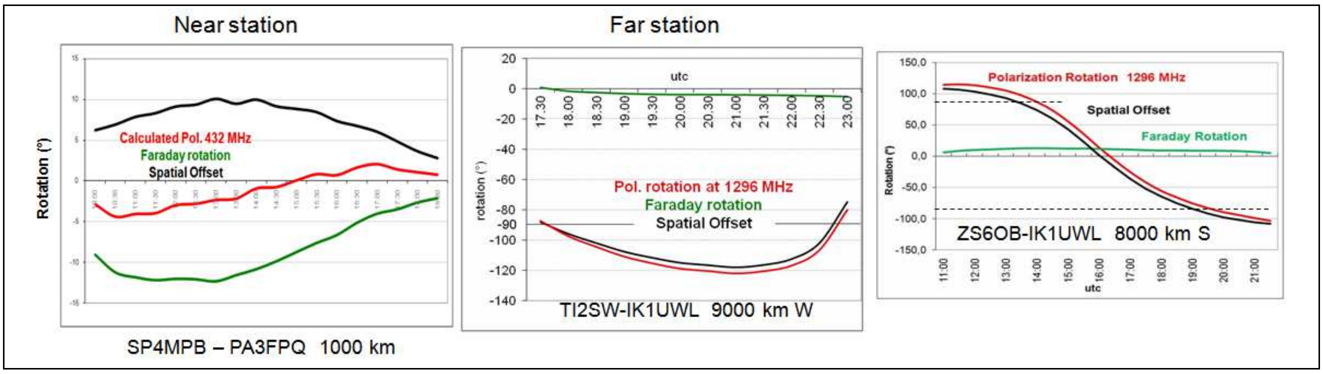
Typical sky noise temperature is 85 °K (low).



Here Faraday rotation is of the order of tens of degrees, often smaller than spatial offset.
For distant stations the length of unfavourable periods is big, so it would be very useful having some way to control rx polarization, such as crossed yagis (not easy to build).
V-H-V transitions are few and far apart..
Cross pol. or circular pol. Is possible when moving to parabolic dishes. This is the obvious trend on this band, when sizable dishes are possible.

20 – 1296 MHz band

Typical sky noise temperature is 68 °K (very low).



On this band Faraday is practically non existent, so spatial offset becomes the dominant factor.
Fortunately, on this band dishes predominate on yagis, and so circular pol., which is the best solution for these problems, is achievable.

21 – VHF/UHF bands overview

VHF bands are dominated by Faraday, UHF bands are dominated by Spatial Offset
Going from 6 m to 23 cm, polarity changes with decreasing speed.
 From peaks of the order of 1200°/h on 6m (because of Faraday), we tend towards 10°-20°/h on 23 cm (due to Spatial Offset).

So when single polarity of the receiving antenna is in use, favorable and unfavorable periods increase in length and decrease in number.
Our Excel sheet has allowed us to get some numbers and orders of magnitude of characteristics, known in practice, of these bands.

References

- Aspects of Weather and Space Weather in the Earth's Upper Atmosphere: The Role of Internal Atmospheric Waves by Michael C. Kelly.
- INGV istituto nazionale di Geofisica e Vulcanologia.
-Total Electron Content Studies of the Ionosphere John A. Klobuchar, Air Force Cambridge Research - Laboratories L. G. Hanscom Field, Massachusetts.
- The Potential of Broadband L-Band SAR Systems for Small Scale Ionospheric TEC Mapping (Remote Sensing Technology Institute, German Aerospace Center (DLR) Oberpfaffenhofen, D – 82234 Wessling, Germany)
- Institute of Communication and Navigation, German Aerospace Center
- Geomagnetism Tutorial Whitham D. Reeve Reeve Observatory Anchorage, Alaska USA
- Frederick University, 7 Y. Frederickou St., Palouriotisa, Nicosia 1036, Cyprus
- Electron density measurements of the plasmasphere – experimental observations and modelling studies
- Cooperative Research Centre for Satellite Systems Department of Physics, La Trobe University Bundoora, Australia
- Propagation Factors In Space Communications (NATO)
- Seasonal variations of storm-time TEC at European middle latitudes Royal Meteorological Institute (RMI), Belgium
- Radio Wave Propagation by Lucien Boithias, published by North Oxford Academic
- Cleo Loi, Australian astrophysicist graduate at the University of Sydney School of Physics.
- CAASTRO , ARC Centre of Excellence for All-sky Astrophysics- Australia
-Science Foundation for Physics - The University of Sydney
-The Murchinson widefield Array
-Density duct formation in the wake of a travelling ionospheric disturbance: Murchison Widefield Array observations (Journal of Geophysical Research)