Polarization for Beginners

Introduction

Anyone starting to play on EME soon discovers that some bizarre polarization effects are frequently observed.
It is important to have at least a basic understanding of these effects if you are to progress very far in EME.

When a linearly-polarized electromagnetic wave passes through the earth's ionosphere, which contains lots of free electrons, the plane of polarization of the wave is rotated by an amount that depends on the number density of the free electrons, the wavelength of the wave, and the longitudinal component of any magnetic field (in this case the earth's magnetic field). From a physicist's perspective the effect is actually better described in terms of left-hand and right-hand circularly polarized waves which experience a slightly different refractive index. The amount of rotation of a linearly polarized wave varies as the square of the wavelength. Typically for a single pass through the ionosphere, the magnitude of the effect is up to about 13 complete rotations at 144MHz , 1.5 rotations at 432MHz , and only about 0.2 of a rotation at 1296MHz. This effect is one of many originally observed by Michael Faraday, and is known as the Faraday effect.

The sense of the rotation depends on whether the magnetic field has a direction the same as or opposite to the wave propagation direction. It is tempting to think that the rotation will simply unwind on the return trip from the moon, but this is unfortunately not the case. Certainly the wave will see the magnetic field as being reversed relative to its own direction, so the rotation will have the opposite sense from the wave's viewpoint, but an observer on the earth will "see" the wave continue to rotate in the same direction on the return trip. This means that when you observe your own EME echo on 144MHz, the polarization direction will typically have gone through about 26 complete rotations, and for all practical purposes its direction is random when it gets back to your antenna. If it happens to line up with your antenna, you may see/hear your echo (if you have enough antenna gain and transmit power), but if it is perpendicular to your antenna you will not see your echo! Actually if you are working a station in the opposite (magnetic) hemisphere, the rotation will unwind, but probably not by the original amount.

There is a simple way of eliminating the effects of Faraday rotation, and that is to use circularly polarized signals. At 1296MHz and above, there are few if any stations operating EME on a casual basis, so everyone uses circular polarization. However at 144MHz, and to a lesser extent at 432MHz, there are large numbers of "tropo" stations experimenting with EME using digital modes such as JT65. These tropo stations nearly all have horizontally polarized (H) antennas. A more serious EME station could certainly use circular polarization to eliminate Faraday effects when working an H station, but with an immediate penalty of 3dB. This cost is too high! So in practice all 144MHz EME stations use linearly polarized antennas, usually H (horizontal) but sometimes V (vertical).

The direct effect of all this is that for any given path between two stations, Faraday rotation will cause at least a 3dB signal loss for half the time. This would not be so bad if the path were reciprocal so that both stations lose the signal at the same time, but Murphy unfortunately has other ideas! One way of overcoming this loss is to use large enough antennas and enough transmit power to reduce the "impossible" times to a small proportion, but the reality is that as you collect DXCC entities, and new ones get harder to find, you will find yourself always trying to work ever smaller stations at the limit of your path budget, and often these will be expedition stations which are only there for a few days.

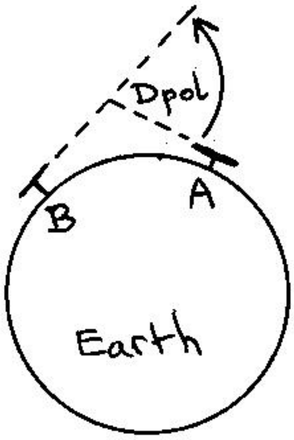
All these effects can be eliminated by having complete control of both your receive and your transmit polarization, but at 144MHz this would be quite unusual. The simplest way to reduce the effects to manageable proportions is to have separate H and V antennas, possibly but not necessarily built on the same boom as each other. These are sometimes referred to as X-pol, though most often they are in fact H and V rather than being inclined at 45 degrees. With an HV antenna array you can limit the loss of signal to no more that 3dB at any time (when the polarization is actually at 45 degrees), and with a complete dual receive system with common local oscillators to match the phase you can combine the two polarizations to optimize the received signal with no loss at all (e.g. using Linrad and MAP65). However the most common configuration is a simple HV array with single receive and transmit channels.

Spatial Polarization

Because of the shape of the earth, two antenna arrays in different locations are unlikely to be parallel, even if they are both pointed towards the moon.
They will always be (nearly) parallel if the stations are located close to each other (within say 1000km), or on diametrically opposite sides of the earth.
Stations with the same longitude will also have parallel antennas when the moon is due north or south of them, but not at other times.
If two stations both have H antennas pointed towards the moon, the difference in the absolute direction of their antennas is called the Spatial Polarization, or sometimes the Geometrical Polarization, or just Dpol in the WSJT programs. This is most easily pictured by imagining that you are sitting on the moon (!) looking back towards the two stations on the earth. It is then obvious for example that at moonrise or moonset two stations with the same longitude will have a Dpol equal to the difference in their latitudes (strictly the moon needs to rise due E or set due W for this to be exactly true).

Although the absolute sense of Dpol is rarely important for simple HV stations, it is helpful to choose an unambiguous direction in which Dpol is positive. Suppose you are Station A and the dx station is B.
If you are sitting on the moon, then the value of Dpol for B reported in A's software is positive if B's antenna appears to be rotated CCW (counter clockwise) from A's antenna.
Alternatively if you are sitting at the base of your antenna looking towards the moon, then B's antenna is rotated CW from your own (A) antenna.
Both the WSJT programs and the VK3UM EME Planner use this convention. W5UN's SkyMoon uses CW and CCW as viewed from your station looking towards the moon. Confused?

I personally find the view from the moon easier to visualize, and it has the advantage that a positive Dpol is CCW, the same convention as is used in plotting a phase diagram.

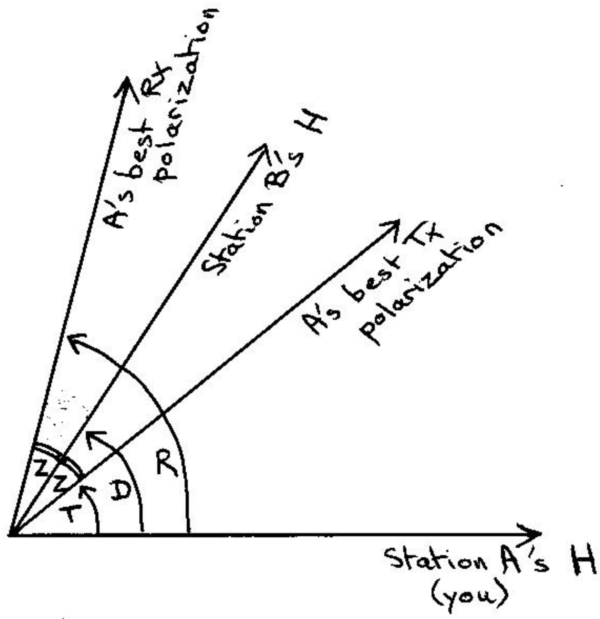


View of A (you) and B from the Moon

Optimum Transmit Polarity

It is not difficult, just a bit confusing, to calculate the optimum transmit polarization for station A (you) to use. You need to know Dpol and also the observed optimum receive polarization direction.
Ian White G3SEK published an article about this in Dubus in 1996 :
http://www.ifwtech.co.uk/g3sek/eme/pol3.htm

When you (A) receive an EME signal from another station B, it will generally be Faraday rotated by some amount Z from its original polarization direction. We disregard any number of complete 180-degree rotations, only the excess matters, having a value between -90 and +90 degrees.
If you were to transmit a return signal with the same polarization as that which you received from B, the return signal would undergo the SAME further rotation Z as before and in the SAME direction, arriving back at B at a polarization angle 2Z to its original direction. So obviously the best strategy is for you to rotate your transmit polarization by 2Z in the opposite direction so that it arrives back at B aligned with his H antenna.



A little algebra shows that relative to A's local horizontal, the optimum transmit direction is given by T = 2D - R, where D is Dpol and R is the observed optimum receive polarization in degrees.
In other words, T should be chosen such that D is the average of T and R.
All the angles are measured positive in a CCW direction, and 180 degrees may be added or subtracted when necessary to keep the values in the range -90 to +90 degrees.

For stations having just a simple HV array it is probably easier to work from a look-up table.

	Optimum Rx Polarization (degrees)									
		-90 (V)	**-67.5**	**-45**	**-22.5**	**0 (H)**	**22.5**	**45**	**67.5**	**90 (V)**
	90	90 (V)	67.5	45	22.5	0 (H)	-22.5	-45	-67.5	-90 (V)
	67.5	45	22.5	0 (H)	-22.5	-45	-67.5	-90/+90 (V)	67.5	45
	45	0 (H)	-22.5	-45	-67.5	-90/+90 (V)	67.5	45	22.5	0 (H)
Dpol	**22.5**	-45	-67.5	-90/+90 (V)	67.5	45	22.5	0 (H)	-22.5	-45
	0	90 (V)	67.5	45	22.5	0 (H)	-22.5	-45	-67.5	-90 (V)
	-22.5	45	22.5	0 (H)	-22.5	-45	-67.5	-90/+90 (V)	67.5	45
	-45	0 (H)	-22.5	-45	-67.5	-90/+90 (V)	67.5	45	22.5	0 (H)
	-67.5	-45	-67.5	-90/+90 (V)	67.5	45	22.5	0(H)	-22.5	-45
	-90	90	67.5	45	22.5	0 (H)	-22.5	-45	-67.5	-90 (V)

Table of Optimum Transmit Polarization as a Function of Dpol and Optimum Receive Polarization

This table will reward some quite careful study.

How to Use the Table

For simple HV stations we really only need the middle column (for H) and one of the two identical outside columns (for V). But the other columns are useful for intermediate cases.

If the received signal is pure H, then use the middle column (0 degrees).

If the received signal is pure V, then use either of the outside columns (+/-90 degrees).

If the H and V signals received are about equal in strength, then use BOTH the +45 and the -45 degree columns, unless you have some means of comparing the phase of the H and V signals so as to determine which of these actually applies.

If you can see both the H and V signals, but the H is significantly stronger than the V, then refer to both the +22.5 and -22.5 degree columns, again unless you have the means to determine which one applies.

If you can see both the H and V signals, but the V is significantly stronger than the H, then refer to both the +67.5 and -67.5 degree columns, again unless you have the means to determine which one applies.

If Station B is using V polarization rather than H, then add/subtract 90 degrees to/from Dpol, but it doesn't actually make any difference to your strategy!

Some Comments on the Table

1. When Dpol is near 0 or +/-90 degrees, and one receive polarization is clearly much stronger than the other, you should transmit with the same polarity as the best receive signal.

2. When Dpol is near 0 or +/-90 degrees, and both H and V polarizations are about equal on receive, you can transmit with H or V; you will lose 3dB in each case.

3. When Dpol is near 45 degrees, and one receive polarization is clearly much stronger than the other, you should transmit with the OPPOSITE polarity to the best receive signal – this is the well-known one-way propagation condition.

4. When Dpol is near 45 degrees, and both H and V polarizations are about equal on receive, you can transmit with H or V; you will lose 3dB in each case.

5. When Dpol is near +/-22.5 degrees (or +/-67.5 degrees), and one receive polarization is clearly much stronger than the other, you can transmit with H or V; you will lose 3dB in each case.

6. When Dpol is near +/-22.5 degrees (or +/-67.5 degrees), and both H and V polarizations are about equal on receive, then you have a problem, and it is CRITICAL whether you use H or V.

Comments 1 and 3 are pretty well known.

Comments 2 and 4 are common sense - if you can't decide between H and V then it probably doesn't matter.

Comment 5 is also common sense, being mid-way between the 0 and 45 degree situations.

Comment 6 does NOT appear to be well known. The problem is that when H and V are approximately equal, then the received polarization is at 45 degrees, but in the absence of some means of comparing the H and V signals to determine their relative phase, you can't determine whether the polarization is at +45 or -45 degrees. However in this case it DOES matter, because in one case you should use H and in the other V. Lacking any knowledge on which to base a decision, it is probably best to transmit one or two sequences of H followed by the same using V, in the hope of being able to determine which one elicits a response from Station B.

VK2KU – 6 May 2010