Polarization

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Lecture # 7

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Polarization

- The polarization of an electromagnetic wave is defined as the orientation of the electric field vector. Recall that the electric field vector is perpendicular to both the direction of travel and the magnetic field vector.
- The polarization is described by the geometric figure traced by the electric field vector upon a stationary plane perpendicular to the direction of propagation, as the wave travels through that plane.

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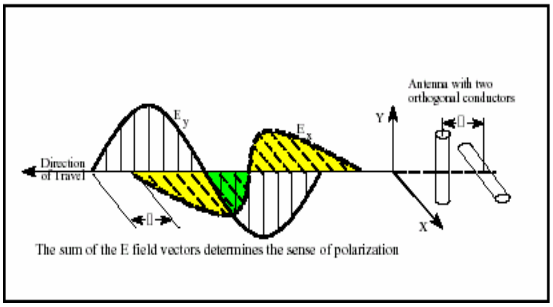

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- Polarization is also describe as the "direction of vibration" on the radio wave.
- It depends the orientation of elements of an antenna, when you set elements vertical, it generates vertical-polarized radio wave similarly when you set as horizontal, it generates horizontal-polarized.
- In the case of YAGI antenna, the direction of Electronic-Field is same as the direction of its elements.
- Radio stations have to set as a same direction of polarization for communication each other.

Types of Polarization

- An electromagnetic wave is frequently composed of (or can be broken down into) two orthogonal. This may be due to the arrangement of power input leads to various points on a flat antenna, or due to an interaction of active elements in an array, or many other reasons.
- The geometric figure traced by the sum of the electric field vectors over time is, in general, an ellipse as shown in Figure 2. Under certain conditions the ellipse may collapse into a straight line, in which case the polarization is called linear.

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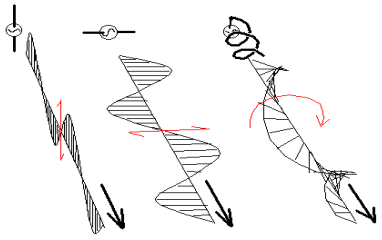
- In the other extreme, when the two components are of equal magnitude and 90^0 out of phase, the ellipse will become circular as shown in Figure 3. Thus linear and circular polarization are the two special cases of elliptical polarization. Linear polarization may be further classified as being vertical, horizontal, or slant.

Polarization and its types



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- Polarization makes the beam more concentrated
- FSS satellites use horizontal and vertical polarization, whereas DBS satellites use left- and right-hand circular polarization
- To use the channels that are available for satellite broadcast as efficiently as possible, both horizontal and vertical polarization (and left- and right-hand circular polarization) can be applied simultaneously per channel or frequency. In such cases the frequency of one of the two is slightly altered, to prevent possible interference

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- Horizontal and vertical transmissions will therefore not interfere with each another because they are differently polarized. This means twice as many programs can be transmitted per satellite
- Consequently, via one and (almost) the same frequency the satellite can broadcast both a horizontal and a vertical polarized signal (H and V), or a left- and right-hand circular polarized signal (LH and RH).

Figure 2 depicts plots of the E field vector while varying the relative amplitude and phase angle of its component parts.

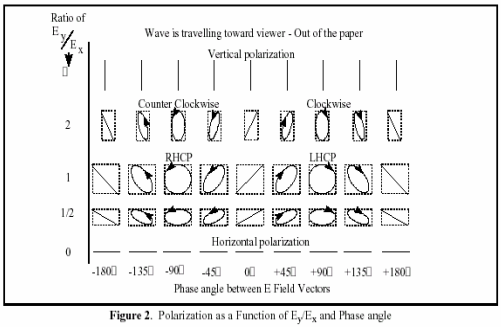

Figure 2. Polarization as a Function of E_y/E_x and Phase angle

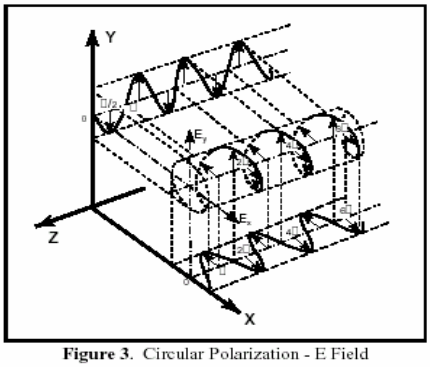

Figure 3. Circular Polarization - E Field

Radio stations have to set as a same direction of polarization for communication each other.

- When you try to hear the vertical-polarized wave with horizontal- polarized antenna, what will be happened? A theory tells it is impossible to receive. In fact, although it is possible, It becomes very difficult (very weak less than -20dB). This is due to:-
  - The radio waves do not travels with pure-polarized condition, and
  - There is no real antenna that has pure-polarized character. Anyway, you should to adjust the polarization for better communication.

Is Circular Polarization better choice for satellite?

- Circular-polarization (CP) is another choice when you could not decide the polarization of your choice.
- CP is the special style of polarization, the direction of Electric-Field rotates one times par one cycle.
- The CP antenna can receive both horizontal and vertical polarized radio wave, even in the direction of slant-polarized.
- CP is very popular technique for satellite communication both commercial and amateur satellite systems.

Antenna Polarization

- Table 1 shows the theoretical ratio of power transmitted between antennas of different polarization. These ratios are seldom fully achieved due to effects such as reflection, refraction, and other wave interactions, so some practical ratios are also included.

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Table 1. Polarization Loss for Various Antenna Combinations

Transmit Antenna Polarization	Receive Antenna Polarization	Ratio of Power Received to Maximum Power					
		Theoretical		Practical Horn		Practical Spiral	
		Ratio in dB	as Ratio	Ratio in dB	as Ratio	Ratio in dB	as Ratio
Vertical	Vertical	0 dB	1	*	*	N/A	N/A
Vertical	Slant (45□ or 135□)	-3 dB	½	*	*	N/A	N/A
Vertical	Horizontal	-□ dB	0	-20 dB	1/100	N/A	N/A
Vertical	Circular (right-hand or left-hand)	-3 dB	½	*	*	*	*
Horizontal	Horizontal	0 dB	1	*	*	N/A	N/A
Horizontal	Slant (45□ or 135□)	-3 dB	½	*	*	N/A	N/A
Horizontal	Circular (right-hand or left-hand)	-3 dB	½	*	*	*	*
Circular (right-hand)	Circular (right-hand)	0 dB	1	*	*	*	*
Circular (right-hand)	Circular (left-hand)	-□ dB	0	-20 dB	1/100	-10 dB	1/10
Circular (right or left)	Slant (45□ or 135□)	-3 dB	½	*	*	*	*

* Approximately the same as theoretical

Note: Switching transmit and receive antenna polarization will give the same results.

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- The sense of antenna polarization is defined from a viewer positioned behind an antenna looking in the direction of propagation. The polarization is specified as a transmitting, not receiving antenna regardless of intended use.
- We frequently use "hand rules" to describe the sense of polarization. The sense is defined by which hand would be used in order to point that thumb in the direction of propagation and point the fingers of the same hand in the direction of rotation of the E field vector.

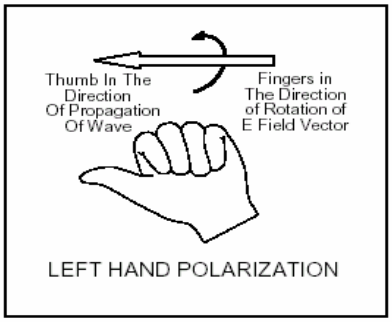

Figure 4. Left Hand Polarization

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- For example, referring to Figure 4, if your thumb is pointed in the direction of propagation and the rotation is counterclockwise looking in the direction of travel, then you have left hand circular polarization.
- The polarization of a linearly polarized horn antenna can be directly determined by the orientation of the feed probe, which is in the direction of the E-field.

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- In general, a flat surface or sphere will reflect a linearly polarized wave with the same polarization as received. A horizontally polarized wave may get extended range because of water and land surface reflections, but signal cancellation will probably result in "holes" in coverage. Reflections will reverse the sense of circular polarization.

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- For a linearly polarized antenna, the radiation pattern is taken both for a co-polarized and cross polarized response.
- The polarization quality is expressed by the ratio of these two responses. The ratio between the responses must typically be great (30 dB or greater) for an application such as cross polarized jamming
- For general applications, the ratio indicates system power loss due to polarization mismatch.
- For circularly polarized antennas, radiation patterns are usually taken with a rotating linearly polarized reference antenna.

If the desired antenna is used for receiving a direct transmission as shown in Figure 5 below, the same polarization sense (specified if transmitting) is required for maximum signal reception in this situation. Buy two right-hand or two left-hand circularly polarized antennas for this case. When you procure antennas, remember that the polarization is specified as if transmitting, regardless of intended use.

Wave propagation between two identical antennas is analogous to being able to thread a nut from one bolt to an identical opposite facing bolt.

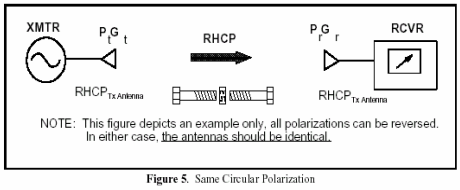

Figure 5. Same Circular Polarization

If the desired antenna is used for a receiving a wave with a single or odd number of reflections, such as a bistatic radar where separate antennas are used for transmit and receive as shown in Figure 6, then opposite circularly polarized antennas would be used for maximum signal reception. In this case buy antennas of opposite polarization sense (one left hand and one right hand).

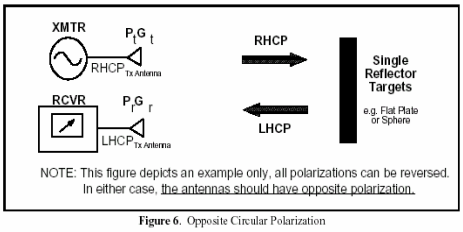

Figure 6. Opposite Circular Polarization

In a corner reflector, waves reflect twice before returning to the receiver as shown in Figure 7, consequently they return with the same sense as they were transmitted. In this case (or any even number of reflections) buy antennas of the same polarization sense.

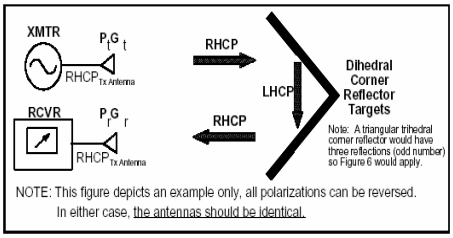

Figure 7. Same Circular Polarization With Corner Reflector

Manual Polarization Switching

- The CP antenna reduces QSB so it might be better for comfortable operation, but the CP antenna is bigger and more complicated than the simple linear-polarized antenna. Also the big and complicated antenna will be expensive. 3dB loss will be a problem with some limited conditions.
- There is another choice. Setup a pair of vertical/Horizontal polarized independent antenna and switch them at your shack. You select where either is better during its pass. This is the theory of "**Divercity**" reception

Polarization of satellite signal

- Applied for geo-stationary satellites
- "Horizontal"polarization = parallel to the equatorial plane
- "Vertical"polarization = parallel to the Earth's axis
- Polarization angle at earth station

$$\xi = \left| \arcsin\left(\frac{p \cdot f}{|f|} \right) \right|$$

  - r = local gravity direction
  - k = the direction of the wave propagation
  - p = unit polarization vector
  - f = k x r, normal to the reference plane
  - x = the angle between the reference plane (r and k) and the polarization vector

Depolarization

- The electric field E_1 is depolarized after going through a depolarizing medium.
- The result is, as shown in the figure, an orthogonal (E_{12}) component may be generated.
- E_{11} is called the co-polar component and E_{12} is called the cross-polar component.
- This phenomenon can cause interference.

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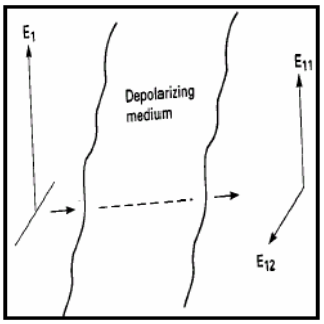

Cross-polarization discrimination (XPD)

- One measure to quantify the effects of polarization is called the cross-polarization discrimination (XPD)

$$XPD = 20 \log \frac{E_{11}}{E_{12}} dB$$

E_{11} is the co-polar strength
E_{12} is the cross-polar strength

Cross-polarization discrimination observations - rain depolarization

- Looking at XPD as a function of the co-polar attenuation (A), it can be concluded that:
  - XPD degrades at a given co-polar attenuation as the frequency decreases
  - XPD degrades with increasing co-polar attenuation
  - XPD for the Vertical Polarization wave is better than that for Horizontal Polarization
  - XPD for the Vertical Polarization and the Horizontal Polarization waves are better that the Circular Polarization

XPD and co-polar attenuation A

$$XPD = U - V \log A$$
$$U = 30 \log f - 10 \log(0.5 - 0.4697 \cos 4\tau) - 40 \log(\cos \theta)$$
$$V = 20 \quad for \ 8 \leq f \leq 15 \ GHz$$
$$V = 23 \quad for \ 15 \leq f \leq 35 \ GHz$$

θ **-> the elevation angle in degrees**

τ –> **the polarization tilt angle**

$\tau = 45$ **for circular polarization**

Ionospheric effects

- **Faraday's effects**
  - **The rotation of a linearly polarized wave due to the earth's magnetic field is called the Faraday's effect. It is proportional to the *1/f2* factor.**
- **Ionospheric scintillation**
  - **Due to the refractive index variations in the ionosphere caused by local concentrations of ionization. It is also proportional to the *1/f2* factor.**