Introduction to Patterns and Gain

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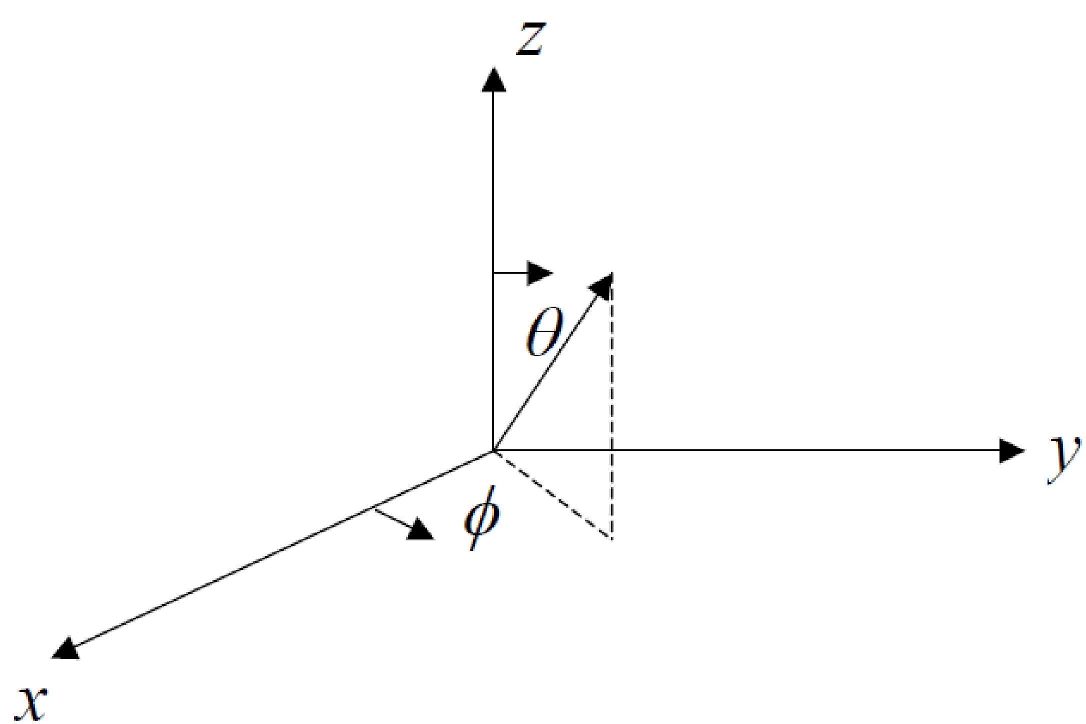
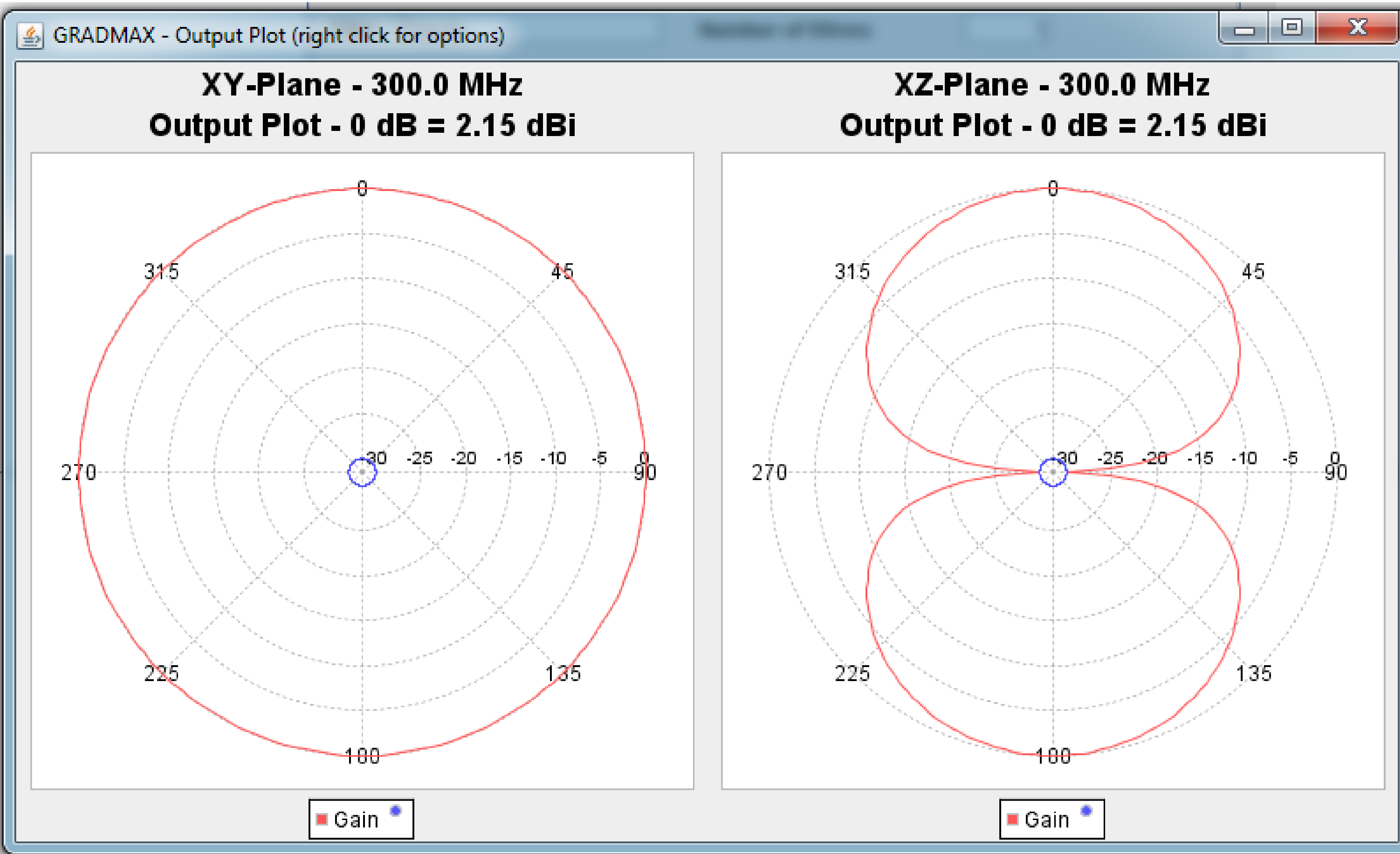
RADIATION PATTERNS (HOW THE ANTENNA DISTRIBUTES ITS INPUT POWER IN SPACE FOR TRANSMITTING MODE)

RECIPROCITY THEOREM: "The TX and RX radiation patterns (and hence also the polarizations) are the same for an antenna made of linear and isotropic material." Non-isotropic materials have electric and magnetic properties that vary with the direction - ε and μ are in general tensors (e.g., Calcium crystal: $CaCO_3$).

Major Cartesian Planes:

1. ***xy*-plane: $\theta = 90^0$** and $0^0 \le \phi \le 360^0$ ("phi-cut")
2. ***xz*-plane: $\phi = 0^0$** and $0^0 \le \theta \le 360^0$ ("theta-cut")
3. ***yz*-plane: $\phi = 90^0$** and $0^0 \le \theta \le 360^0$ ("theta-cut")




GRADMAX - Output Plot (right click for options)
XY-Plane - 300.0 MHz
Output Plot - 0 dB = 2.15 dBi
XZ-Plane - 300.0 MHz
Output Plot - 0 dB = 2.15 dBi
0
45
90
135
180
225
270
315
-30 -25 -20 -15 -10 -5 0
Gain
0
45
90
135
180
225
270
315
-30 -25 -20 -15 -10 -5 0
Gain

Although the radiation pattern can be computed either from the electric or the magnetic field, we will always consider only the electric field without however any loss in generality. Within this context, the **magnitude** of the radiation pattern is always computed from the absolute value of the electric field, which in the case of an ideal dipole (short dipole of length Δz with an **uniform** current distribution I) is given by

$$\left|\vec{E}\right| = \left[\frac{I\Delta z}{4\pi} w\mu\right]\frac{\sin\theta}{r} \qquad (*)$$

where the term in **brackets** is a **constant**. The pattern can then be determined with the normalization of (*) with respect to its maximum and by noting that the angular variation of the pattern is independent of $1/r$. **"The rate of decay of the electric field in [V/m] from a given angle θ_1 to another angle θ_2 is independent of r, although the absolute values of the electric field at either angle does vary with r (e.g., $\left|\vec{E}(\theta_1)\right|=20$ & $\left|\vec{E}(\theta_2)\right|=18$ @ r_1 and $\left|\vec{E}(\theta_1)\right|=10$ & $\left|\vec{E}(\theta_2)\right|=9$ @ r_2, such that when normalized the patterns are the same at any r), WITH r AT THE FAR-FIELD OF THE ANTENNA:**

$$r > \frac{2D^2}{\lambda}$$

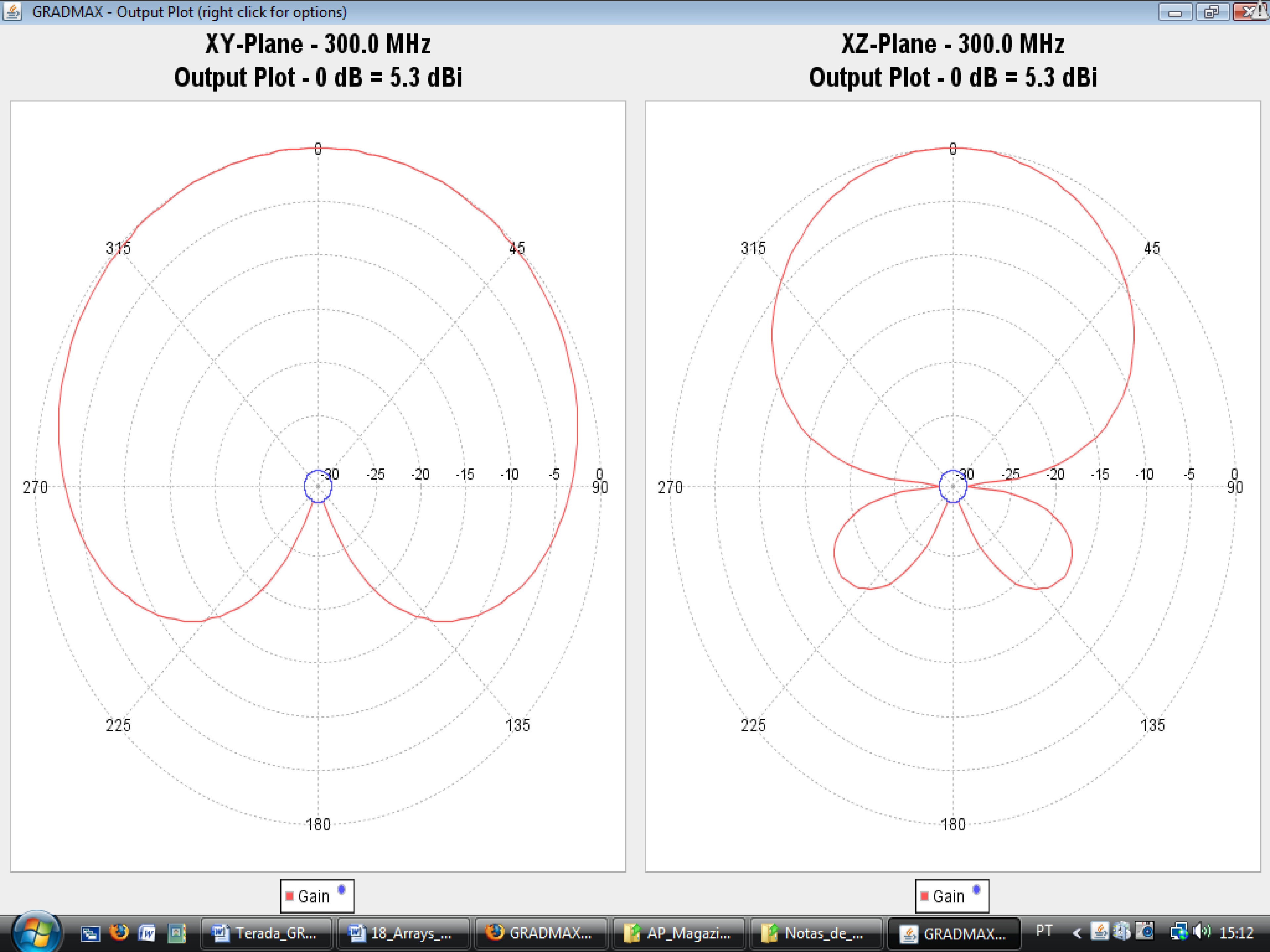
where D is the maximum length or dimension (extent) of a given finite antenna (e.g., the length of a dipole or the diameter of a parabolic dish).

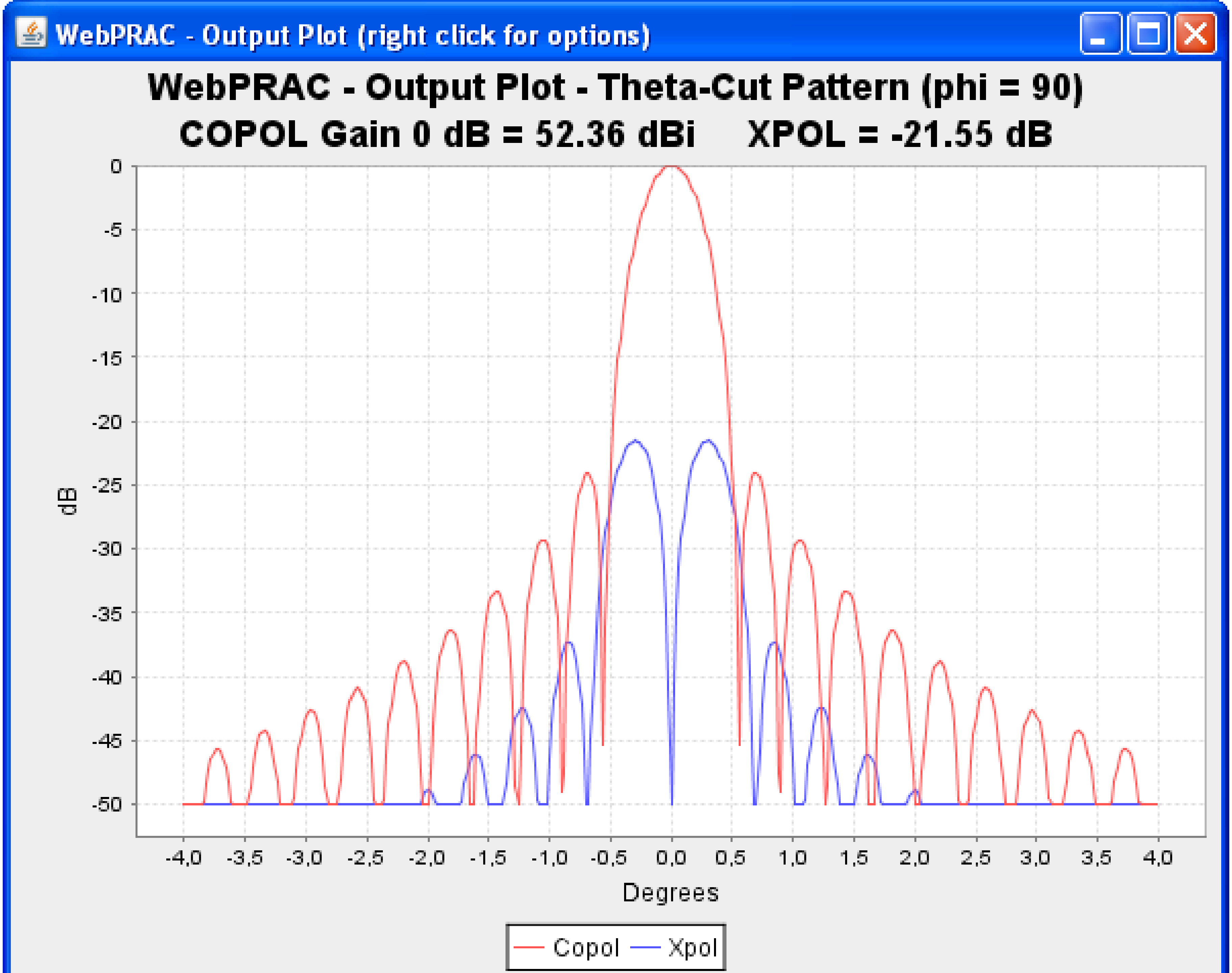
"Usually, the radiation patterns are plotted as normalized power patterns, which are just the square of the field pattern in (*) after normalization. Sometimes in order to better visualize the sidelobes and crosspolar lobes it is preferred to present the pattern in decibels, which is just 20 log of the field pattern in (*) after normalization (or 10 log of the power pattern).

Radiation patterns are plotted in **rectangular** or **polar** cuts as

1. Magnitude of the normalized **field** pattern:
   a. **LINEAR**: $\left|F(\theta,\phi)\right|$
   b. Decibels [**dB**]: $20\log\left|F(\theta,\phi)\right|$

2. Normalized **power** pattern:
   a. **LINEAR**: $\left|F(\theta,\phi)\right|^2$
   b. Decibels [**dB**]: $10\log\left|F(\theta,\phi)\right|^2 = 20\log\left|F(\theta,\phi)\right|$


GRADMAX - Output Plot (right click for options)
XY-Plane - 300.0 MHz
Output Plot - 0 dB = 5.3 dBi
XZ-Plane - 300.0 MHz
Output Plot - 0 dB = 5.3 dBi
0
45
90
135
180
225
270
315
-30
-25
-20
-15
-10
-5
0
Gain
Gain
Terada_GR...
18_Arrays_...
GRADMAX...
AP_Magazi...
Notas_de_...
GRADMAX...
PT
15:12


WebPRAC - Output Plot (right click for options)
WebPRAC - Output Plot - Theta-Cut Pattern (phi = 90)
COPOL Gain 0 dB = 52.36 dBi XPOL = -21.55 dB
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
dB
-4,0 -3,5 -3,0 -2,5 -2,0 -1,5 -1,0 -0,5 0,0 0,5 1,0 1,5 2,0 2,5 3,0 3,5 4,0
Degrees
Copol
Xpol

NOTE THAT THE NORMALIZED FIELD PATTERN (1b) AND THE POWER PATTERN (2b) ARE THE SAME IN dB ("the definition of decibel is 10 log P1/P2, where P1 and P2 are POWER QUANTITIES, thus the SQUARE of the field in 1b above – P2 in this case is always the normalization factor or maximum power within the pattern").

In this class, we will normally use **field** patterns in **dB** (1b or 2b above). In general, **rectangular plots** with limited angular range (i.e., from -8 to +8 degrees) are used for high-gain antennas such as reflectors, from which a detailed view of the main lobe and near-in sidelobes can be obtained. **Polar plots** will be used for wire antennas, horns and other lower gain antennas, where the far-out and back-lobe region is normally of main concern. **CONTOUR *uv*-plots (rectang.) are also often used for high-gain antennas.**

A measure of how well the power is concentrated in the main lobe is the sidelobe level (SLL):

$$SLL_{dB} = 20\log\frac{|F(SLL)|}{|F(\max)|} = \frac{\text{"2nd highest level in 1a, 1b, 2a or 2b}}{\text{(highest level other than the peak)"}}$$

"DEGREE/LEVEL OF VISUALIZATION OF SIDELOBES:

2a < 1a < 1b or 2b"

The width of main beam is quantified as the *half-power beamwidth* HP:

$$HP = \left| \theta_{HP\,left} - \theta_{HP\,right} \right|$$

where $\theta_{HP\ left}$ and $\theta_{HP\ right}$ are points to the "left" and "right" of the main beam maximum for which the normalized power pattern has a value of **one-half (-3dB)**.

There are two pattern cuts (planes) of special interest, normally called the principal plane patterns:

1. E-plane pattern because it contains the electric field vector. **“Note that ANY physical plane containing the electric field vector qualifies as the E-plane. For the ideal dipole, for example, ANY plane containing the *z*-axis is the principal E-plane, including the major Cartesian planes *xz- and yz-* in this specific case. Of course the physical position of the E-plane with respect to the Cartesian coordinate system varies in function of the antenna type and position: For example the same ideal dipole when placed along the *x*-axis will have as E-planes the major Cartesian planes *xz-* (as before) and *yz-*.**
2. H-plane pattern which is the pattern taken at a plane orthogonal to the E-plane, containing the magnetic field vector.

NOTIONS OF GAIN (G) AND DIRECTIVITY (D): MAXIMUM IN THE RADIATION PATTERN

$$P_{radiated}\,[\mathrm{W/m^2}] = \frac{P_{in}G}{4\pi r^2} \quad \text{and}$$

$$P_{radiated}\,[\mathrm{W/m^2}] = \vec{E} \times \vec{H} = \frac{1}{\eta_0}\left|\vec{E}\right|^2$$

a. The gain (include ohmic losses due to real implementation) or directivity of an antenna is always defined with respect to some other antenna (dBi: isotropic/uniform power radiation or dBd: dB over the half-wave dipole which has a directivity of 1.65 or 2.15 dB: 1 dBd = 2.15 dBi, thus an antenna with a directivity of 6.1 dBi or 3.95 dBd). Thus an antenna with 40 dBi of gain has a power density 40 dBs higher WHEN COMPARED TO THE ISOTROPIC ANTENNA WITH THE SAME INPUT POWER at a given direction.

b. For example, consider two antennas: One is the traditional isotropic antenna, and the other is a “semi-isotropic” antenna (i.e., it radiates uniformly into half-space). It is evident that the isotropic antenna will distribute 100 watts (input power) uniformly into the space, but any receiving antenna will not receive the whole 100 w. You would have to receive/integrate all the power in the whole sphere to receive 100w. Similarly, the semi-isotropic will distribute the 100w in half-space. So any antenna would receive at any given direction double of the power received with the isotropic one, but none would receive the whole 100w. You would have to integrate the half-sphere to get 100w.

c. With an antenna of 40 dBi of gain (10000 more gain), the area of uniform distribution of power would be concentrated to 1/10000 of the sphere. So if your receiving antenna is large enough to cover 1/10000 of the sphere AT A GIVEN *r*, then it would receive the whole 100w. If your antenna is larger than that IT WOULD NOT RECEIVE MORE THAN 100w given that the transmitting antenna only redistributes/concentrate 100w.

d. When you compute EIRP (Effective ISOTROPIC Radiated Power) you add the maximum input power in dB to the antenna gain (or multiply if both are not in dB). AGAIN THE RESULT SHOWS AN AMPLIFICATION IN POWER DENSITY WITH RESPECT TO THE ISOTROPIC ANTENNA.

NOTIONS OF POLARIZATION:

- ✓ USUAL TYPE OF POLARIZATIONS: LINEAR, CIRCULAR AND ELLIPTICAL.
- ✓ "The polarization of an antenna is the polarization of its radiated wave when operating in the transmitting mode".

"Polarization is a basic characteristic of an electromagnetic wave and describes the motion of the electric field vector at a fixed point in space as a function of time." Thus, the electric field vector varies in amplitude and direction (motion) constrained to a line in the linear polarization and to a circle in the circular polarization (constant amplitude), as time goes by.

“ELECTROMAGNETIC FORCE is a real effect: FIELD is a mathematical entity, a theoretical tool to allow us to better understand, model and simulate the electromagnetic phenomenum. For example, the electric field describes the path(s) in which a free electric charge would follow if released within the field (attraction/repulsion due to an existing electric FORCE). The more intense the field is (i.e., the higher is its magnitude), the stronger is the force to be exerted on the charges.

“By placing an antenna with the same polarization in the direct path of the wave (e.g., main beam of the TX antenna since the polarization normally degenerates off the main beam), the modulated signal used in the TX can be recovered in the RX forming a communication link. A linearly polarized antenna receives either RHCP (left-handed circular polarization) or LHCP (left-handed circular polarization) with a 3 dB loss.”