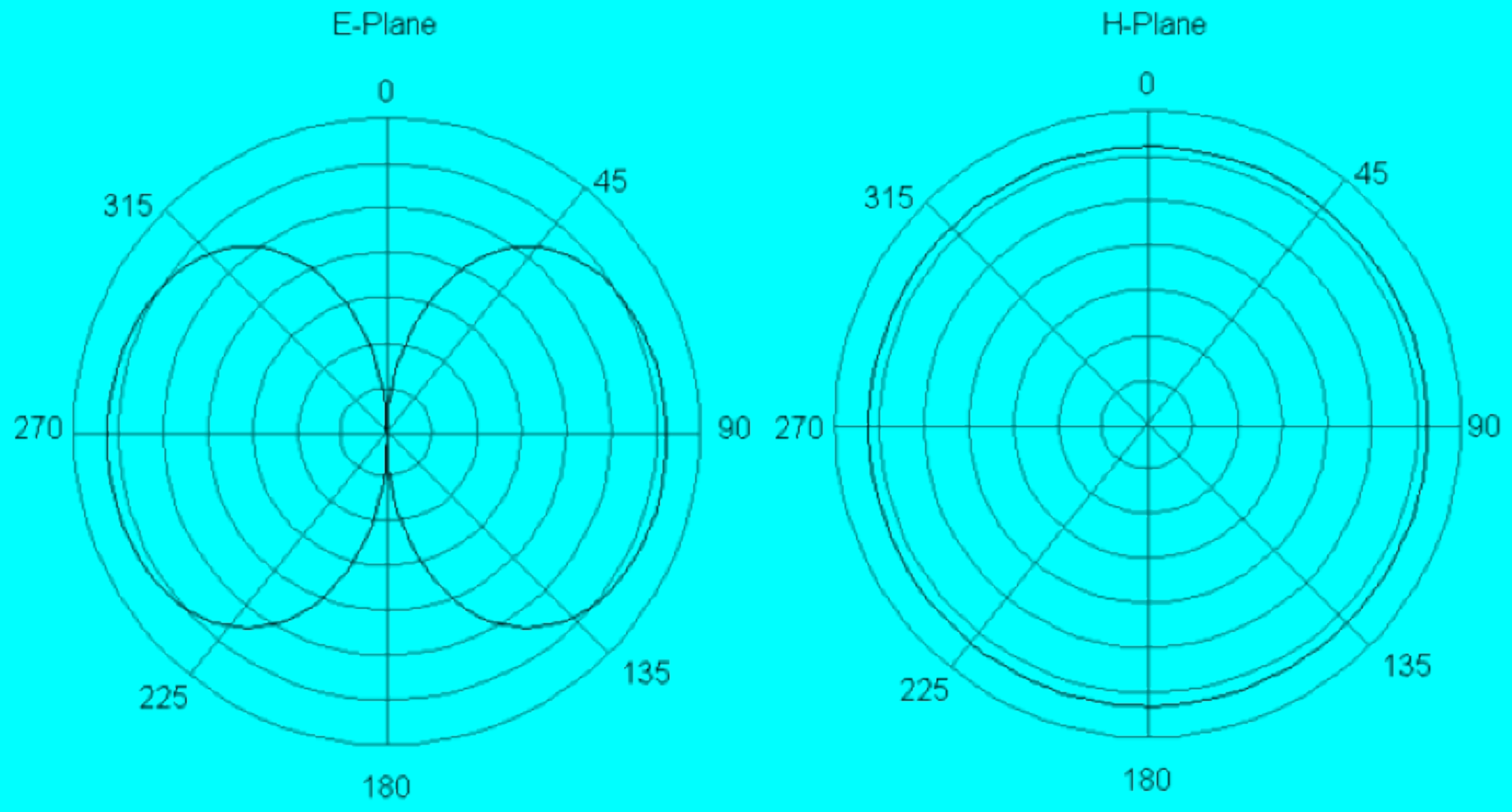
mobilefish.com

LORA / LORAWAN TUTORIAL 39

dBi, dBd, Ground Effect, E & H plane, Antenna Gain, and other antenna terminology



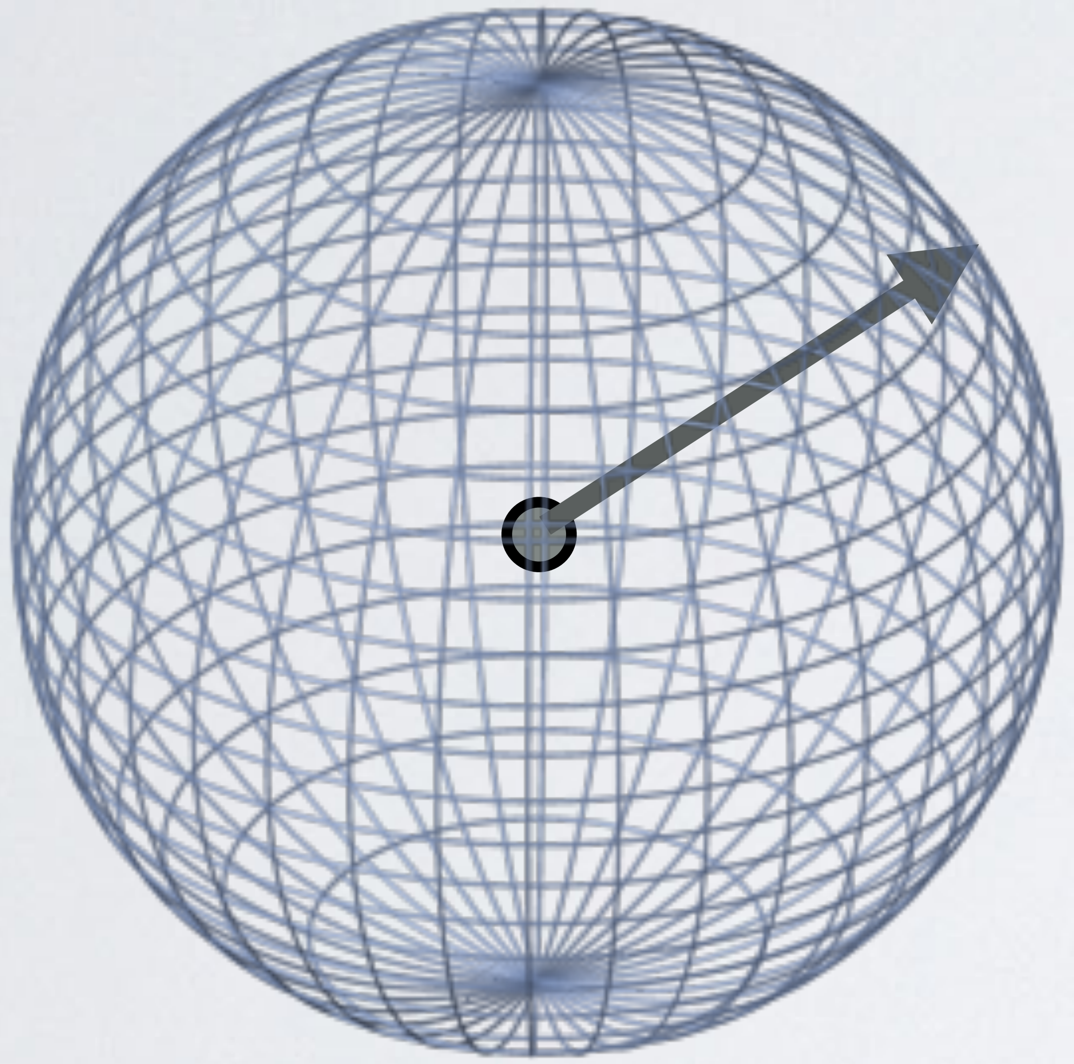
v1.0.0

INTRO

- In this tutorial I will:
  - again explain the difference between dBi and dBd,
  - what an antenna E-plane and H-plane is,
  - what the effect is of ground to on an antenna,
  - what the difference is between main, back and side lobes,
  - what antenna gain is,
  - what negative antenna gain is,
  - what the relationship is between ERP, antenna gain and tx power,
  - how to calculate loss using an example,
  - what unity gain is,
  - what an antenna beam width is,
  - what a take of angle is,
  - and what a front-to-back ratio is.

ISOTROPIC ANTENNA

- An isotropic antenna is a hypothetic (not physically realisable) point source antenna, that radiates its power uniformly in all directions.



Radiation pattern of an isotropic antenna.

- An isotropic antenna is considered a lossless antenna which means it has an antenna efficiency of 0 dB (or 100%). Antenna efficiency is explained in tutorial 32.

REFERENCE 1/2 WAVE DIPOLE ANTENNA

- A special tuned ½λ dipole antenna is used as a reference antenna for test purposes.
- A reference ½λ dipole antenna has an isotropic gain of 2.15 dBi.

Source:
http://schwarzbeck.de/en/antennas/precision-dipoles.html

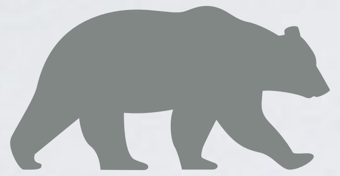
dBd versus dBi

- dBi refers to the antenna gain with respect to an isotropic antenna.
  If antenna A has a gain of 3 **dBi** it means antenna A has twice (2x) the power relative to an **isotropic antenna** in the peak direction.

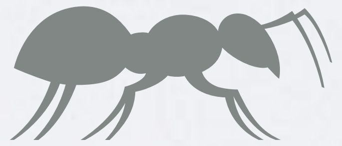
- dBd refers to the antenna gain with respect to a reference ½λ dipole antenna.
  If antenna B has a gain of 3 **dBd** it means antenna B has twice (2x) the power relative to a **reference ½λ dipole antenna** in the peak direction.

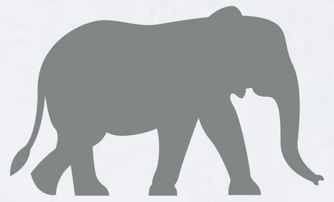
- If an antenna manufacturer specifies its antenna gain, it must use the reference **i** in dB**i** or **d** in dB**d** otherwise you do not know the antenna's actual gain.

dBd versus dBi

- Let's say a bear  is 2x stronger. This does not mean anything!
  Note: 2x is the same as 3dB, see tutorial 5.

- Now let's say:

  - Animal X is 2x stronger than an ant (3dB$_{\textbf{ant}}$) 

  - Animal Y is 2x stronger than an elephant (3 dB$_{\textbf{elephant}}$) 

  - So the reference "ant" and "elephant" are important to determine animal X and Y actual strength.

- The same applies to antenna gains, the reference **i**(sotropic) or **d**(ipole) is needed.

dBd versus dBi

- The relationship between dBd and dBi is:
  dBi = dBd + 2.15

- Examples:

  - Antenna A has a gain of 0 dBi, which is the same as -2.15 dBd

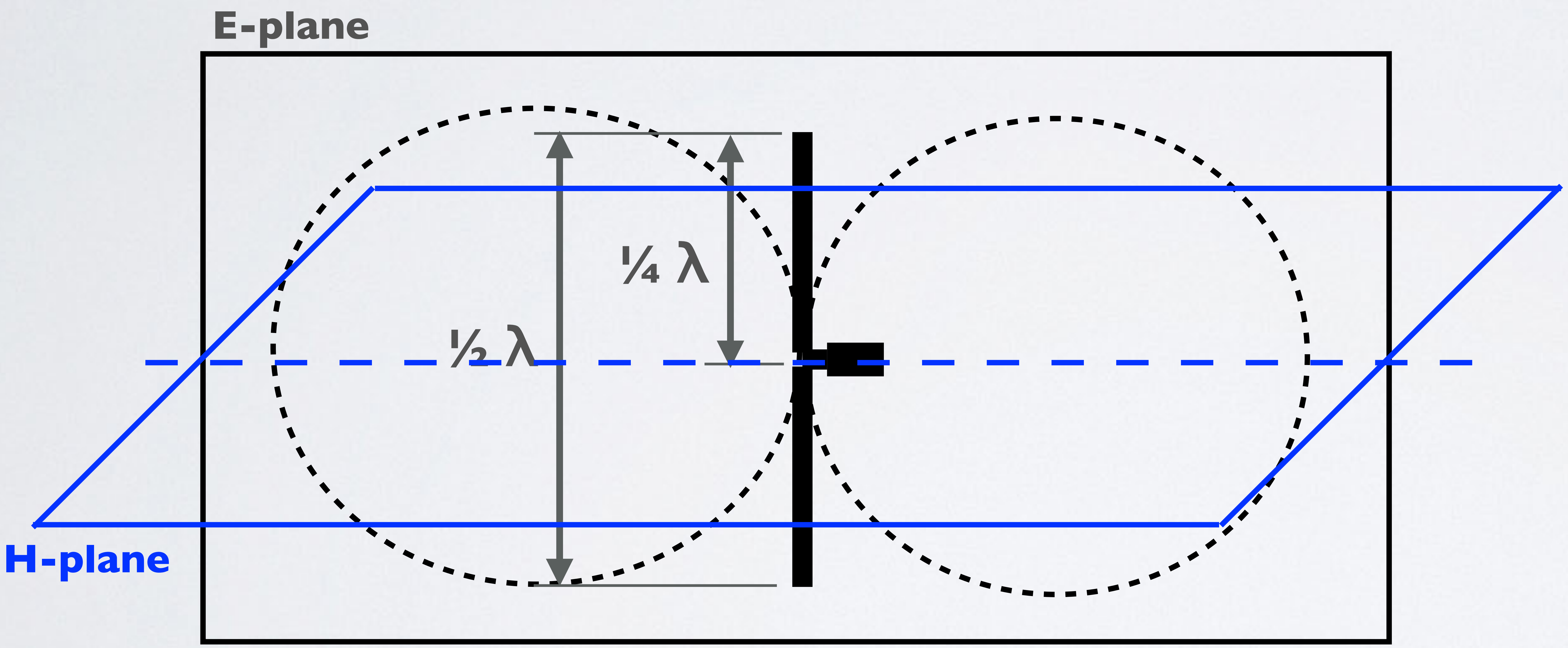
  - Antenna B has a gain of 2.15 dBi, which is the same as 0 dBd

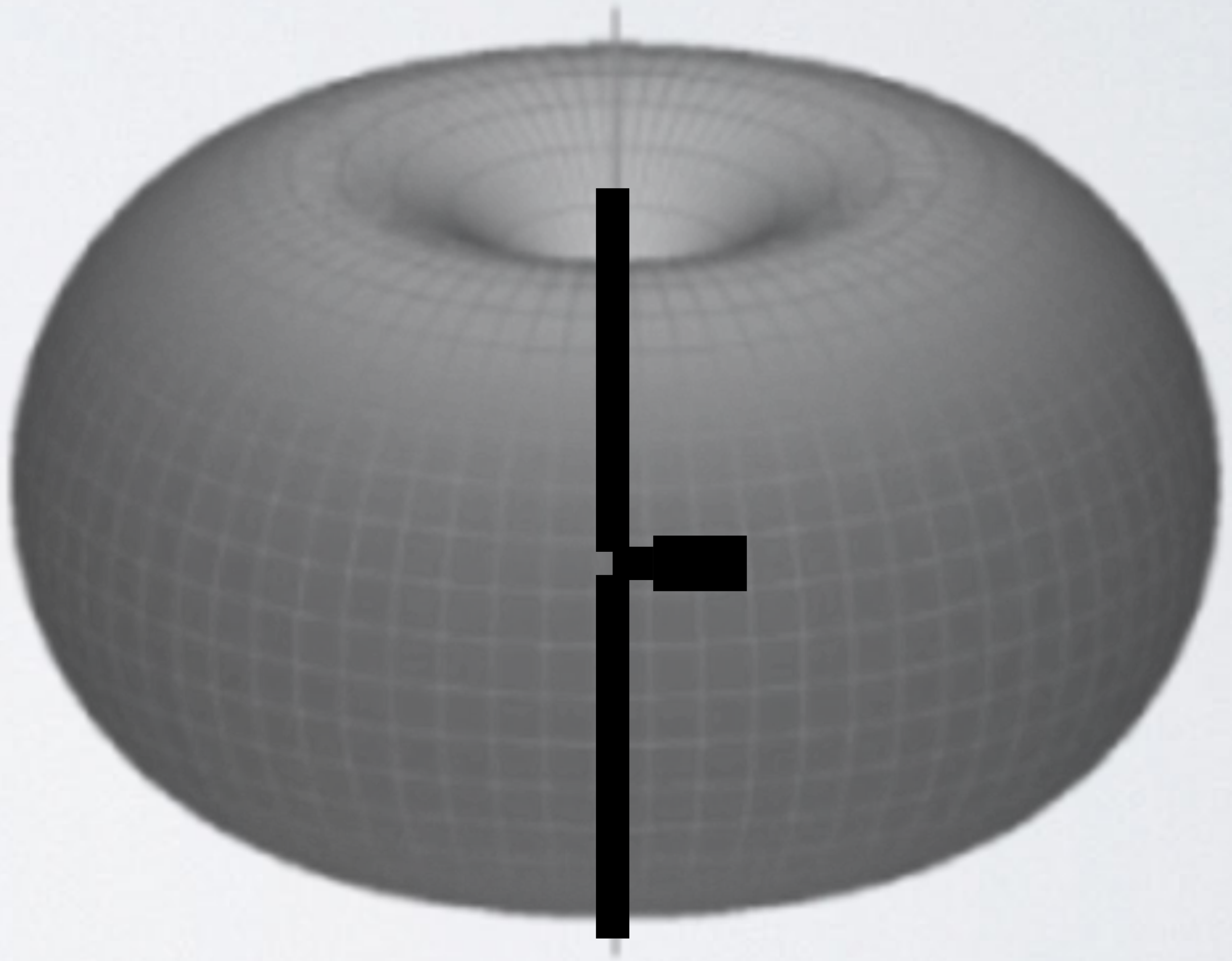
  - Antenna C has a gain of 0 dBd, which is the same as 2.15 dBi

  - Antenna D has a gain of 3 dBd, which is the same as 5.15 dBi

ANTENNA E-PLANE AND H-PLANE

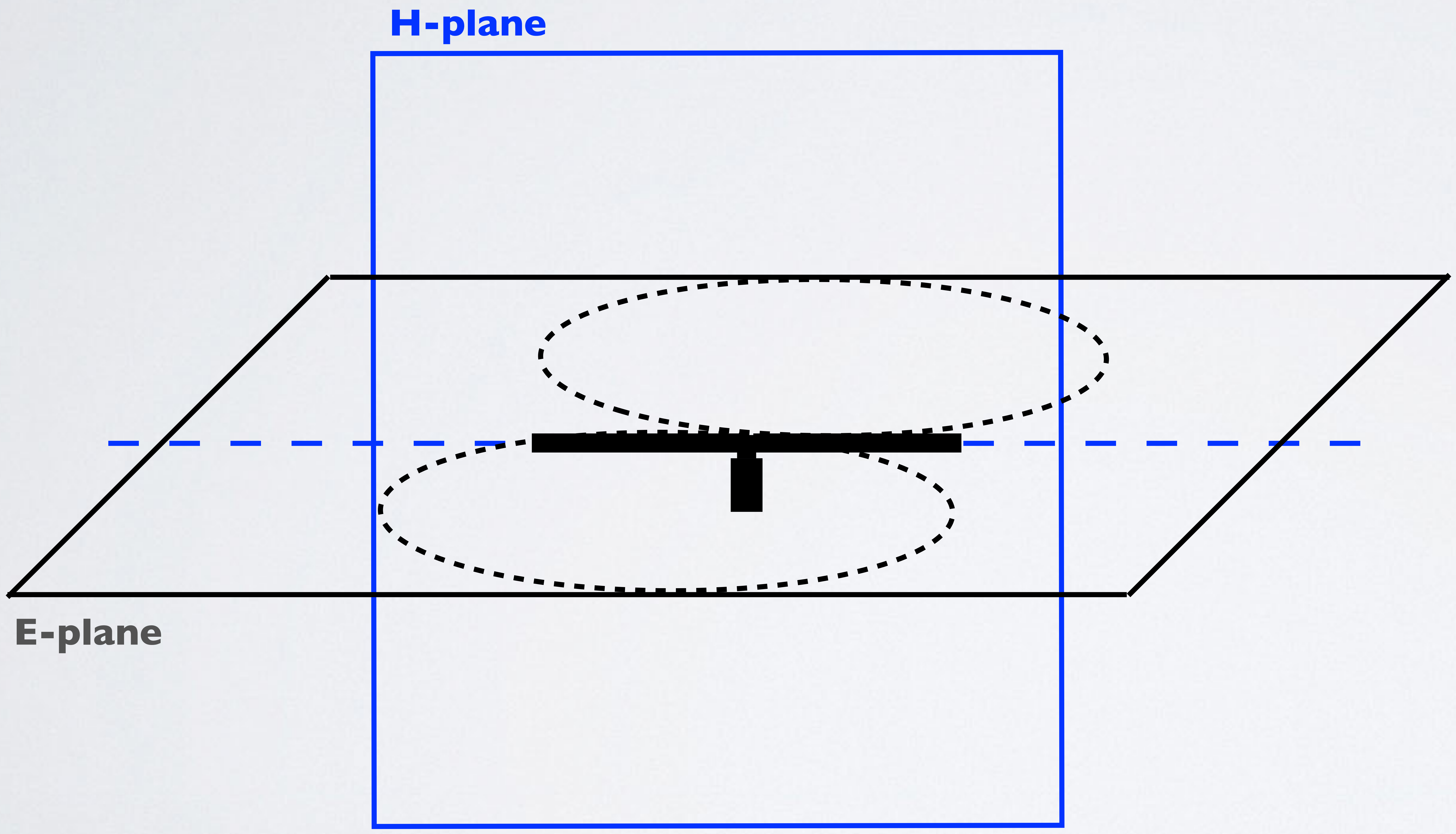
- For a vertical polarised antenna the E-plane coincides with the vertical plane. The E-plane and H-plane (H refers to the magnetic fields) are 90 degrees apart.

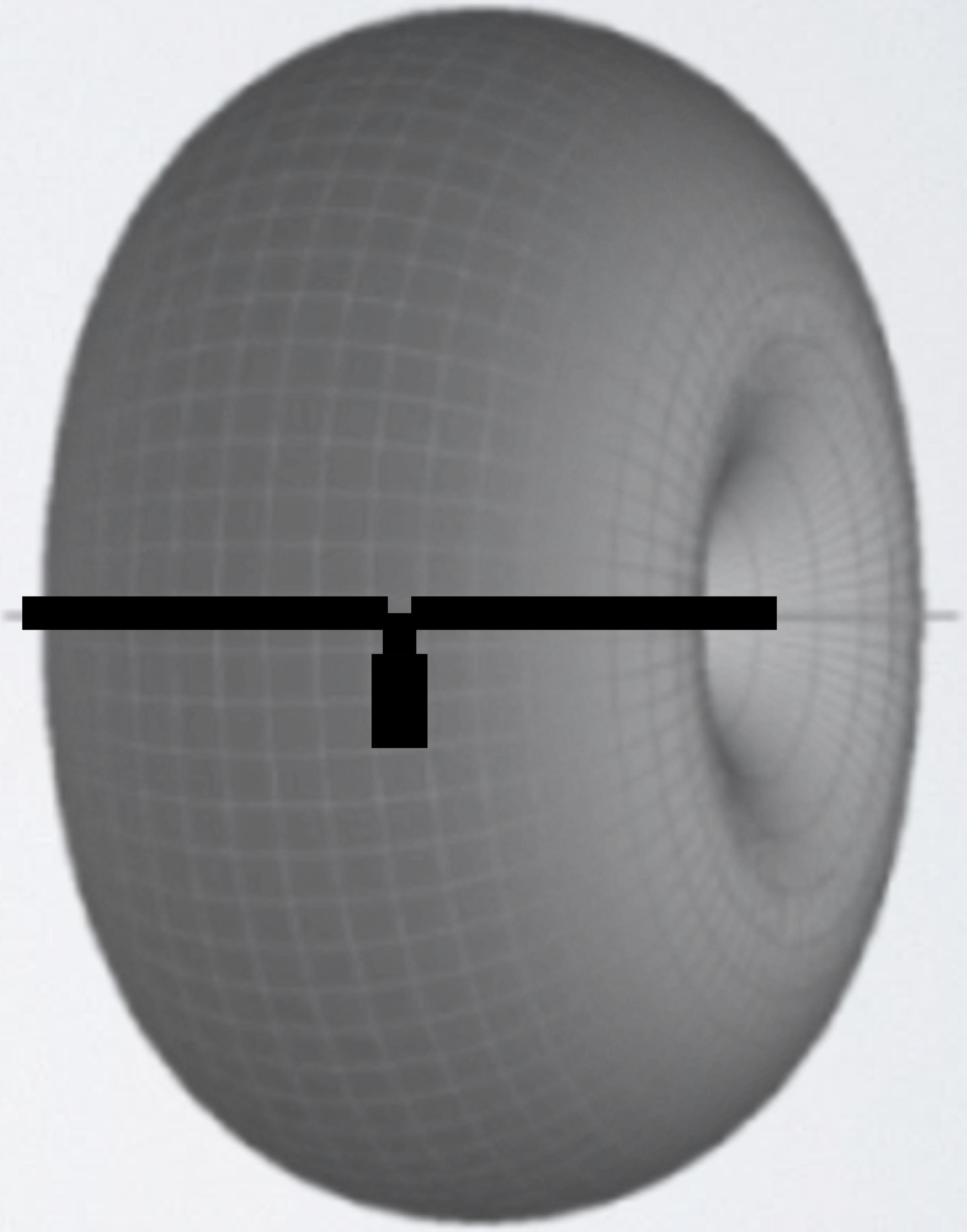




ANTENNA E-PLANE AND H-PLANE

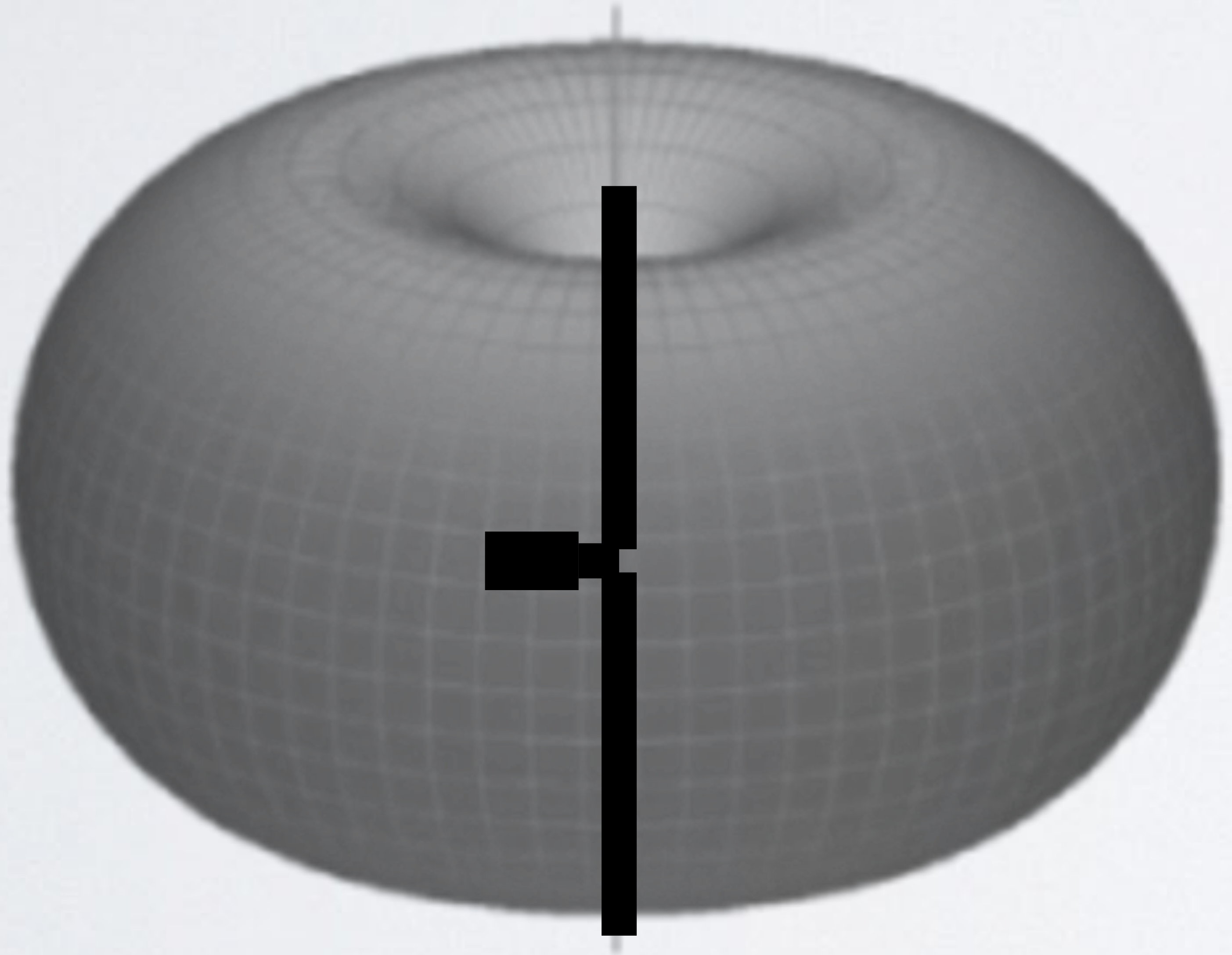
- For a horizontal polarised antenna the E-plane coincides with the horizontal plane. The E-plane and H-plane (H refers to the magnetic fields) are 90 degrees apart.



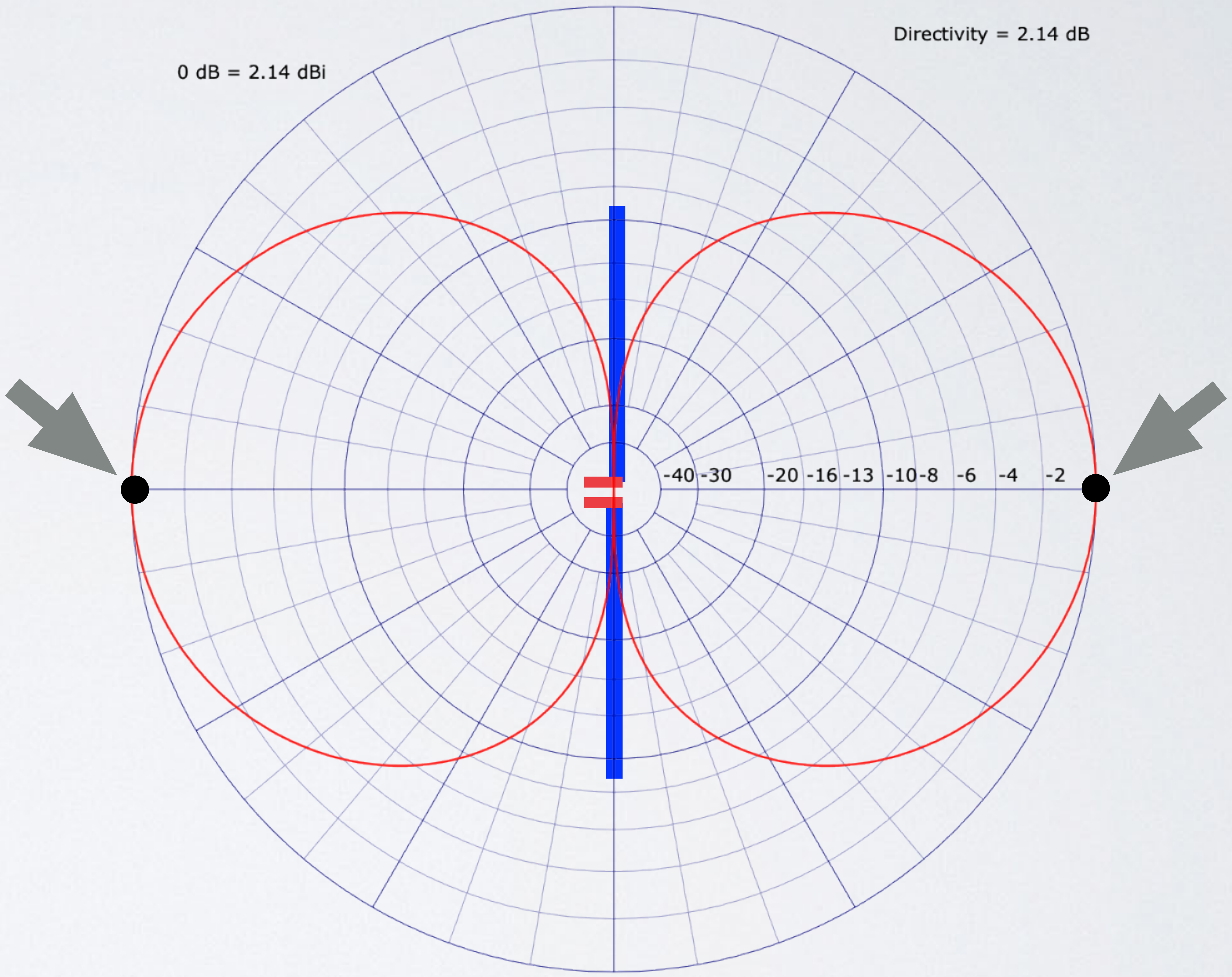


ANTENNA E-PLANE AND H-PLANE

- In the E-plane the radiation pattern of a ½λ dipole antenna looks like the number 8 (see figure right) with the maxima perpendicular on the dipole axis.

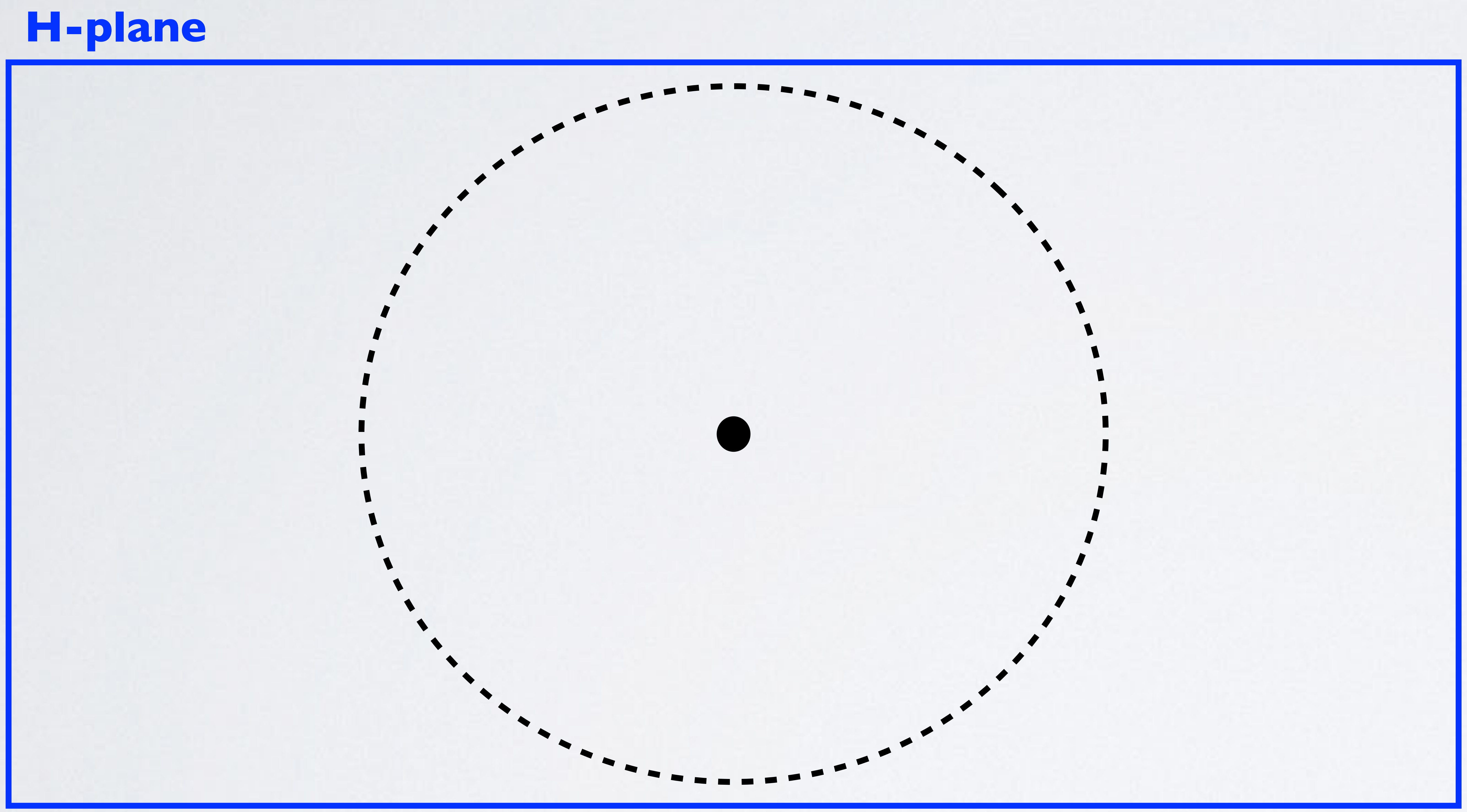


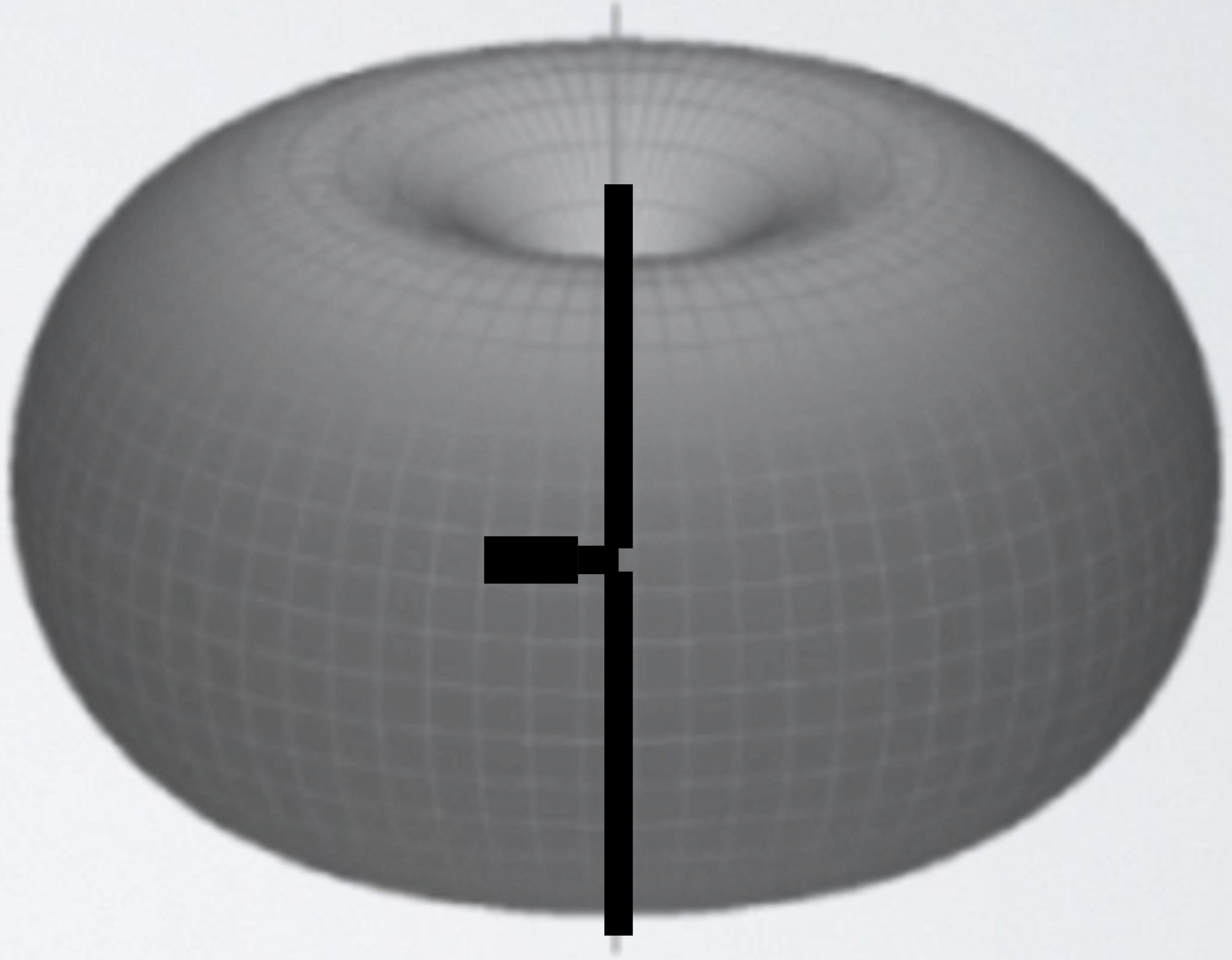
Radiation pattern E-plane



ANTENNA E-PLANE AND H-PLANE

- The radiation pattern is circular in the H-plane for a ½λ dipole antenna.

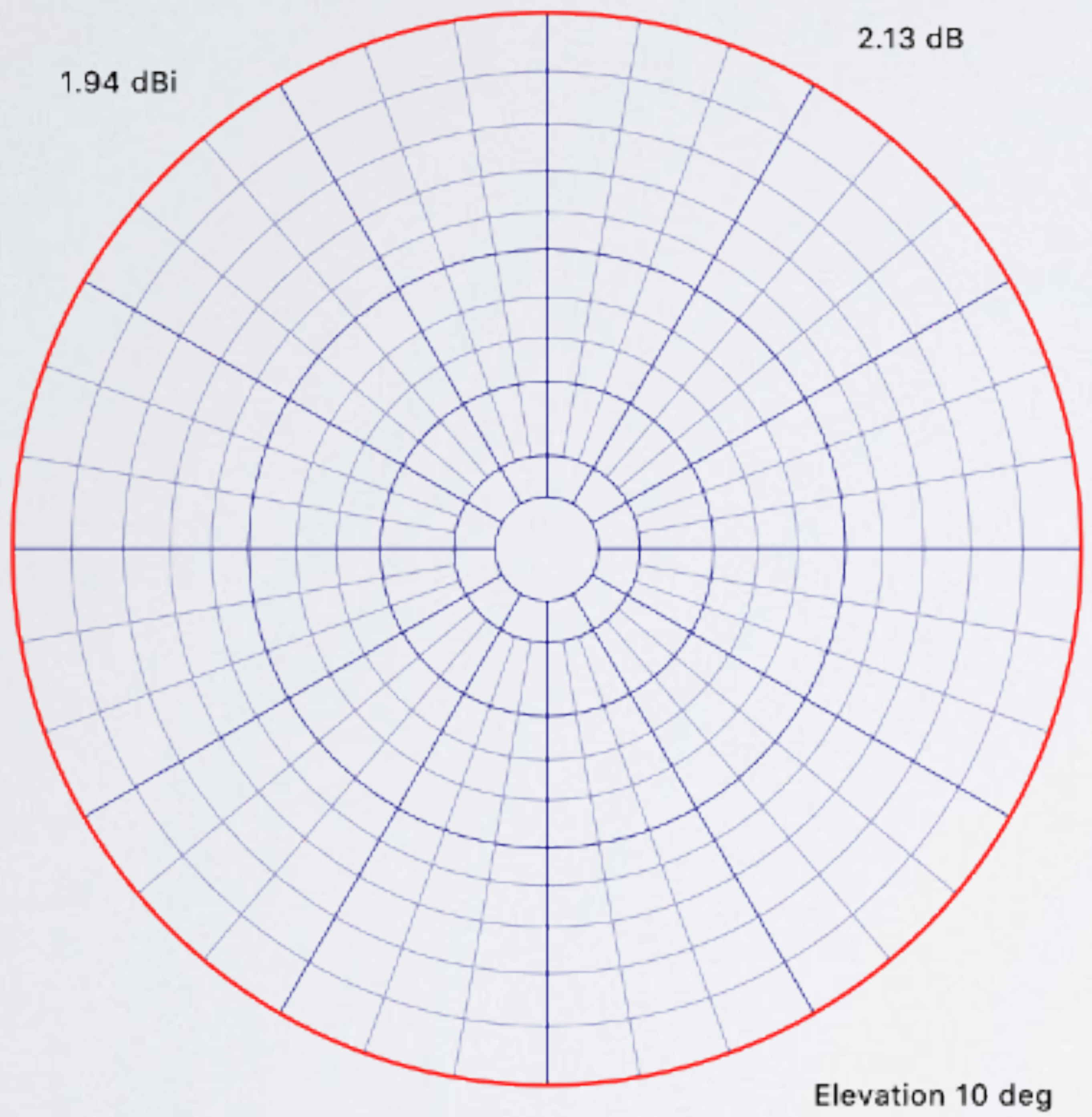


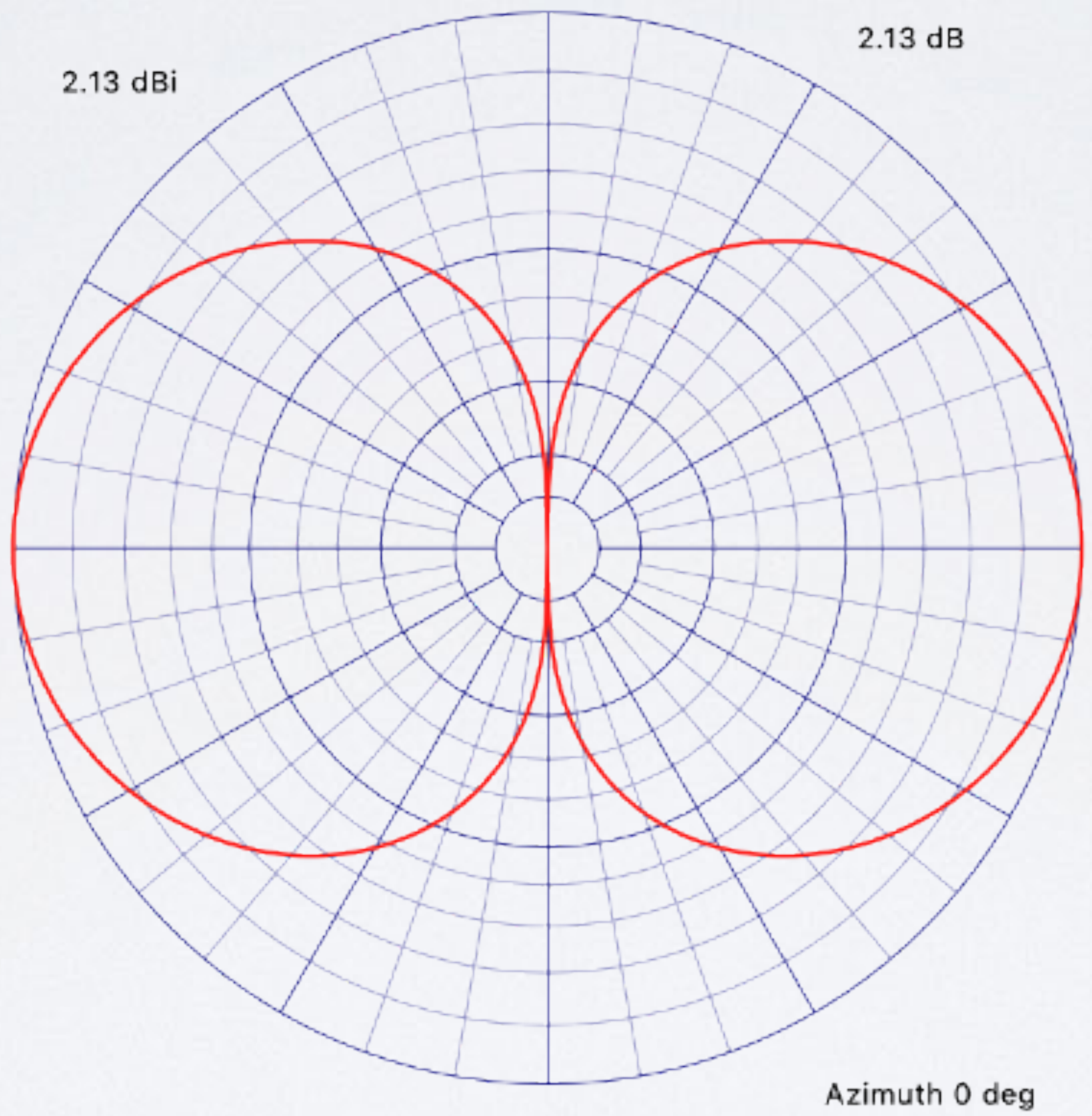


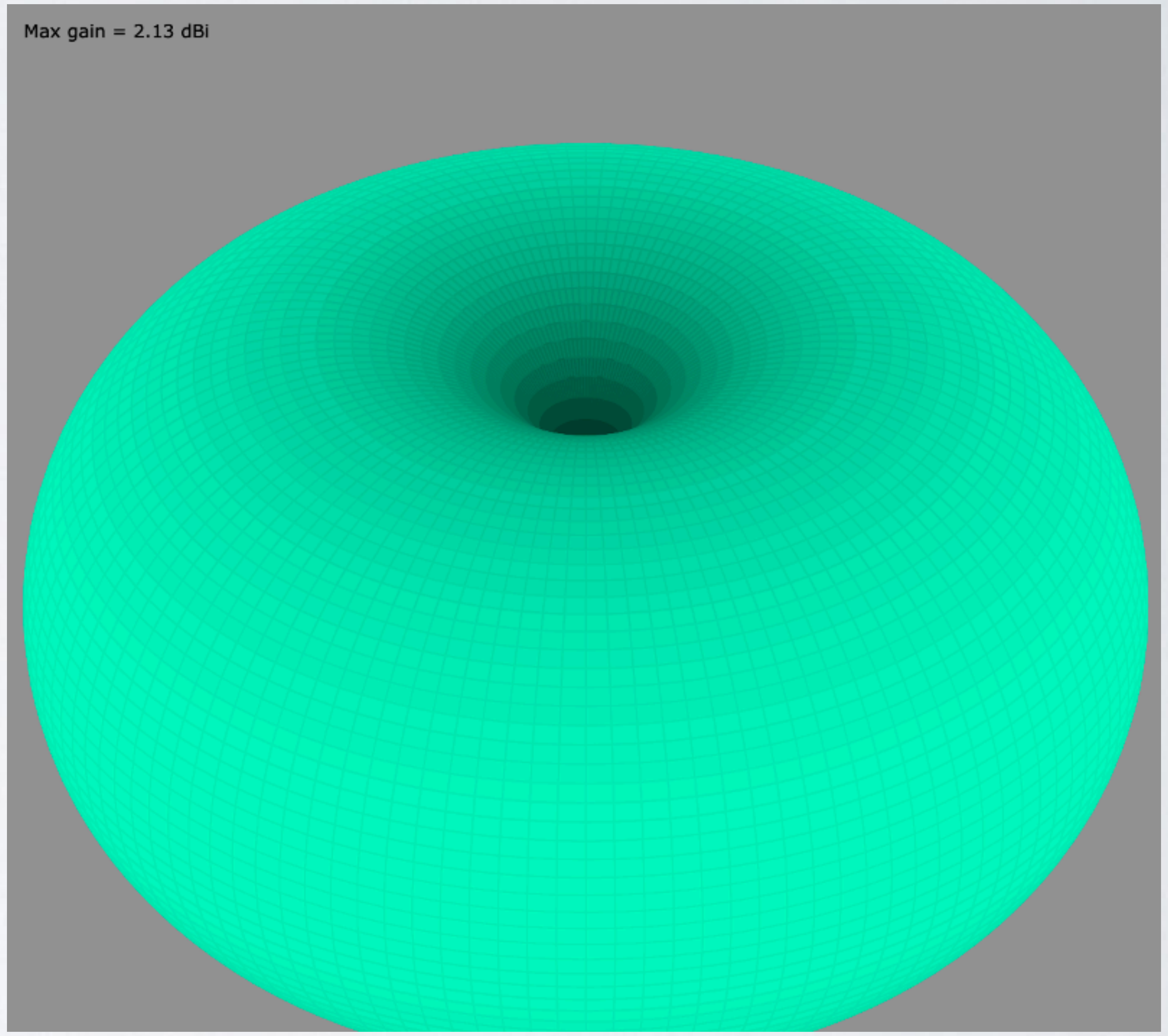
mobilefish.com

GROUND EFFECT

- Radiation patterns of a ½λ dipole antenna, vertical polarised, in free space. Free space means there is no ground effect.



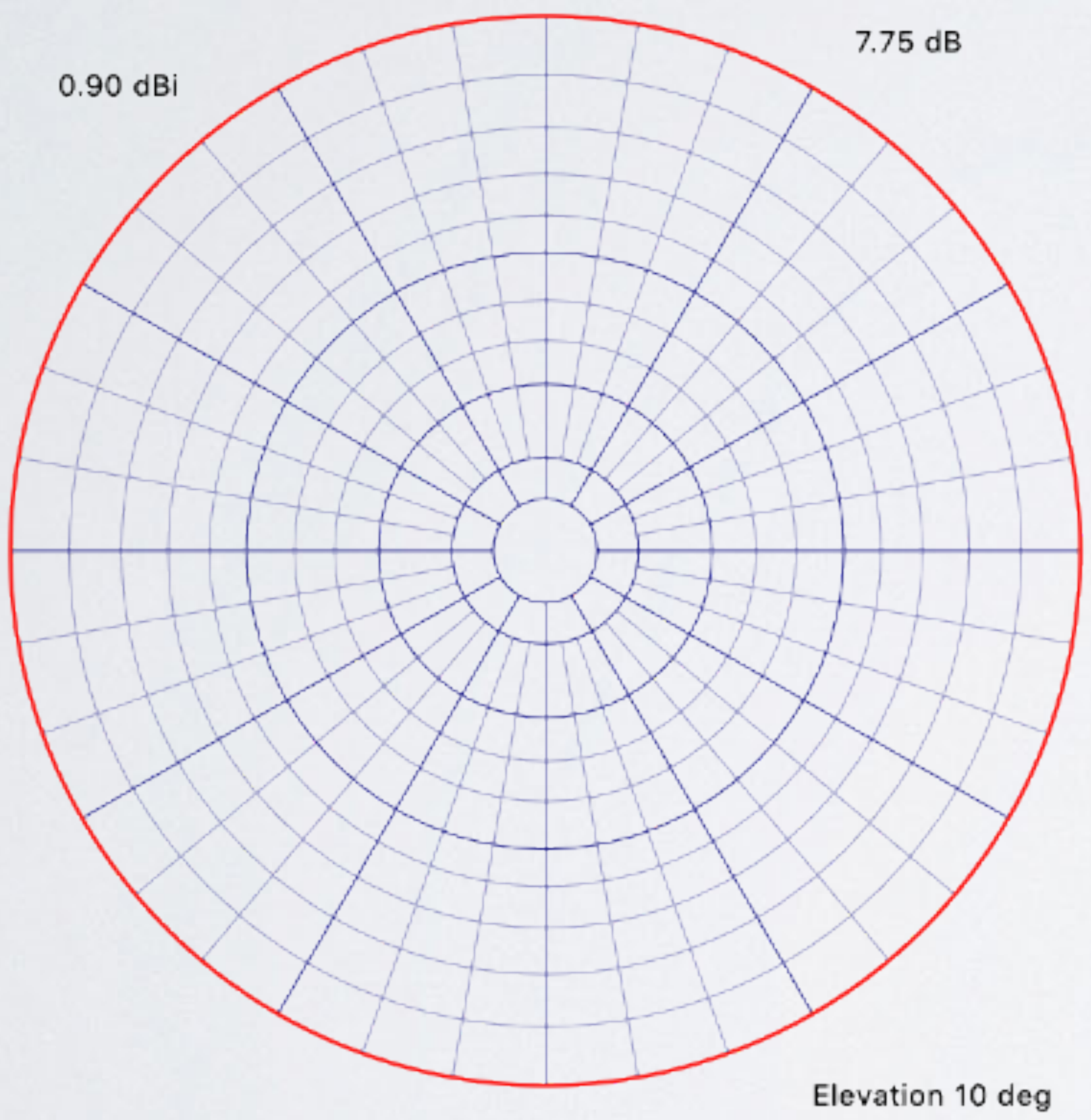


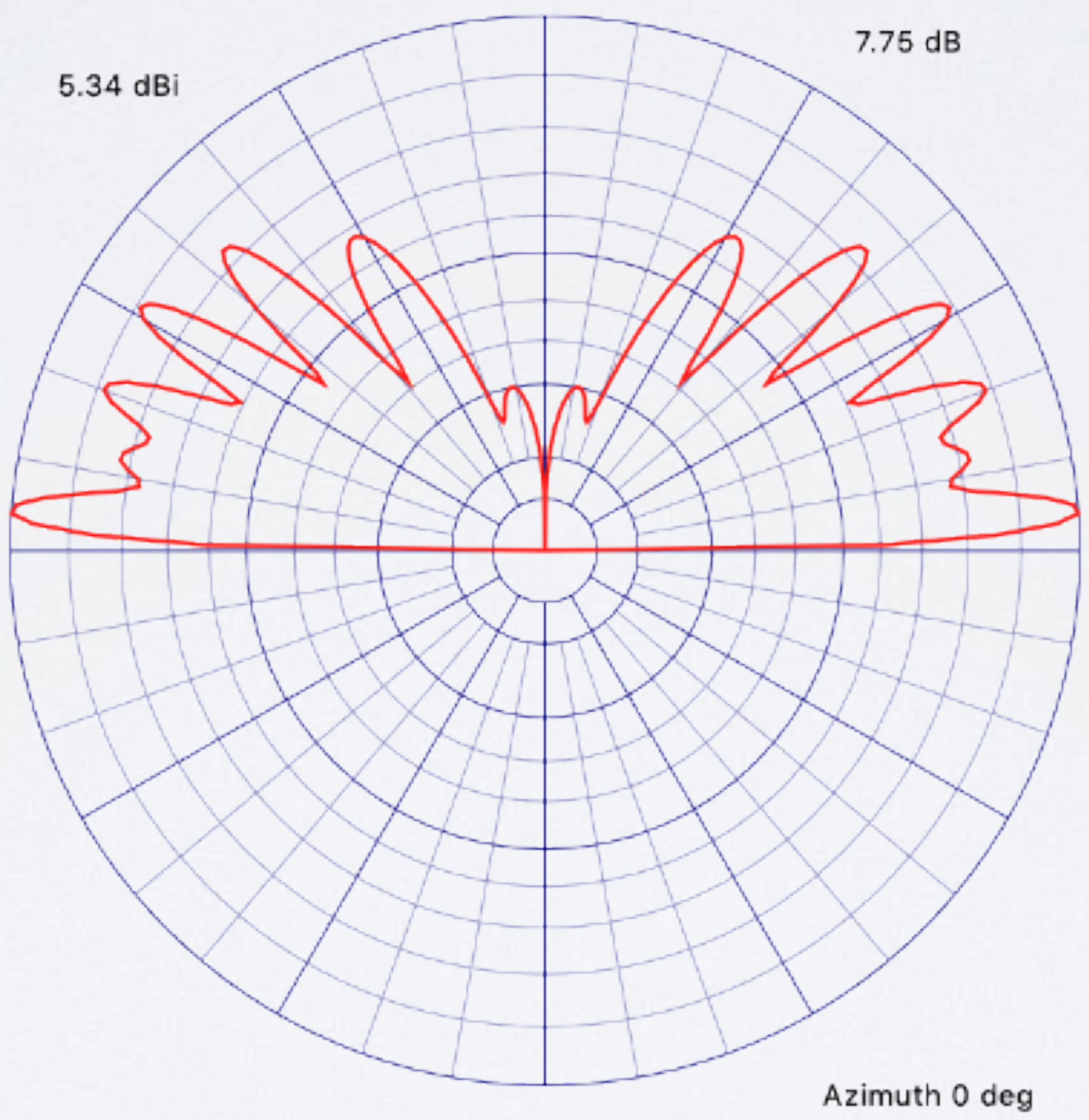


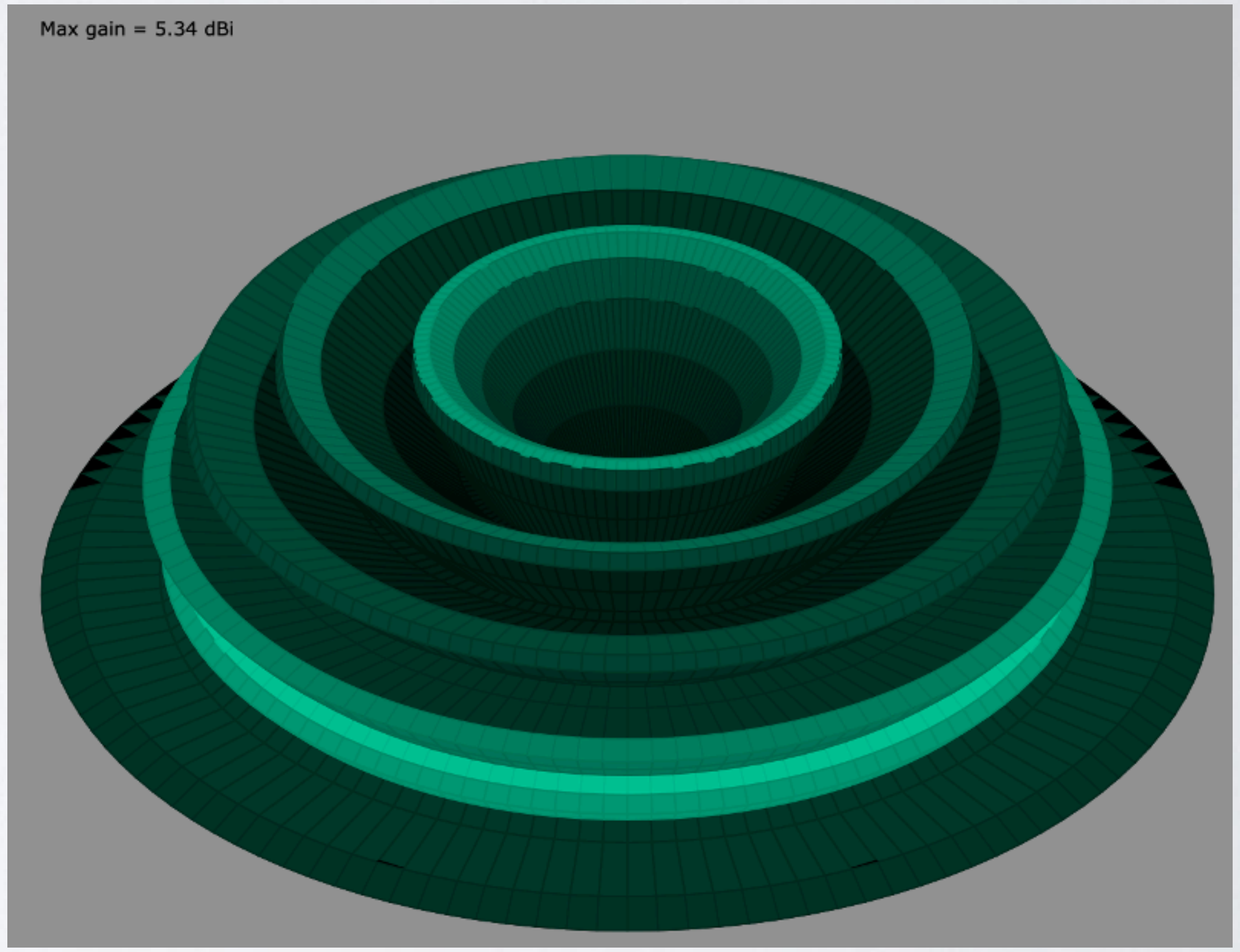
http://www.mobilefish.com/download/lora/dipole_vertical_868mhz.nec.txt

GROUND EFFECT

- Radiation patterns of a ½λ dipole antenna, vertical polarised, one meter above perfect ground (= perfect conductivity).
  The influence of the ground is significant due to reflection.

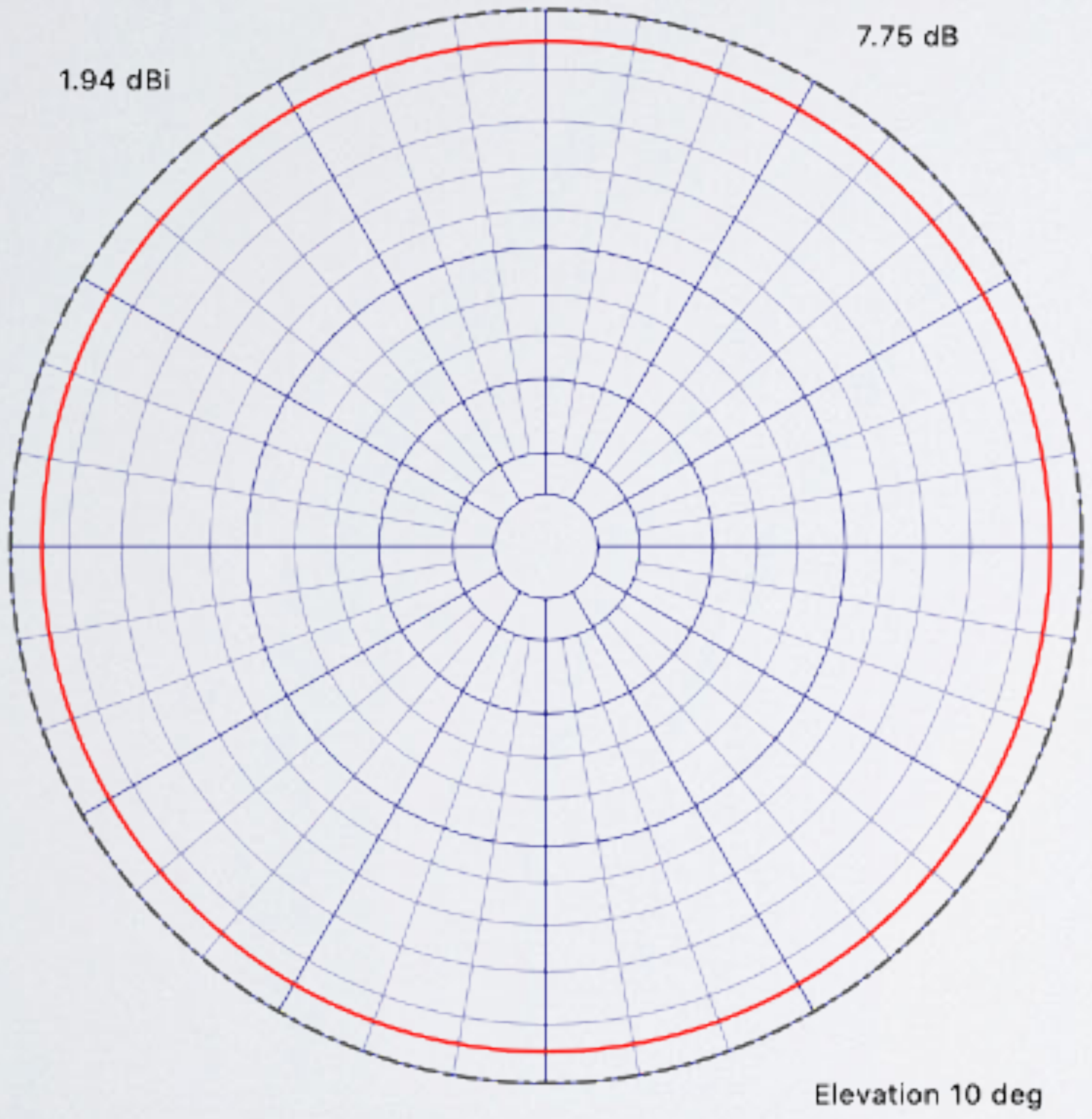


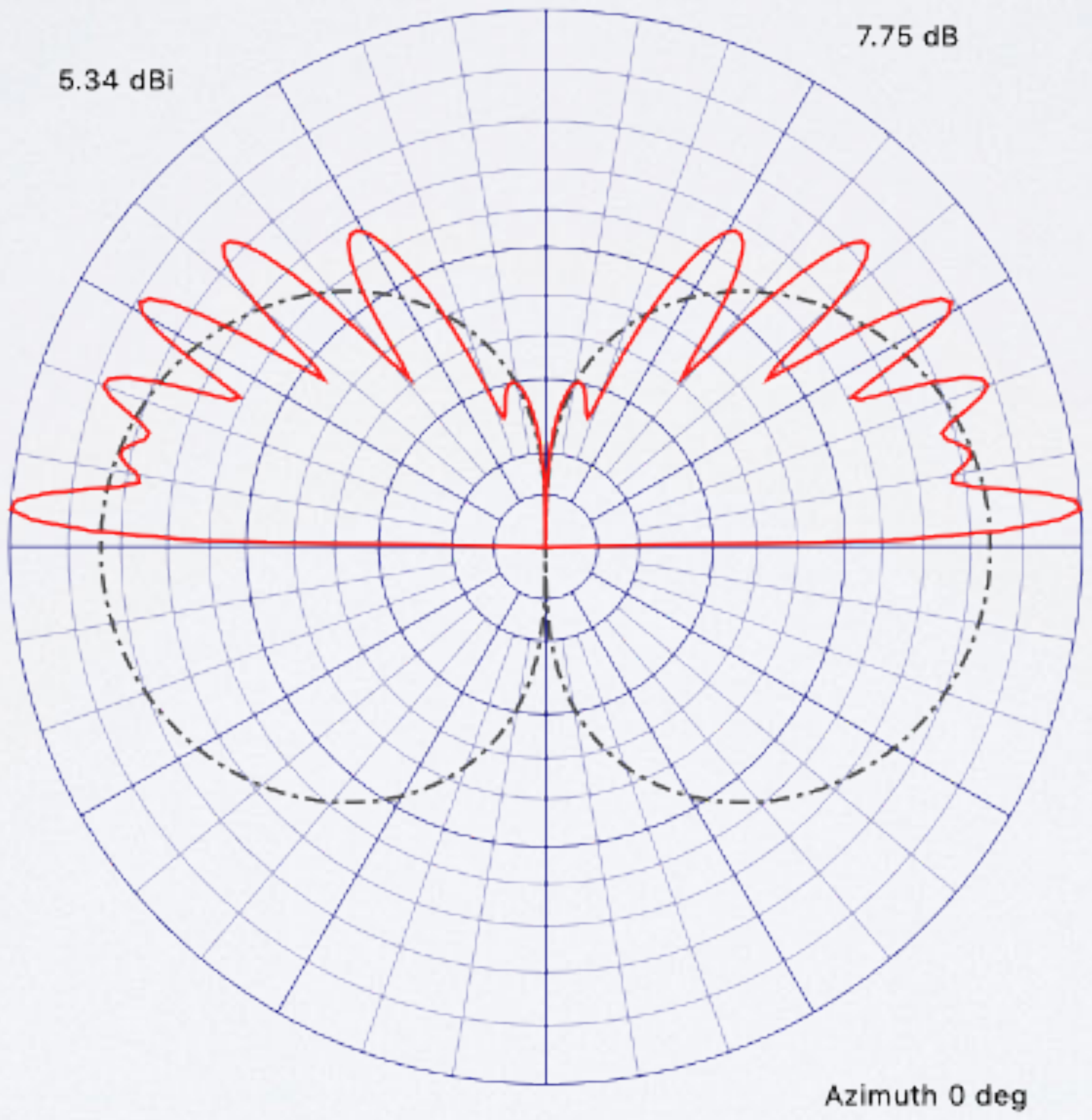




GROUND EFFECT

- The ½λ dipole antenna, vertical polarised. Comparing free space to one meter above perfect ground its maximum gain increased from 2.13 dBi to 5.34 dBi due to the ground effect.





--------- 2019-7-8 15:18 ---- (nec2c) -----

Frequency 868.000 MHz
Feedpoint(1) - Z: (73.114 + i 3.559) I: (0.0136 - i 0.0007) VSWR(Zo=50 Ω): 1.5:1
Antenna is in free space.
Directivity: 2.13 dB
Max gain: 2.13 dBi (azimuth 180 deg., elevation 0 deg.)
Front-to-back ratio: 0.00 dB (elevation 2 deg)
Front-to-back ratio: 0.00 dB (elevation of front lobe)
Front-to-rear ratio: 0.00 dB
Average Gain: 0.9993 (0.003 dB)
Compute time: 0.05 sec

Free space

--------- 2019-7-8 15:19 ---- (nec2c) -----

Frequency 868.000 MHz
Feedpoint(1) - Z: (73.087 + i 3.492) I: (0.0137 - i 0.0007) VSWR(Zo=50 Ω): 1.5:1
Ground - Rel. dielectric constant 20.000, conductivity: 0.03030 mhos/meter. (NEC-2 ground)
Directivity: 7.75 dB
Max gain: 5.34 dBi (azimuth 180 deg., elevation 4 deg.)
Front-to-back ratio: 0.00 dB (elevation 4 deg)
Front-to-back ratio: 0.00 dB (elevation of front lobe)
Front-to-rear ratio: 0.00 dB
Average Gain: 0.5745 (2.407 dB)
Compute time: 0.04 sec

Perf. ground

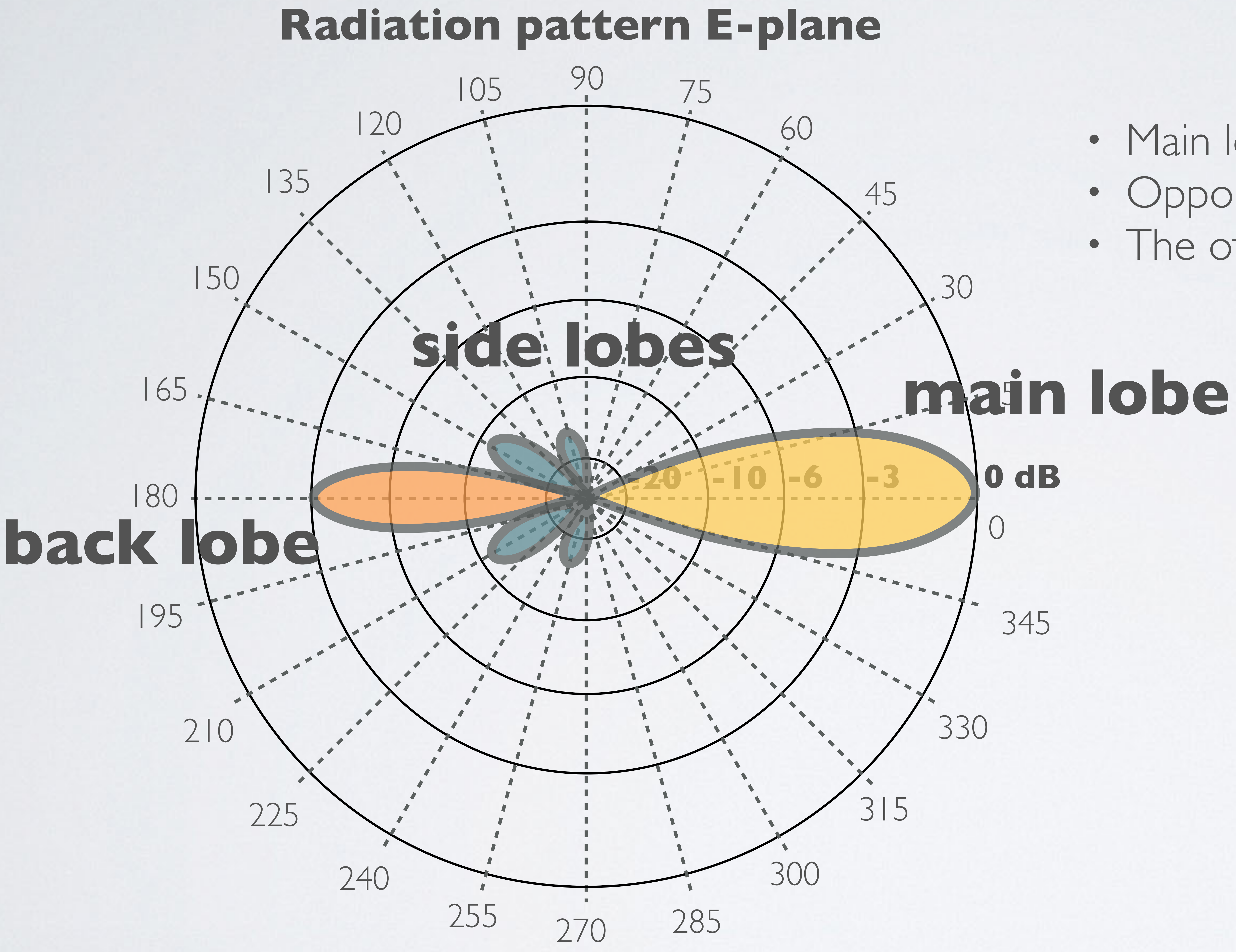
GROUND EFFECT

- Please be aware an antenna normally does not operate in free space, unless its actually in deep space.

- An antenna has always some ground effect, how much this effect is, depends on the antenna distance to the ground and the ground conductivity.

- Use an antenna modelling software such as the 4NEC2 (see tutorial 38), to investigate the ground effect.

MAIN LOBE, BACK LOBE, SIDE LOBES



- Main lobe is the lobe containing the highest power.
- Opposite of the main lobe is the back lobe.
- The other lobes are called the side lobes.

ANTENNA GAIN

- The antenna gain (G) is defined as the maximum radiated power produced by the antenna ($P_{antenna}$) main lobe compared to a reference isotropic antenna ($P_{isotropic}$) or reference dipole antenna (P_{dipole}) supplied with the same input power.

- Question: An antenna has a gain of 2.15 **dBi**. What does this mean?

- Answer: 2.15 dBi is compared to a reference **isotropic** antenna.
  $G = 10 \times \log10(P_{antenna} / P_{isotropic})$ (Equation explained in tutorial 5)
  $P_{antenna} / P_{isotropic} = 10^{(G/10)}$
  $P_{antenna} / P_{isotropic} = 10^{(2.15/10)} = 1.64$
  $P_{antenna} = 1.64 \times P_{isotropic}$
  It means the antenna has a maximum power gain of 1.64 over a reference isotropic antenna.

ANTENNA GAIN

- Question: An antenna has a gain of 3 **dBd**. What does this mean?

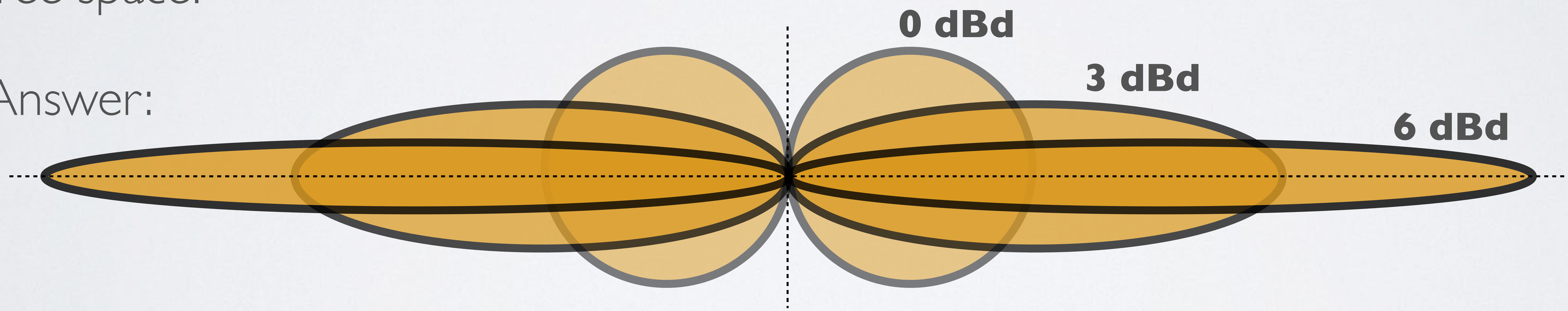
- Answer: 3 dBd is compared to a reference **dipole** antenna.
  $G = 10 \times \log10(P_{antenna} / P_{dipole})$
  $P_{antenna} / P_{dipole} = 10^{(G/10)}$
  $P_{antenna} / P_{dipole} = 10^{(3/10)} = 2$
  $P_{antenna} = 2 \times P_{dipole}$
  It means the antenna has a maximum power gain of 2 over a reference dipole antenna.

ANTENNA GAIN

- Let's say you have two ½λ dipole antenna's X and Y, both operating in free space and both are using the same input power.
  Antenna X has a gain of 0 dBd and antenna Y has a gain of 6 dBd.
  Note: Antenna Y does not exist. I made it up for educational purpose.

- Question: In general what will the radiation patterns for both antennas looks like in free space?

- Answer:

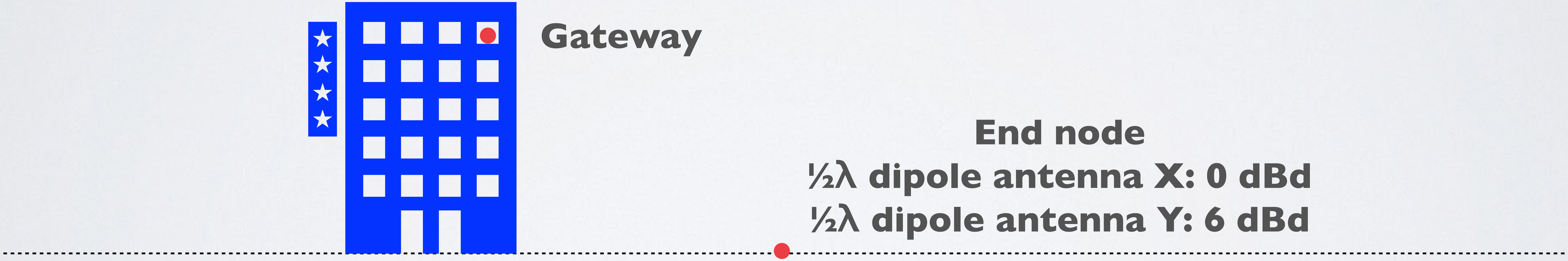


Radiation pattern must be flatter to increase the gain.

ANTENNA GAIN

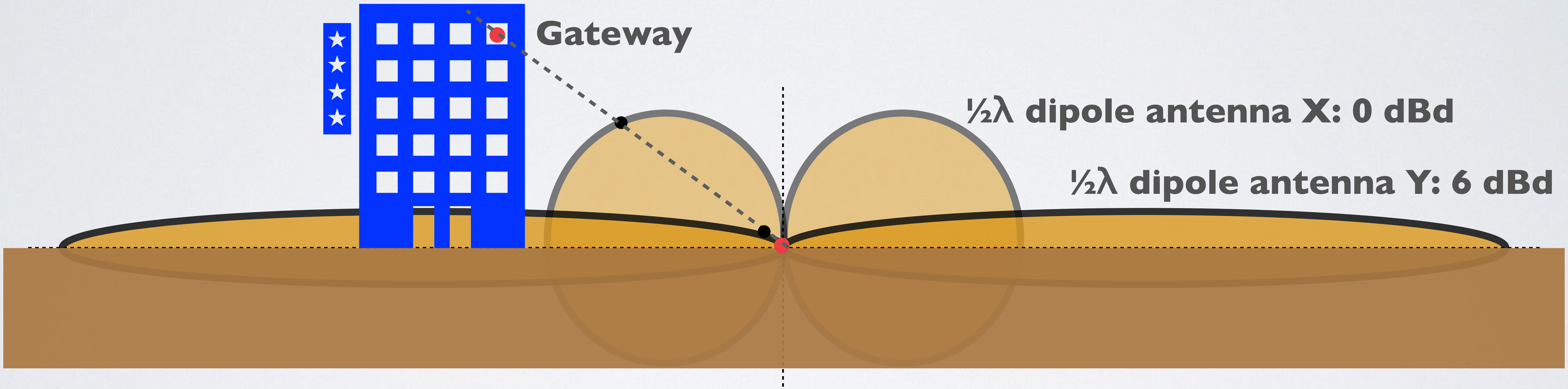
- Let's say you have two ½λ dipole antenna's X and Y (vertical polarised) and both are using the same input power. Antenna X has a gain of 0 dBd and antenna Y has a gain of 6 dBd. Note: Antenna Y does not exist. I made it up for educational purpose.

- Question: The gateway is located at the 5th floor of a building and the end node is located nearby the building at the ground. Which antenna should I use for the end node?



ANTENNA GAIN

- Answer: Choose the ½λ dipole antenna X with a gain of 0 dBd.
  If you use antenna Y the radiation pattern will be flatter.



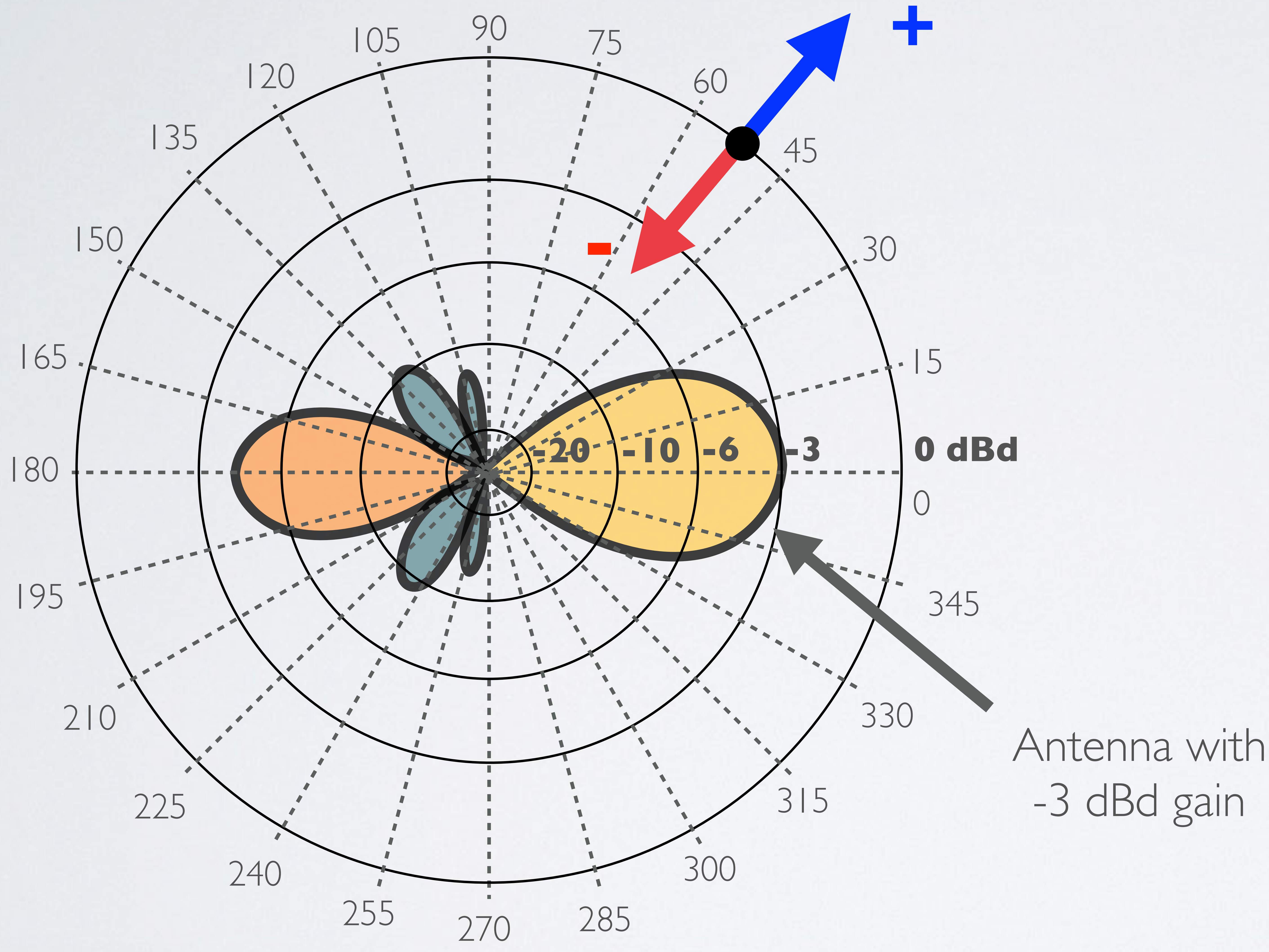
- With this silly example I want to take my point across that a higher gain antenna is not always preferable.

NEGATIVE ANTENNA GAIN

- An antenna can have a negative gain.
  For example an antenna has a gain of -3 dBd or -1.15 dBi

- -3 dB**d** is compared to a reference dipole antenna.
  $G = 10 \times \log10(P_{antenna} / P_{dipole})$
  $P_{antenna} / P_{dipole} = 10^{(G/10)}$
  $P_{antenna} / P_{dipole} = 10^{(-3/10)} = 0.5$
  $P_{antenna} = 0.5 \times P_{dipole}$
  It means the antenna has a maximum power gain of half over a reference dipole antenna.

NEGATIVE ANTENNA GAIN

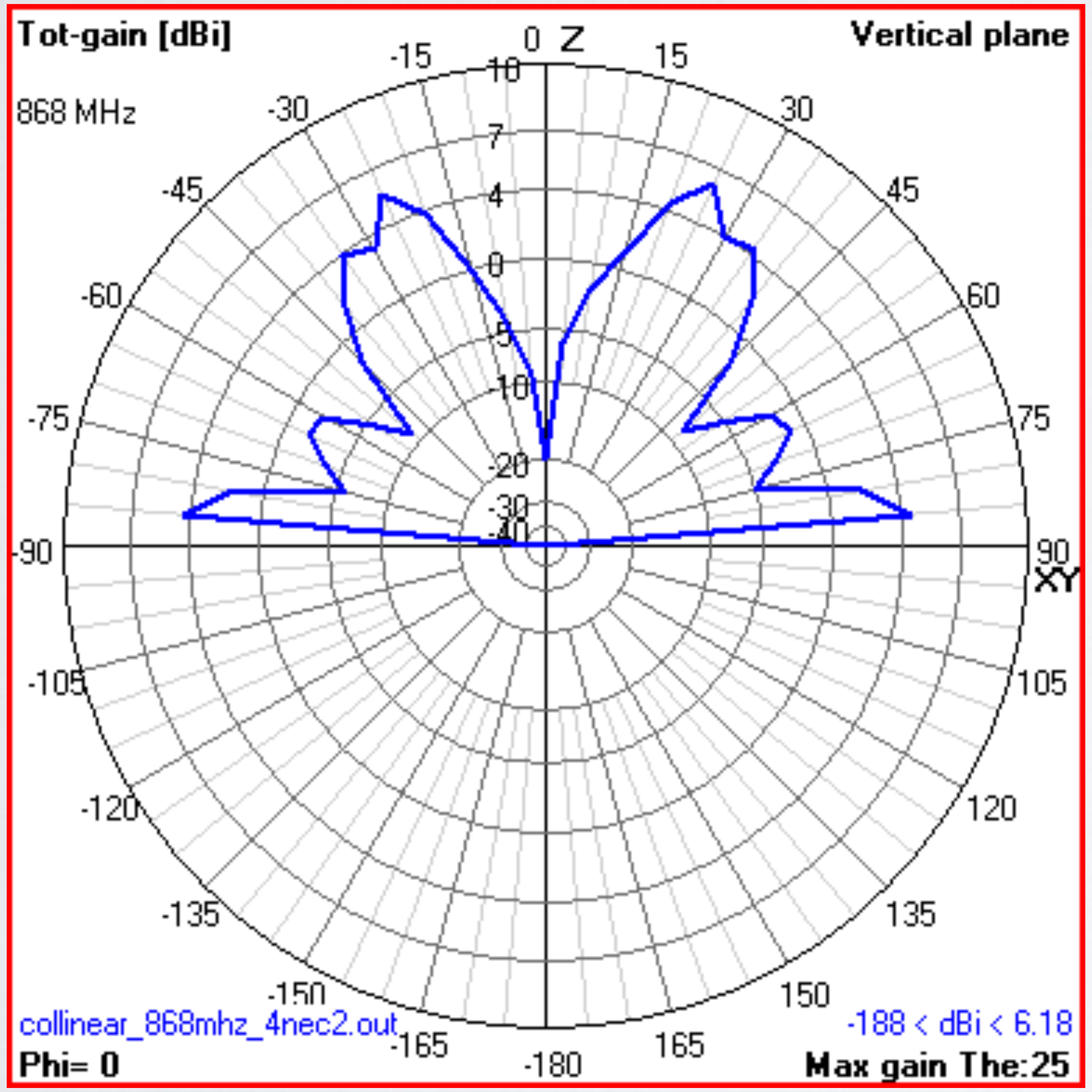


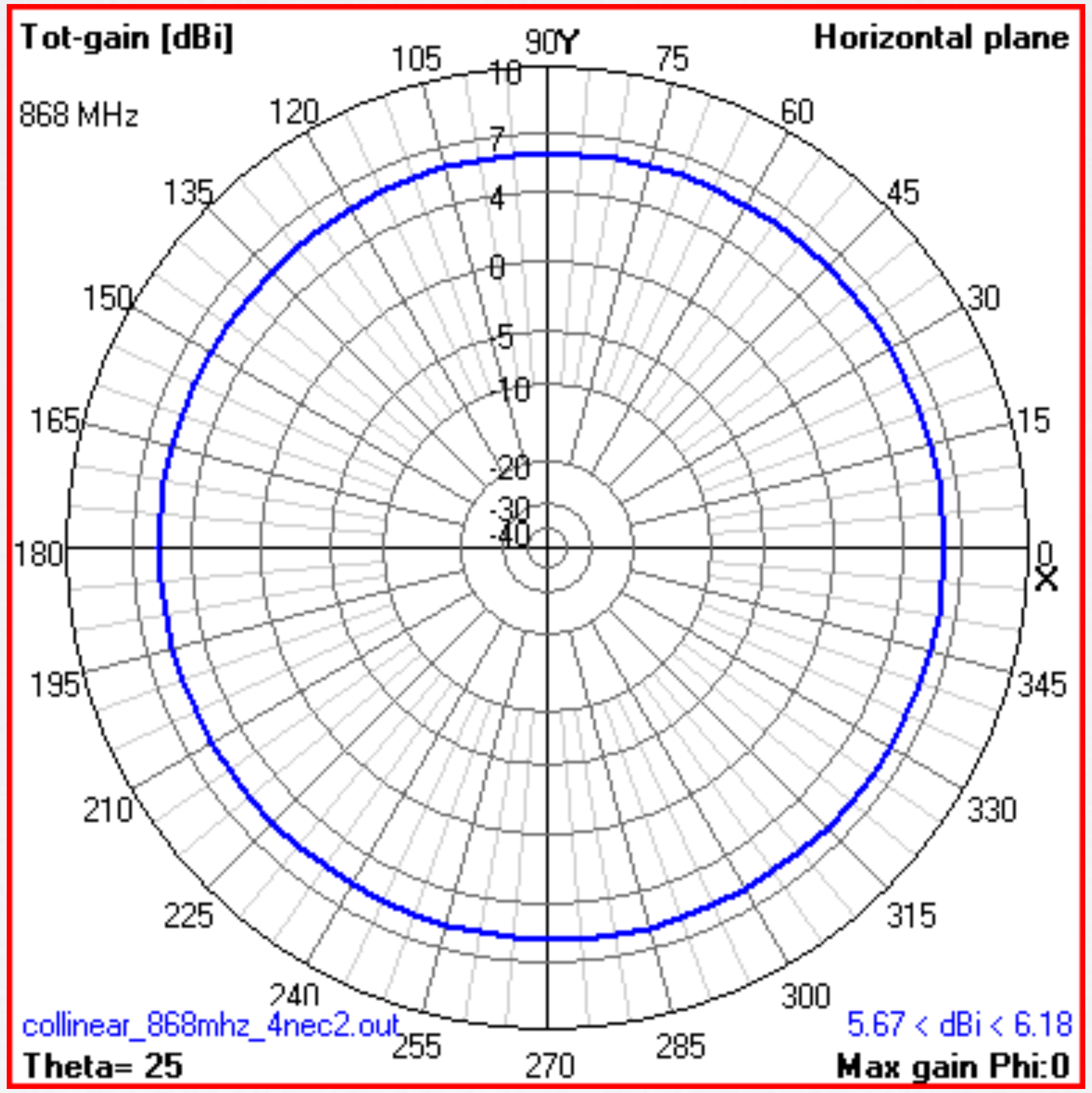
A negative gain means that the antenna radiates less than the reference antenna and a positive number means that the antenna radiates more than the reference antenna.

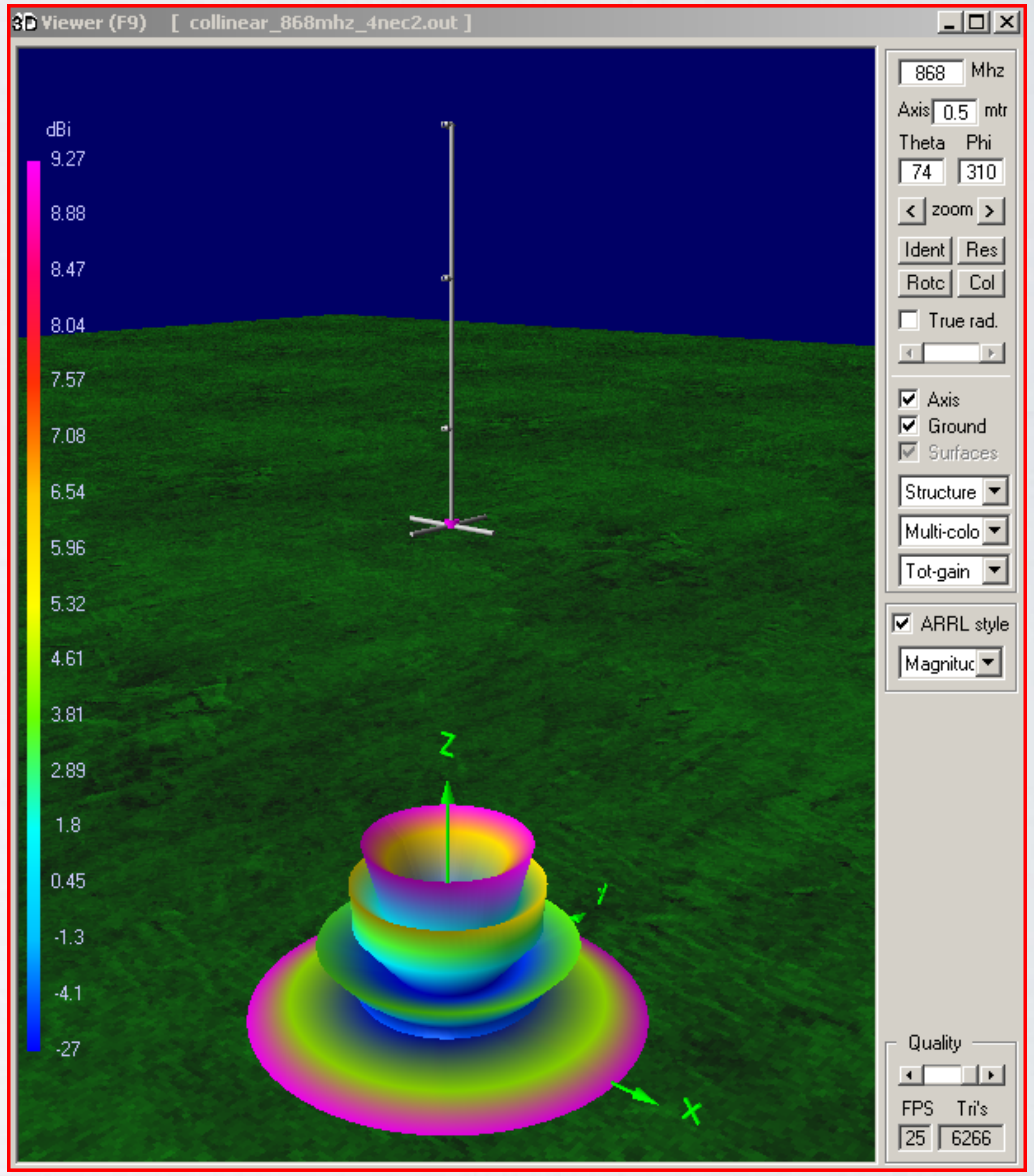
The reference antenna can be an isotropic or dipole antenna.

ANTENNA GAIN

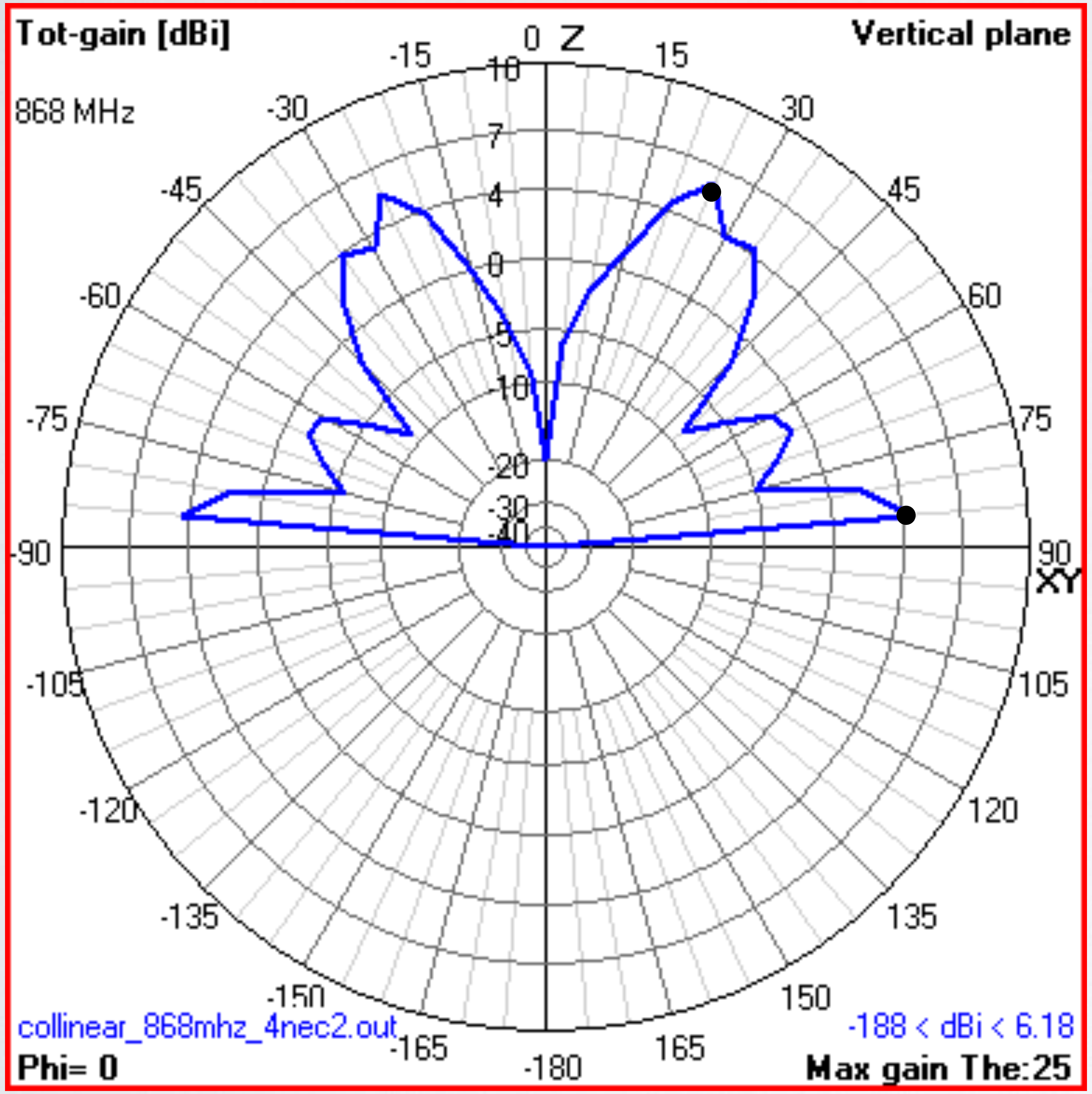
- I have a collinear antenna and its antenna gain is 6.18 dBi.
- This is the vertical and horizontal radiation pattern of this antenna.







ANTENNA GAIN



The specified antenna gain is 6.18 dBi.

This maximum antenna gain does not apply in all directions only at an elevation angle Θ=25°

At elevation Θ=85° the antenna gain around 4 dBi.

ERP, ANTENNA GAIN & TX POWER

- The relationship between EIRP and ERP is (also see tutorial 9):
  EIRP (dBm) = ERP (dBm) + 2.15
  or
  EIRP(mW) = 1.64 x ERP (mW)

- The factor **1.64** was explained earlier:
  $P_o/P_i = 10^{(A/10)} = 10^{(2.15/10)} \approx 1.64$

- As explained in tutorial 11 when using the EU863-870 ISM band:
  - The maximum ERP = 25 mW for uplink and downlink (slot 1)
  - The maximum ERP = 500 mW for downlink (slot 2)

- ERP=25 mW equals: 10xlog10(Po / Pi) = 10xlog10(25) = 13.9794 dBm ≈ 14 dBm
  ERP=500 mW equals: 10xlog10(Po / Pi) = 10xlog10(500) = 26.9897 dBm ≈ 27 dBm

ERP, ANTENNA GAIN & TX POWER

- ERP converted to EIRP:
  ERP = 25 mW: EIRP = 1.64 x ERP = 1.64 x 25 = 41 mW
  ERP = 500 mW: EIRP = 1.64 x ERP = 1.64 x 500 = 820 mW

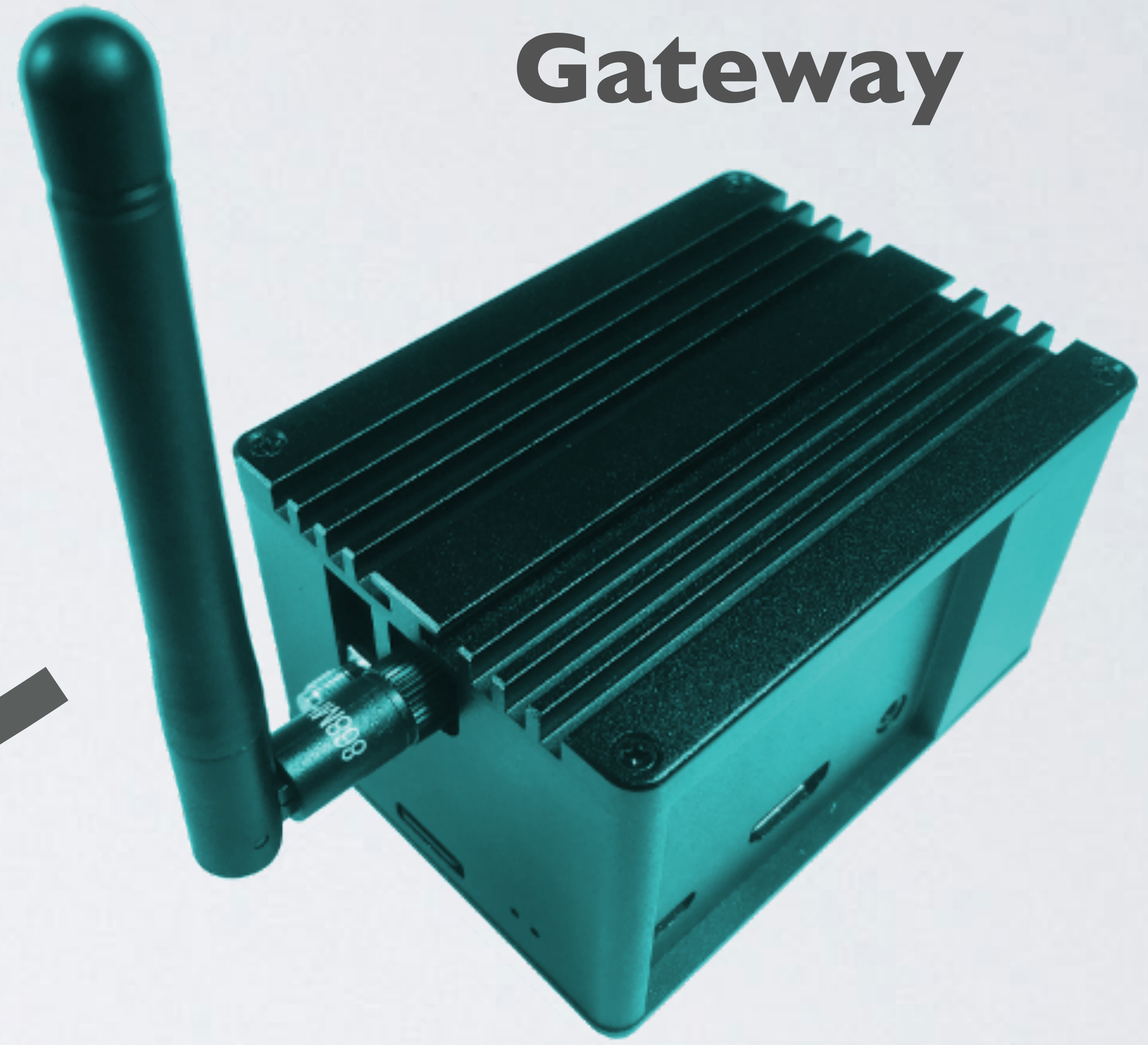
- EIRP=41 mW equals: 10xlog10(Po / Pi) = 10xlog10(41) = 16.1278 dBm ≈ 16 dBm
  EIRP=820 mW equals: 10xlog10(Po / Pi) = 10xlog10(820) = 29.1381 dBm ≈ 29 dBm

- When operating in the EU863-870 ISM band there is no specific limit set with regard to the antenna gain but is is indirectly limited, see this equation:
  ERP= Tx power (dBm) + antenna gain (dBd) - cable loss (dBm) (see tutorial 9)

ERP, ANTENNA GAIN & TX POWER

EU863-870 ISM band

Gateway

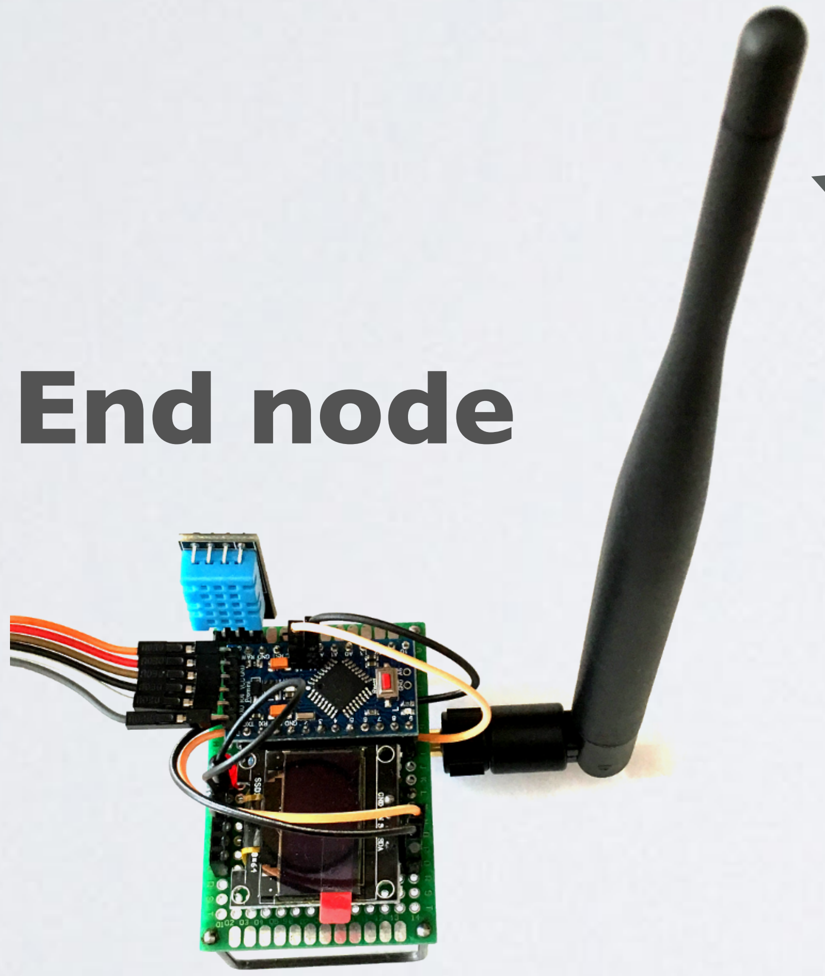


Uplink

max ERP = 25 mW ≈ 14 dBm

max EIRP = 41 mW ≈ 16 dBm

End node



Downlink

max ERP = 25 mW ≈ 14 dBm (slot 1)

max ERP = 500 mW ≈ 27 dBm (slot 2)

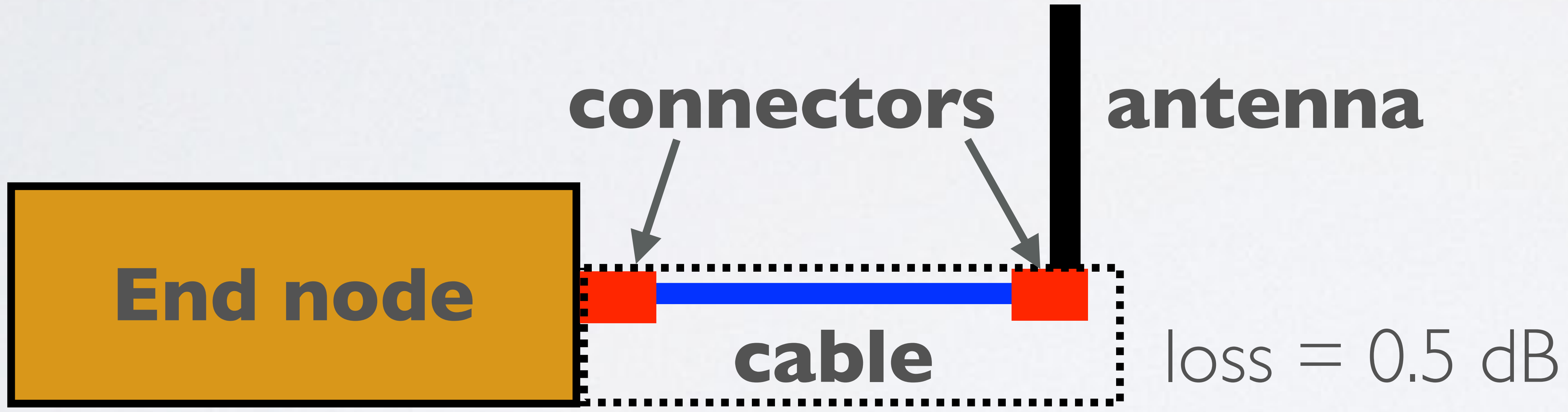
max EIRP = 41 mW ≈ 16 dBm (slot 1)

max EIRP = 820 mW ≈ 29 dBm (slot 2)

ERP, ANTENNA GAIN & TX POWER

- Let's assume you are using the EU863-870 ISM band and you are attaching different antennas with different gains to the same end node and the total loss between end node and antenna (cable + connectors) is 0.5 dB.

  Antenna A, gain = 2 **dBd**
  Antenna B, gain = 5 **dBd**
  Antenna C, gain = -1.5 **dBd**
  Antenna D, gain = 2 **dBi**
  Antenna E, gain = 5 **dBi**
  Antenna F gain = -1.5 **dBi**



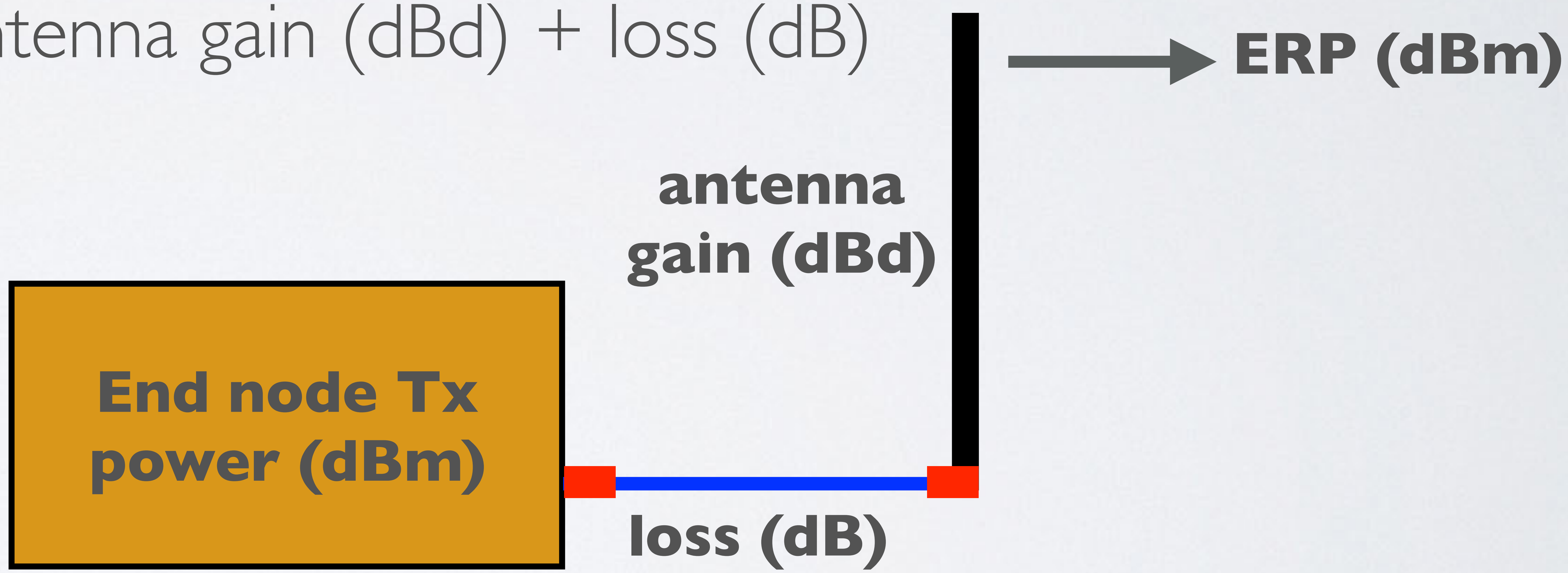
- Question: Calculate the maximum allowed end node transmission power for each antenna. Reminder: When using EU863-870 ISM band, the maximum end node transmission power is: ERP = 25 mW ≈ 14 dBm or EIRP = 41 mW ≈ 16 dBm.

ERP, ANTENNA GAIN & TX POWER

- **Answer A:**
  In this example I am using the **ERP value**.
  When using ERP, the antenna gain must be converted into dBd.
  EU863-870 ISM band: Max ERP = 25 mW ≈ 14 dBm

- ERP (dBm) = Tx power (dBm) - loss (dB) + antenna gain (dBd)
  Tx power (dBm) = ERP (dBm) - antenna gain (dBd) + loss (dB)

  dBd = dBi - 2.15



ERP, ANTENNA GAIN & TX POWER

- Antenna A, gain = 2 dBd
  Antenna B, gain = 5 dBd
  Antenna C, gain = -1.5 dBd

  Antenna D, gain = 2 dBi = 2 - 2.15 = -0.15 dBd
  Antenna E, gain = 5 dBi = 5 - 2.15 = 2.85 dBd
  Antenna F gain = -1.5 dBi = -1.5 - 2.15 = -3.65 dBb

- Antenna A: Max Tx power = 14 - 2 + 0.5 = 12.5 dBm
  Antenna B: Max Tx power = 14 - 5 + 0.5 = 9.5 dBm
  Antenna C: Max Tx power = 14 + 1.5 + 0.5 = 16.0 dBm

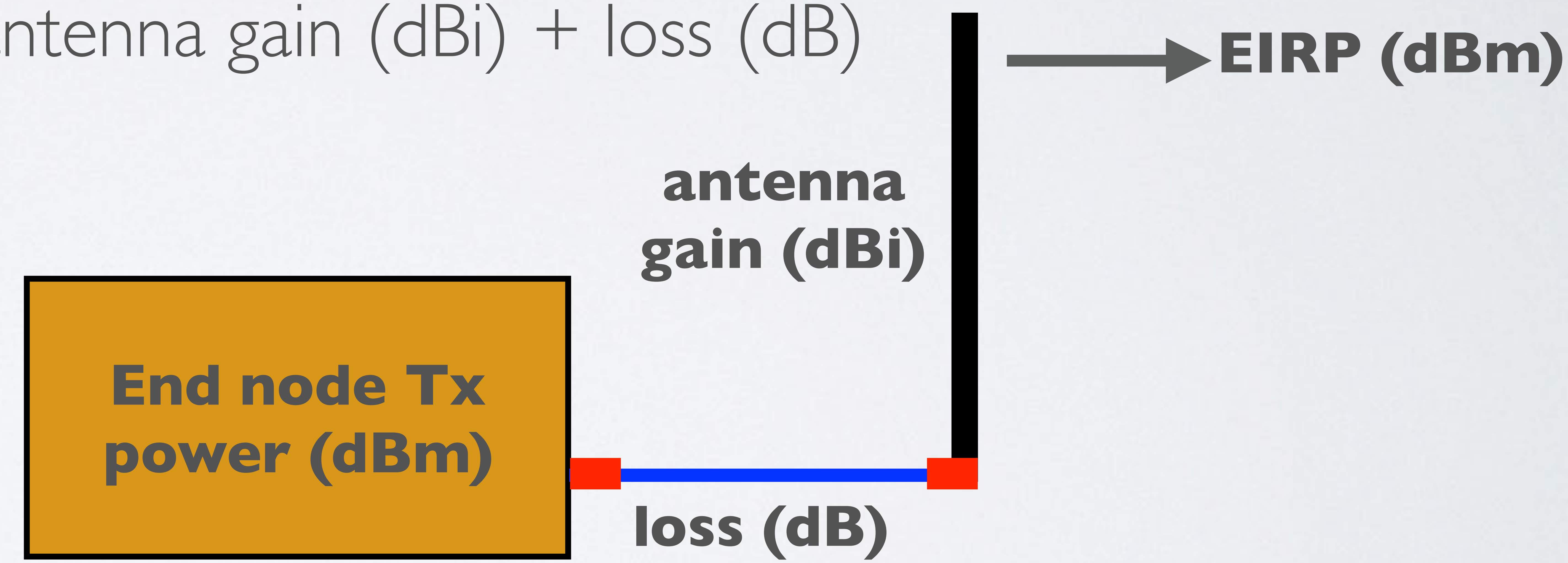
- Antenna D: Max Tx power = 14 + 0.15 + 0.5 = 14.65 dBm
  Antenna E: Max Tx power = 14 - 2.85 + 0.5 = 11.65 dBm
  Antenna F: Max Tx power = 14 + 3.65 + 0.5 = 18.15 dBm

ERP, ANTENNA GAIN & TX POWER

- **Answer B:**
  In this example I am using the **EIRP value**.
  When using EIRP, the antenna gain must be converted into dBi.
  EU863-870 ISM band: Max EIRP = 41 mW ≈ 16 dBm

- EIRP (dBm) = Tx power (dBm) - loss (dB) + antenna gain (dBi)
  Tx power (dBm) = EIRP (dBm) - antenna gain (dBi) + loss (dB)

  dBi = dBd + 2.15



ERP, ANTENNA GAIN & TX POWER

- Antenna A, gain = 2 dBd = 2 + 2.15 = 4.15 dBi
  Antenna B, gain = 5 dBd = 5 + 2.15 = 7.15 dBi
  Antenna C, gain = -1.5 dBd = -1.5 + 2.15 = 0.65 dBi

  Antenna D, gain = 2 dBi
  Antenna E, gain = 5 dBi
  Antenna F gain = -1.5 dBi

- Antenna A: Max Tx power = 16 - 4.15 + 0.5 = 12.35 dBm
  Antenna B: Max Tx power = 16 - 7.15 + 0.5 = 9.35 dBm
  Antenna C: Max Tx power = 16 - 0.65 + 0.5 = 15.85 dBm

- Antenna D: Max Tx power = 16 - 2 + 0.5 = 14.5 dBm
  Antenna E: Max Tx power = 16 - 5 + 0.5 = 11.5 dBm
  Antenna F: Max Tx power = 16 + 1.5 + 0.5 = 18.0 dBm

LOSS ESTIMATES

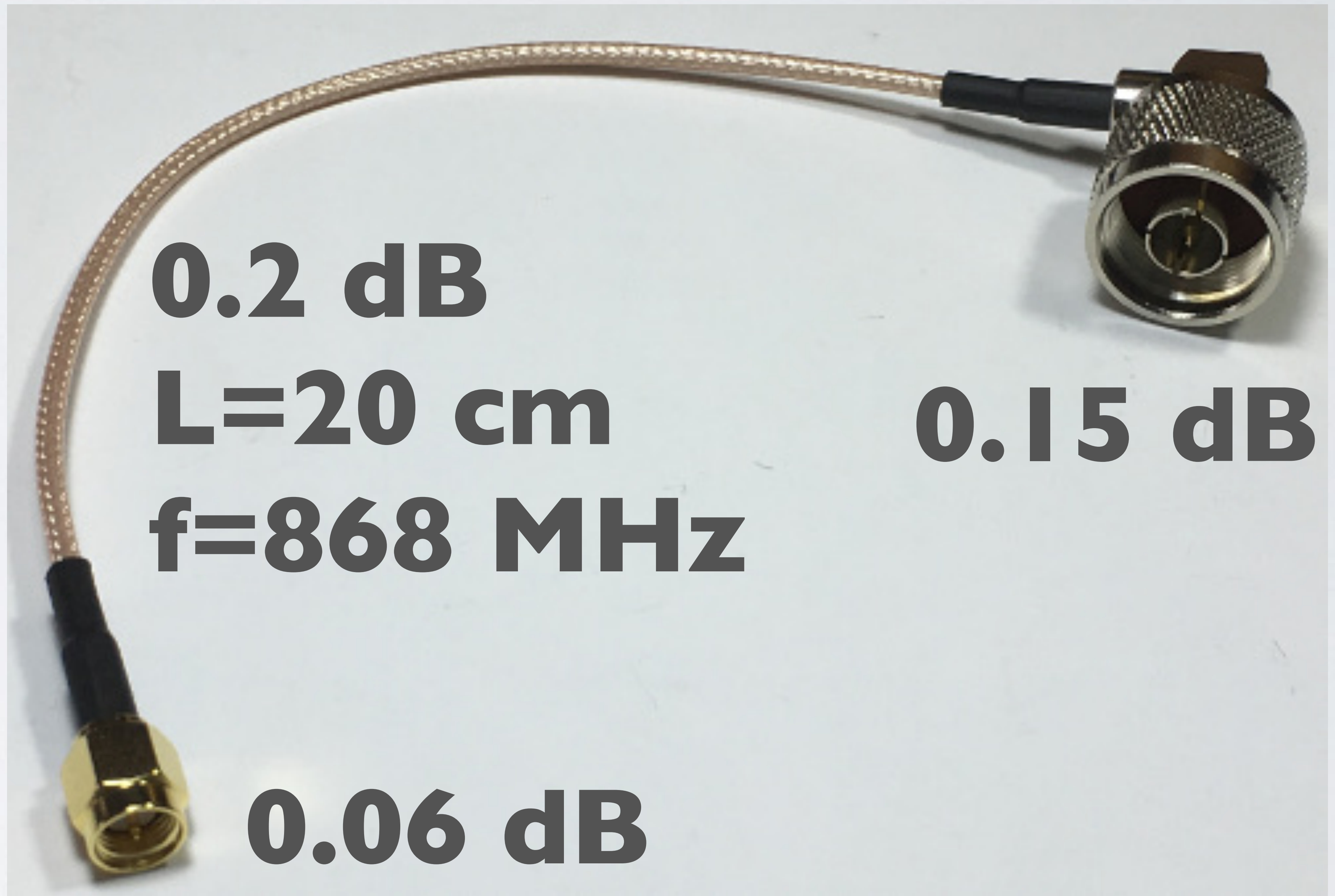
- Cables and connectors have a certain loss. Normally these losses can be found in the manufacturers specifications. I have bought many connectors and cables from Chinese web shops. Unfortunately these web shops do not provide loss figures and I do not have the equipment to actually measure these losses. As an alternative I have searched the web for comparable connectors and use their loss figures. Or better yet buy from reputable manufacturers.

- In the following slides you will see several connectors with their losses. I am using these loss figures as **rough estimates**.
  Please do your own research! Use these estimates at your own risk!

- Insertion loss is the loss of signal power resulting from the insertion of a device in a transmission line and is usually expressed in decibels.

LOSS ESTIMATES

RF coaxial cable RG316, length 20 cm with type N male plug right angle to SMA male connector.

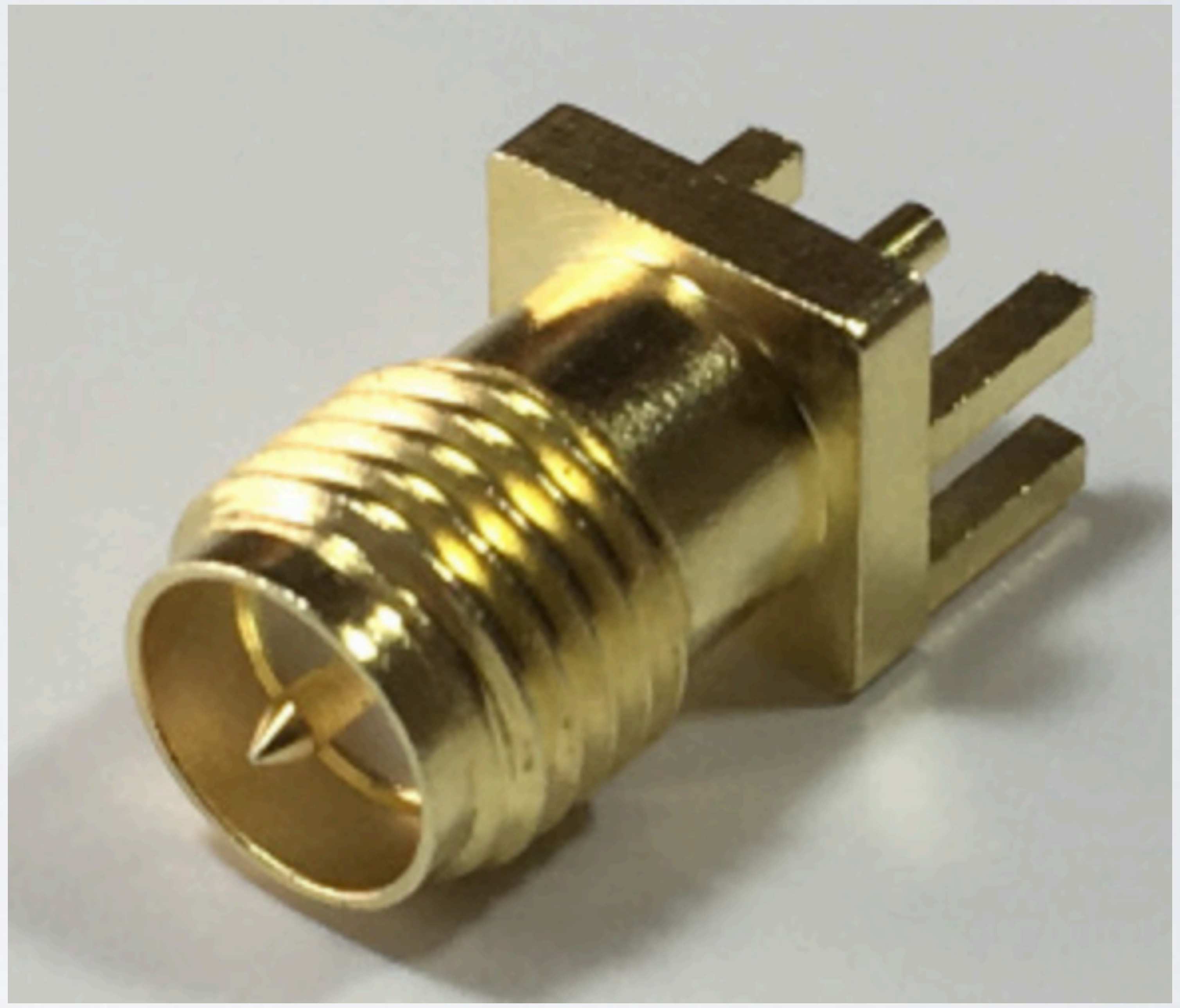


0.2 dB

Type N female chassis mount 4-hole connector

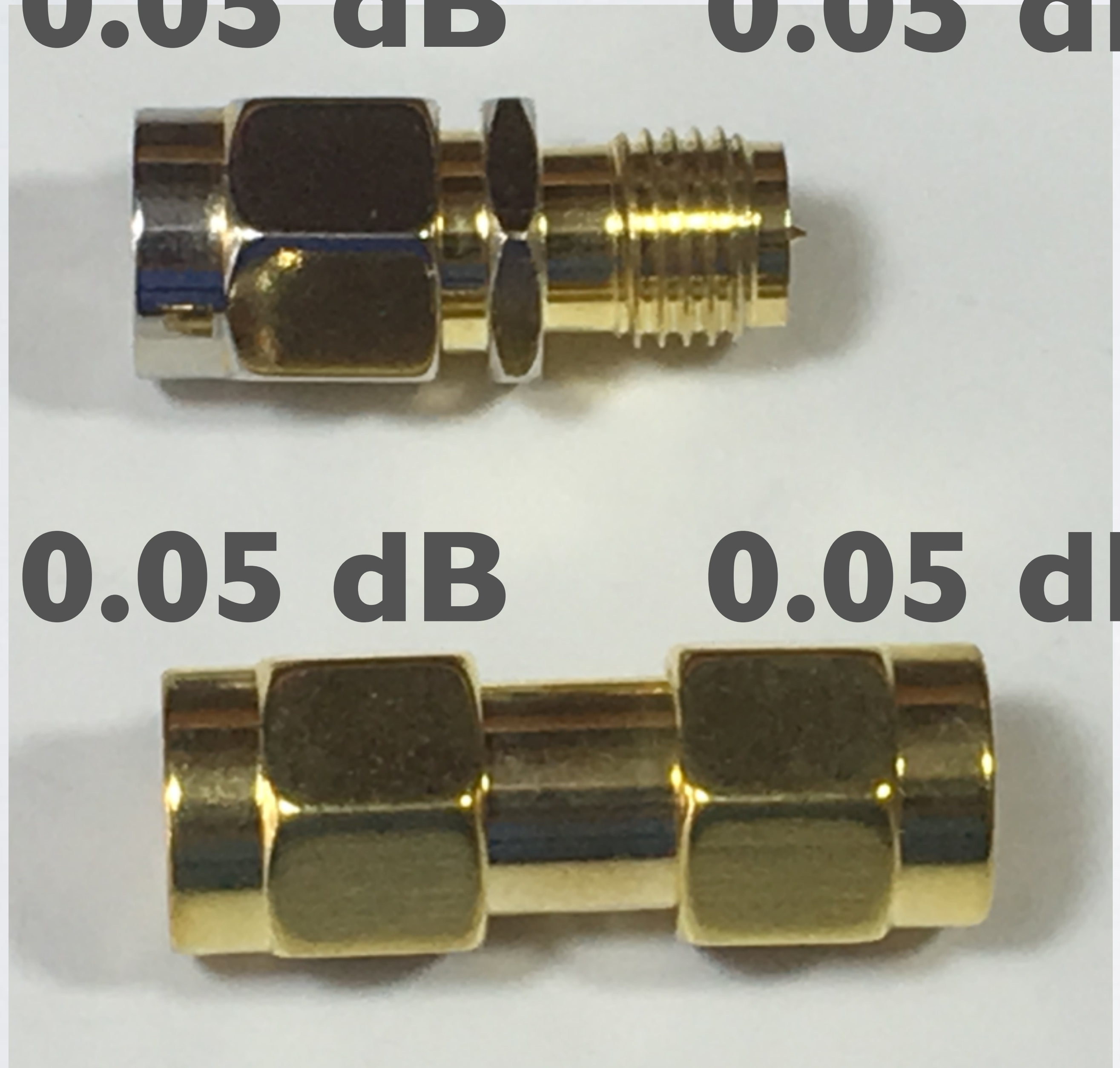
LOSS ESTIMATES

SMA edge mount connector.



0.14 dB

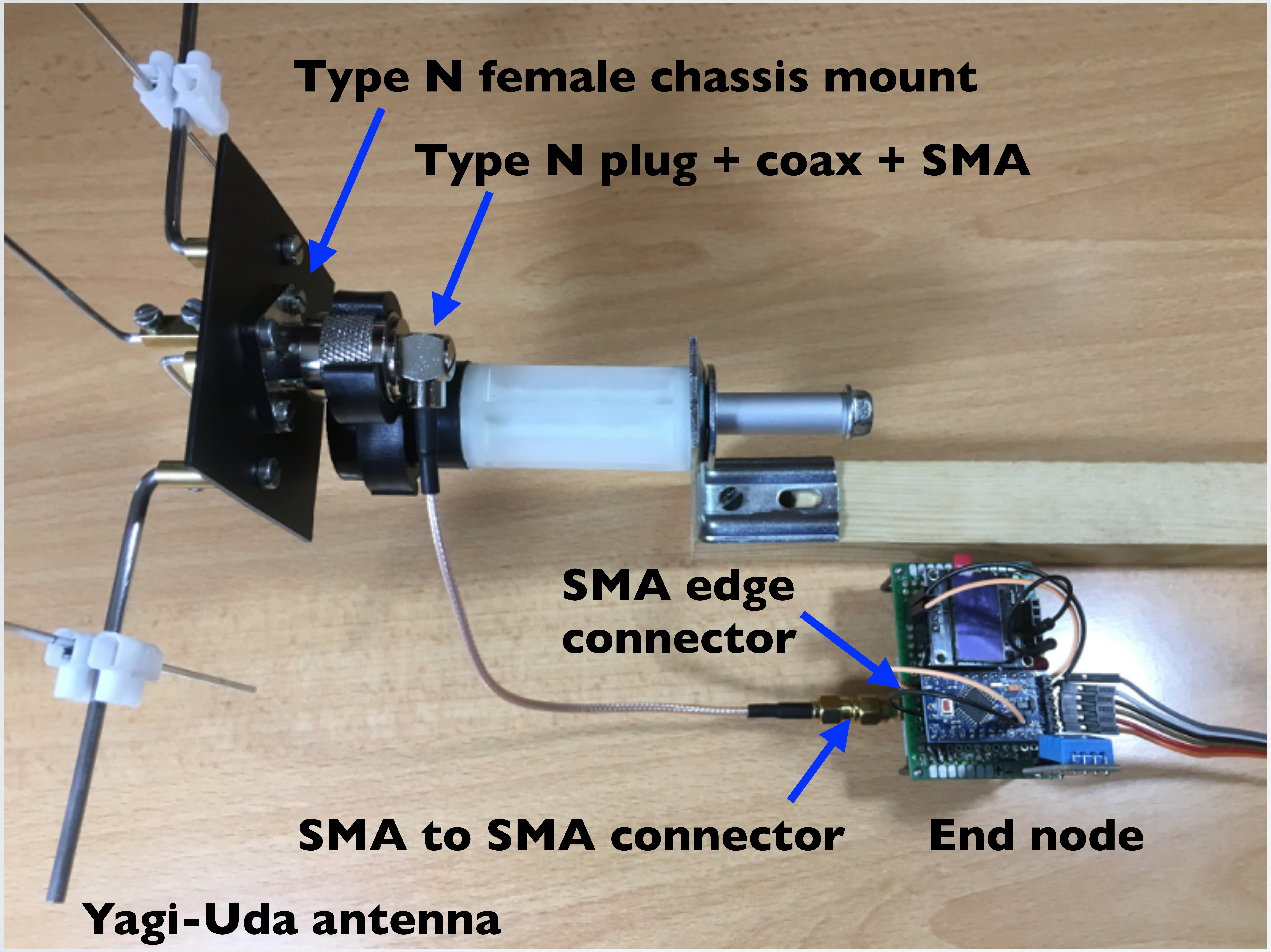
0.05 dB 0.05 dB



0.05 dB 0.05 dB

SMA to SMA connector

CALCULATE LOSS EXAMPLE



Type N female chassis mount:
0.2 dB

Type N plug + coax + SMA:
0.15 + 0.2 + 0.06 = 0.41 dB

SMA to SMA connector:
0.05 + 0.05 = 0.1 dB

SMA edge connector:
0.14 dB

Total loss:
0.2 + 0.41 + 0.1 + 0.14 =
0.85 dB

UNITY GAIN

- The antenna gain is expressed in dBi or dBd.
  For example: Antenna XYZ has a gain of 0 dBd or 2.15 dBi.

- Sometimes antenna manufacturers are using the term unity gain.
  "Antenna XYZ has unity gain with respect to an isotropic radiator."

- Unity gain is the power radiated by the antenna with the equivalent of 1x whatever the input power is. In other words radiated power equals the input power.

- **Unity gain means a power gain of 1.**
  The antenna manufacturer must specify which reference antenna is used (isotropic or dipole).

UNITY GAIN

- Example A:
  "Antenna ABC has unity gain with respect to a dipole."

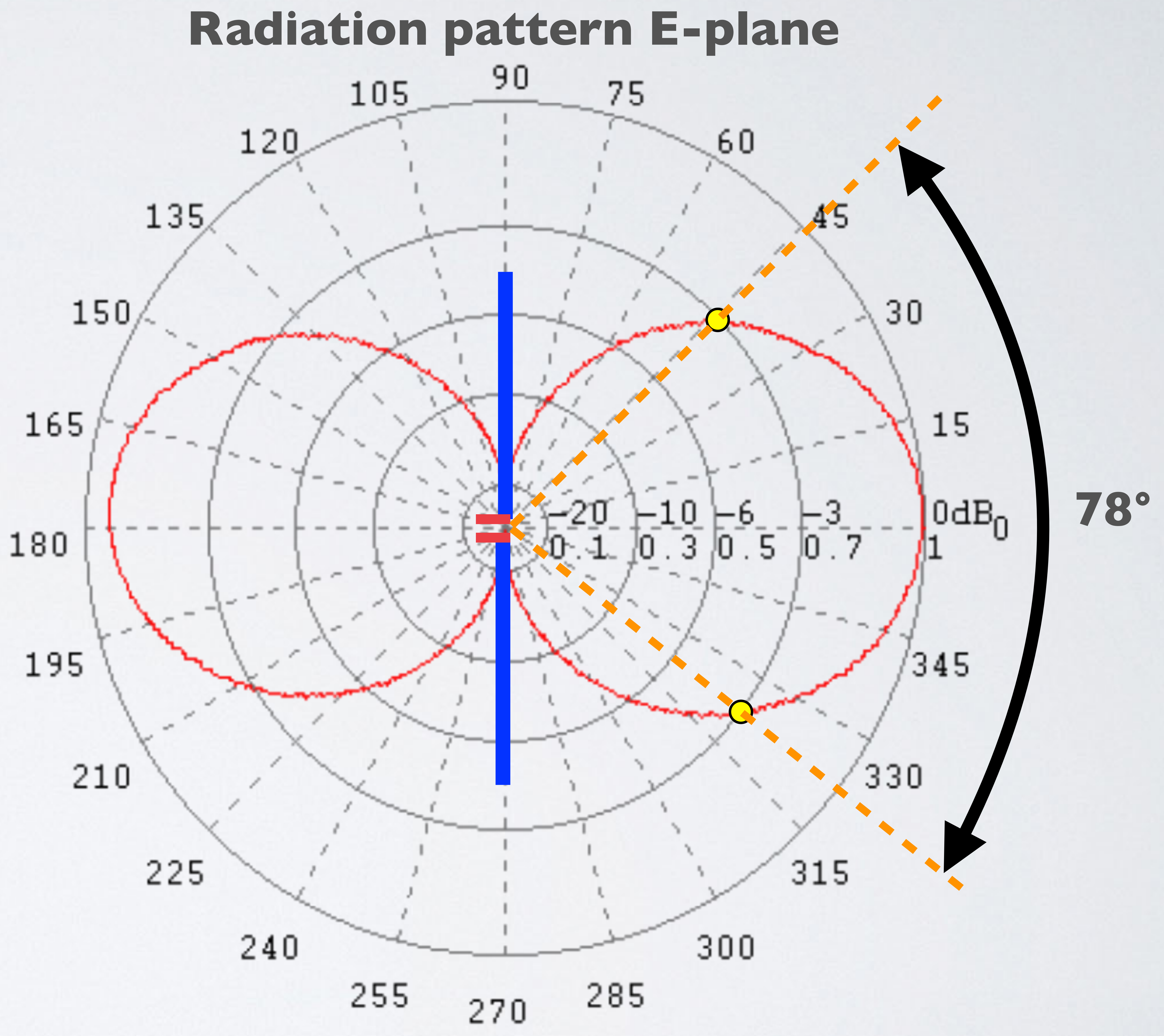
- $G = 10 \times \log10(P_{antenna} / P_{dipole})$
  $G = 10 \times \log10(1) = 0$ dBd = 2.15 dBi
  Thus: unity gain = 0 dBd = 2.15 dBi

- Example B:
  "Antenna XYZ has unity gain with respect to an isotropic radiator."

- $G = 10 \times \log10(P_{antenna} / P_{isotropic})$
  $G = 10 \times \log10(1) = 0$ dBi = -2.15 dBd
  Thus: unity gain = 0 dBi = -2.15 dBd

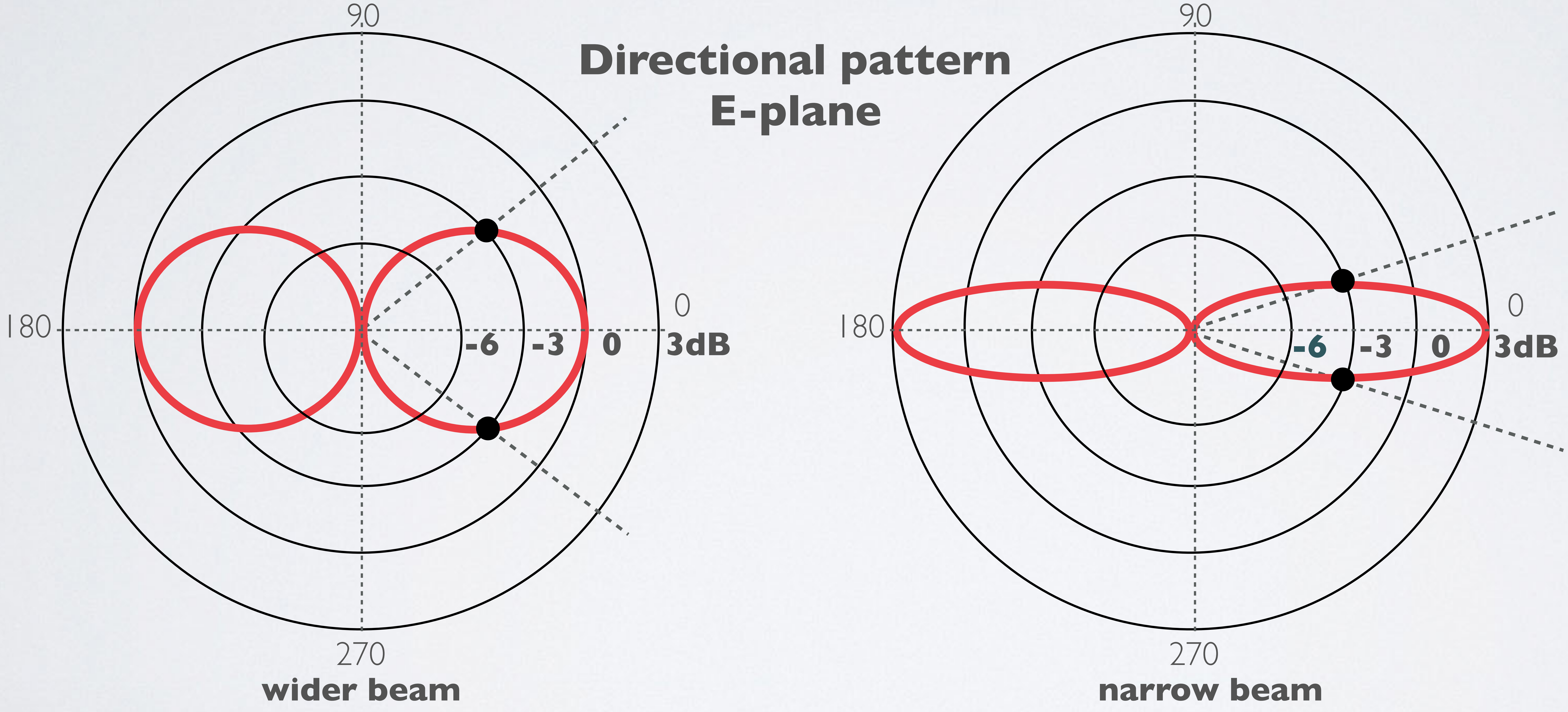
ANTENNA BEAM WIDTH

- The antenna beam width, also known as half power beam width, is the angle between the half power (-3 dB) points of the main lobe.
- The antenna beam width is the area where most of the power is radiated
- The antenna beam width for a reference ½λ dipole antenna is approx. 78°.



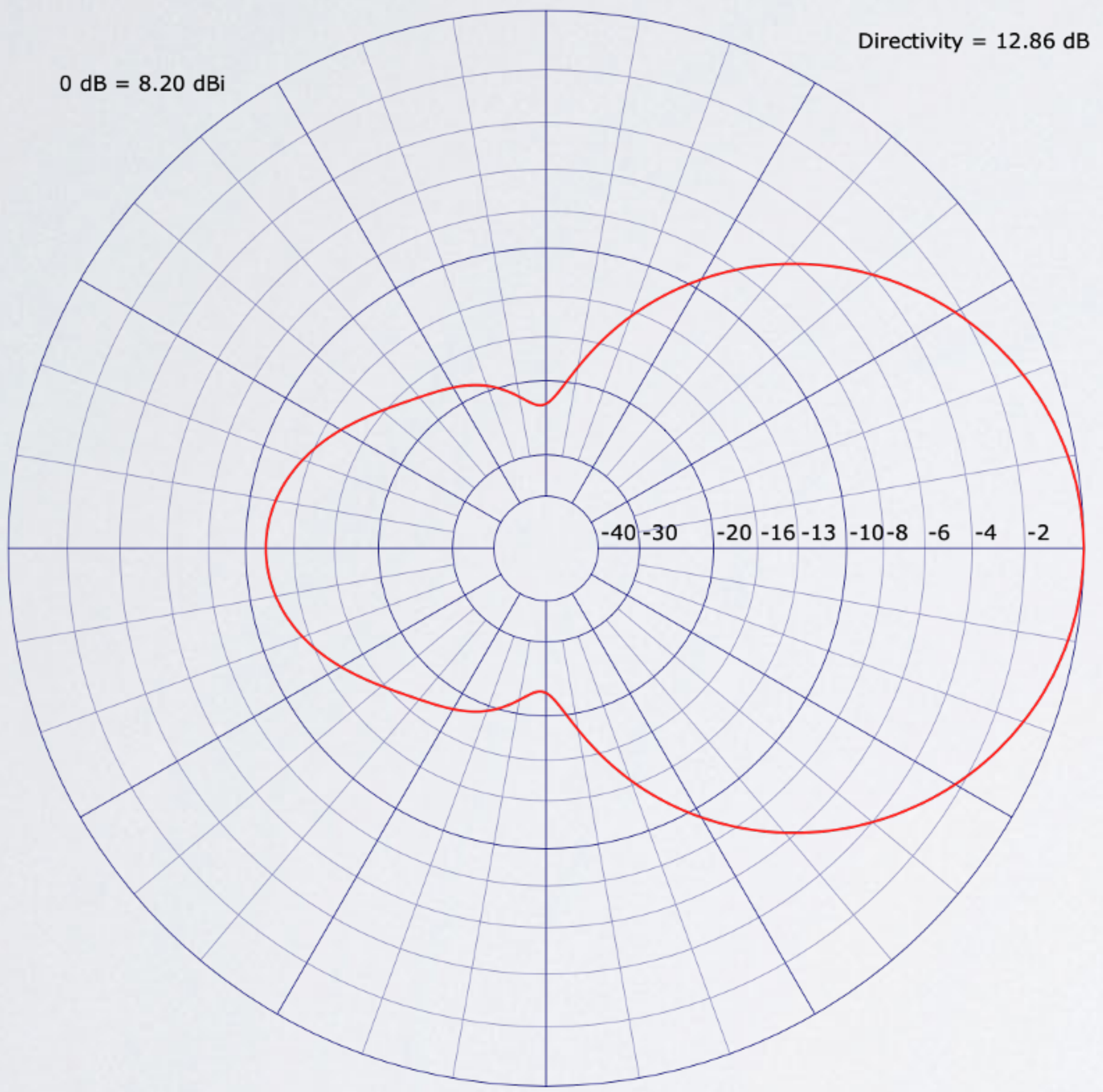
ANTENNA BEAM WIDTH

- An antenna with a narrow beam width tends to have a higher gain.
- An antenna with a wider beam width tends to have a lower gain.

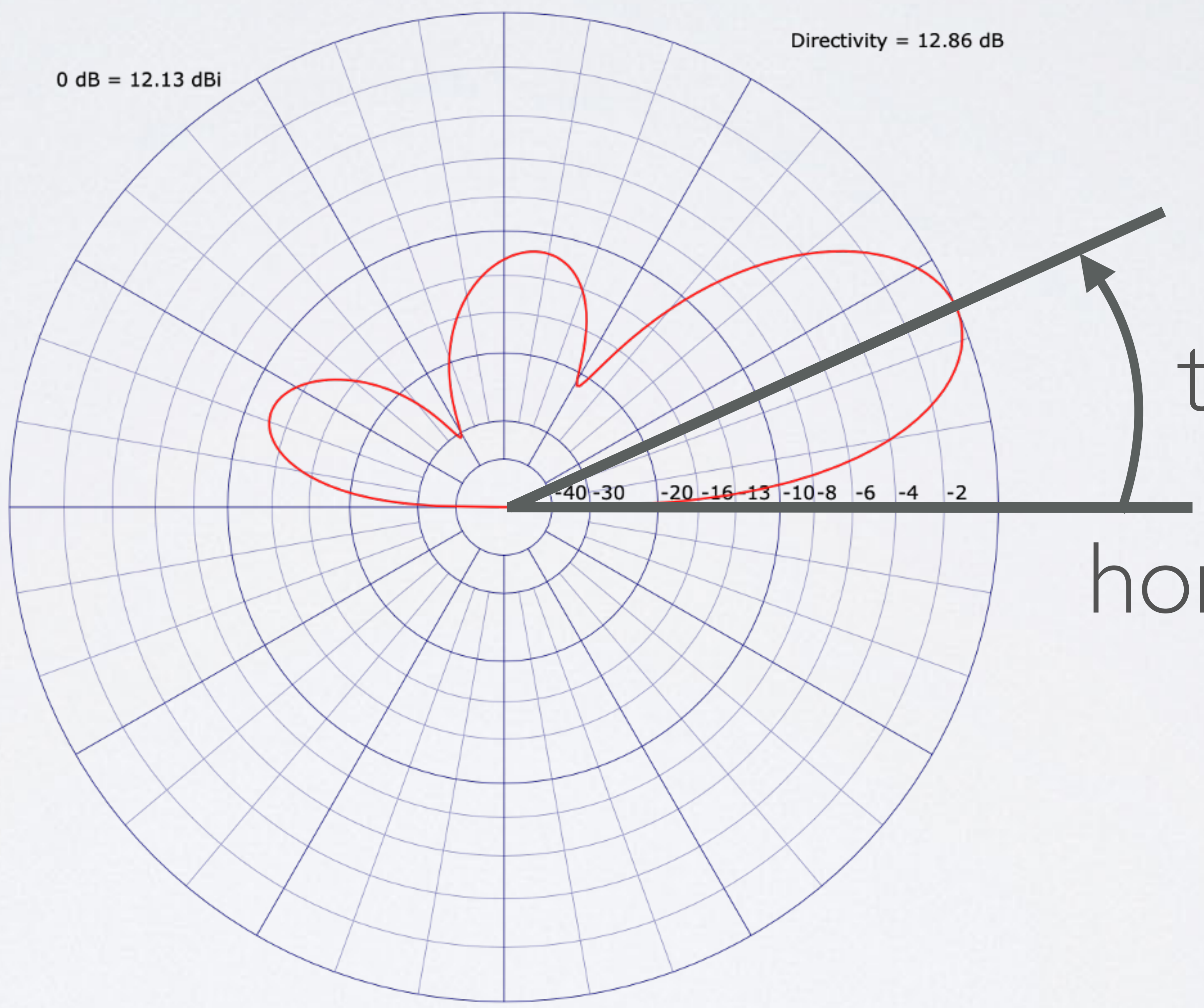


TAKE OFF ANGLE

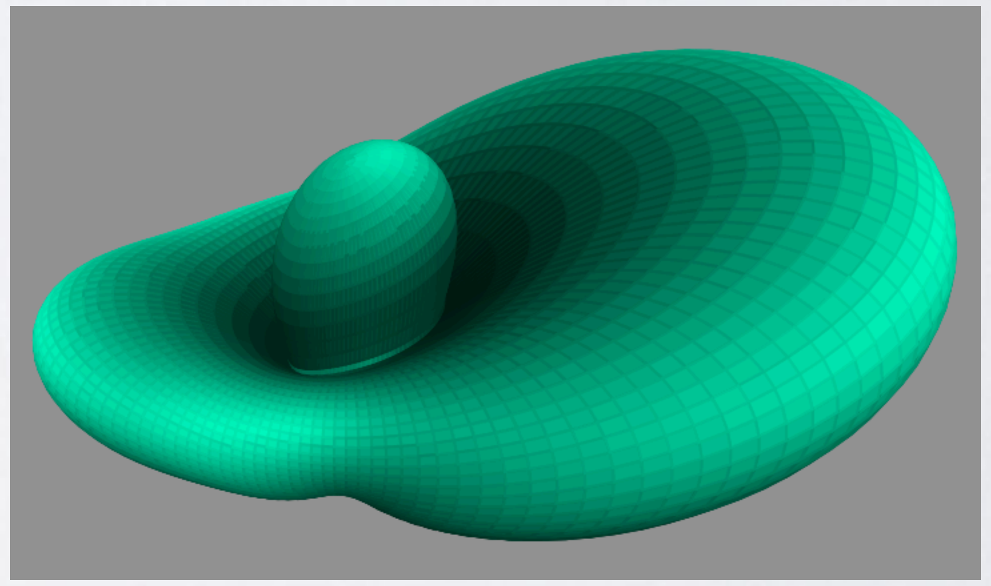
- The take off angle is the angle where the gain of the elevation plot peaks.



Azimuth plot

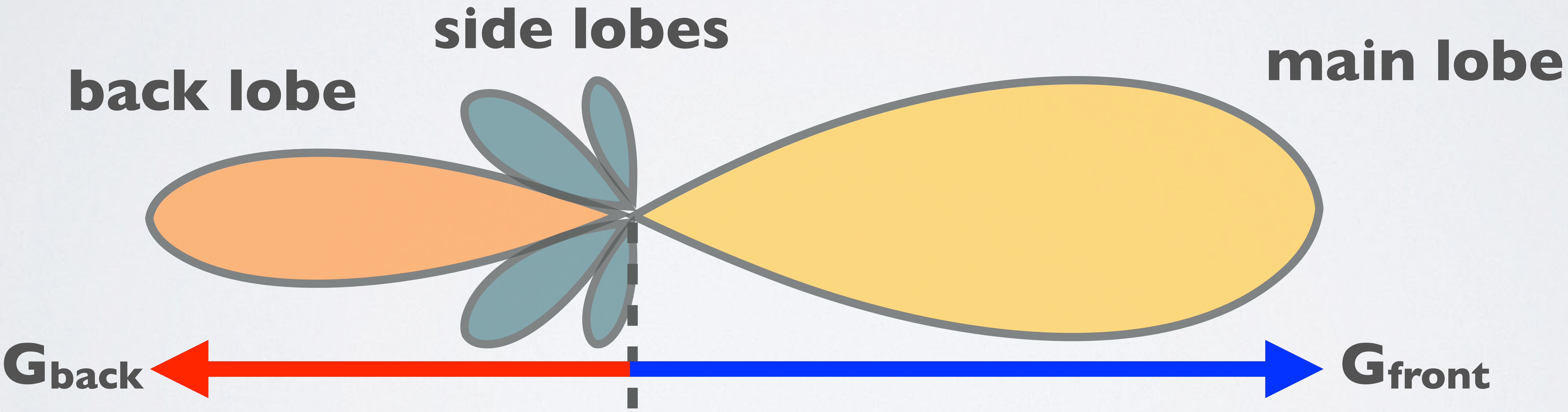


Elevation plot



FRONT-TO-BACK RATIO

- The objective of a directional antenna is to transmit most of its radiated power in the forward direction and minimise its radiated power in the rearward direction.
- The Front-to-Back Ratio (FBR) is expressed in dB (e.g. dBi or dBd) and is the forward gain minus the rearward gain.



FRONT-TO-BACK RATIO

- For example:
  Forward gain = 9 dBi,
  Rearward gain = -4 dBi
  Front-to-back = 9 - -4 = 13 dBi

- The higher the FBR, the more directionally efficient the antenna is.