P&S: Our Daily Exposure to Electromagnetic Radiation

FS 2025: Antenna Basics and Measurements

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Questions for today

P&S FS 2025: Timeline

Date	Topic	
27. Feb 2025	Lecture: PPS Organization, Introduction, basics and definitions	
06. Mar 2025	Lecture: Measuring EM-radiation: Fields, Antennas & Anechoic Chamber	
13. Mar 2025	Lecture: Measuring EM-radiation: The Spectrum Analyzer	
20. Mar 2025	Lecture: Measuring EM-radiation: Personal exposure assessment using exposimeters Project: Group assignment and choice of the topic	
27. Mar 2025	Project: Concretization and writing the research plan Discussion in individual group meetings (outside of usual P&S time slot)	
03. Apr 2025	*Individual work*	***Marco not in Zurich from 1. - 6. April***
10. Apr 2025	*Individual work, group meetings as necessary*	
17. Apr 2025	*Individual work, group meetings as necessary*	
24. Apr 2025	*Individual work, group meetings as necessary*	***Easter Break – no lecture***
01. May 2025	*Individual work, group meetings as necessary*	***Tag der Arbeit – no lecture on Thursday***
08. May 2025	*Individual work, group meetings as necessary*	
15. May 2025	*Individual work, group meetings as necessary*	
22. May 2025	**P&S Presentations**	
29. May 2025	***Auffahrt – no lecture***	
06. Jun 2025	**Written report deadline** *(1 week after end of semester)*	

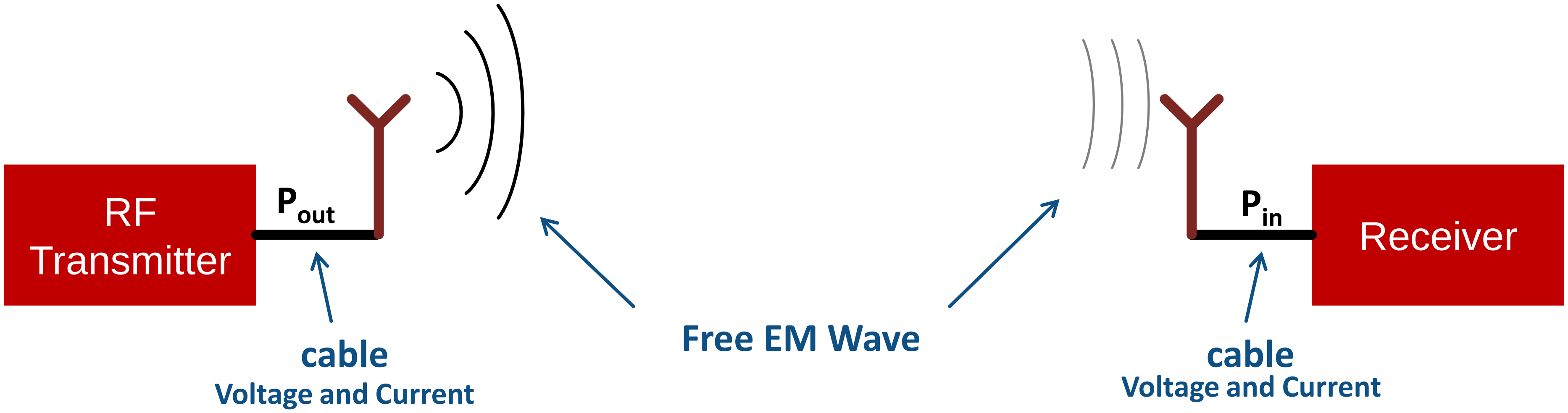
Today

- Antennas
- Antenna Gain, radiation patten, dBi
- Friis equation
- Anechoic chamber

What is an Antenna and what are its tasks?

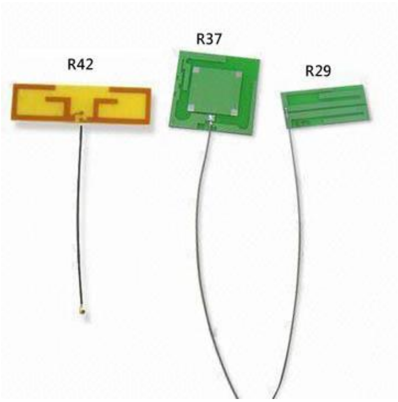
Antennas

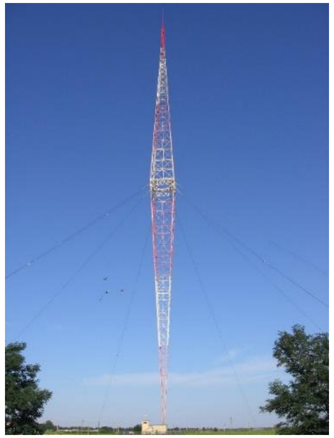
- Transform guided RF power (e.g. voltage and currents in a coax cable) into electromagnetic waves
- Collect and transform electromagnetic power into guided RF power
- Can be designed to have a "preferred direction" of transmission and reception (symmetric)

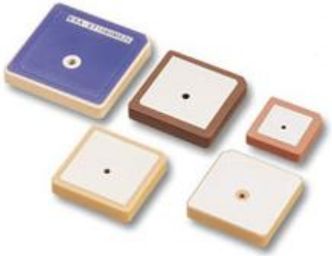


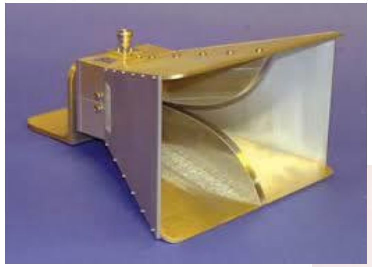
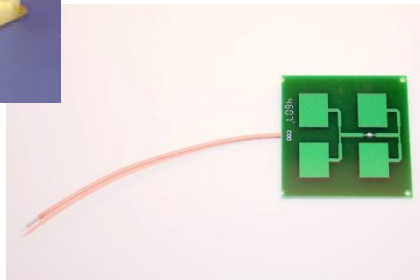
Antennas come in various types an shapes

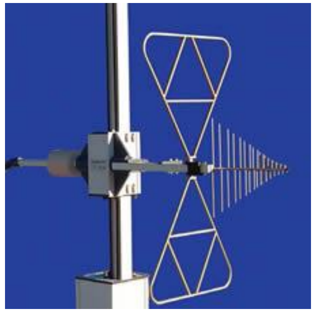






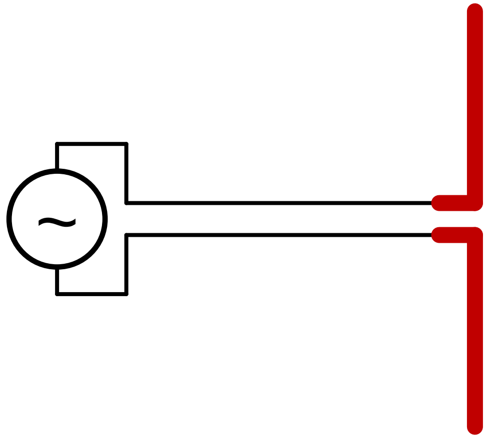



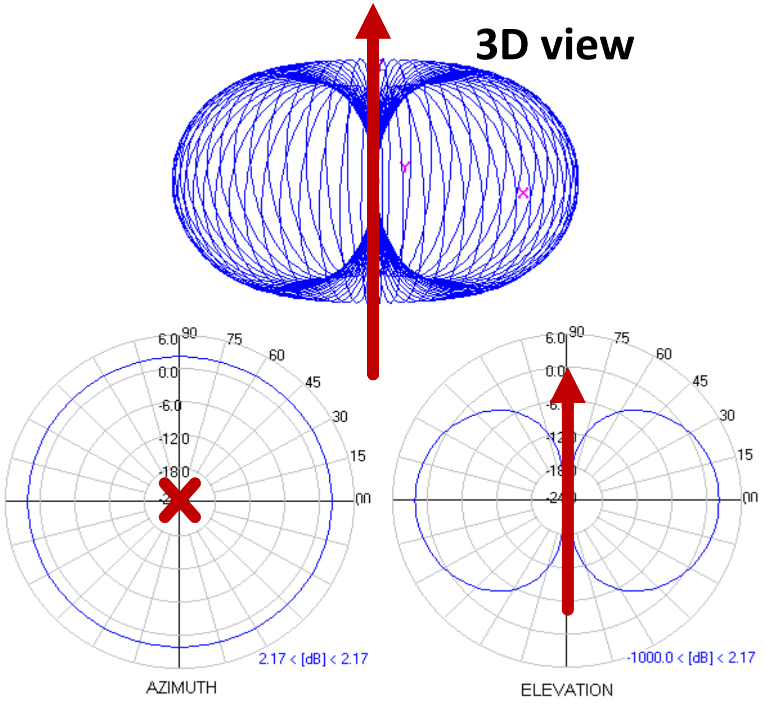
Radiation Pattern

Describes the directional properties of an antenna

- TX: Relative emitted power density for a given input power when looking at the antenna from different angles
- RX: Relative sensitivity to EM radiation coming in from different angles
- Does not depend on direction of energy flow (transmit and receive patterns are identical!)

Example: Half-Wave Dipole antenna



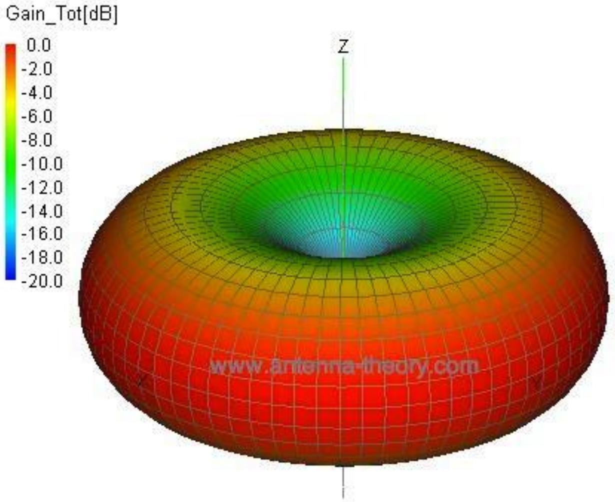


Top view **Side view**

Radiation Pattern

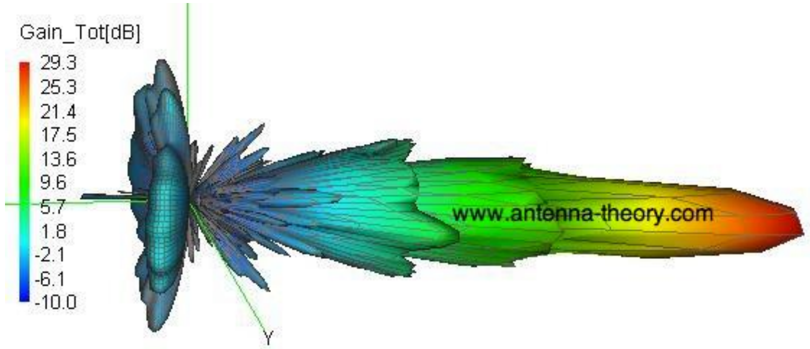
Dipole antenna: omnidirectional



Parabolic dish antenna: highly directive

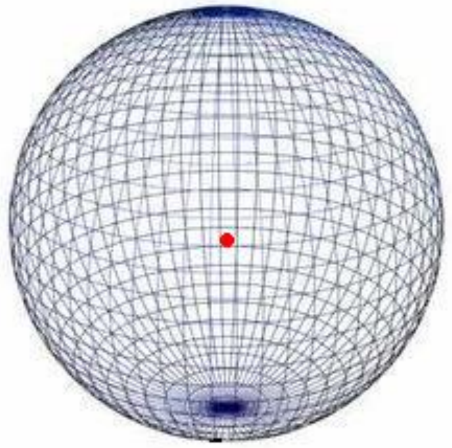




Antenna directivity, Gain, dBi

Reference antenna: isotropic radiator

- Does not exist in reality (not realizable)
- RF power fed to antenna is completely and **evenly radiated in all directions**
- Radiated power density of isotropic radiator: $S = \frac{P_t}{4\pi d^2}$ [W/m²]
- Point source
- Has a **gain** of **1.0** (linear) or **0 dBi** (per definition)
- dBi = dB relative to isotropic radiator



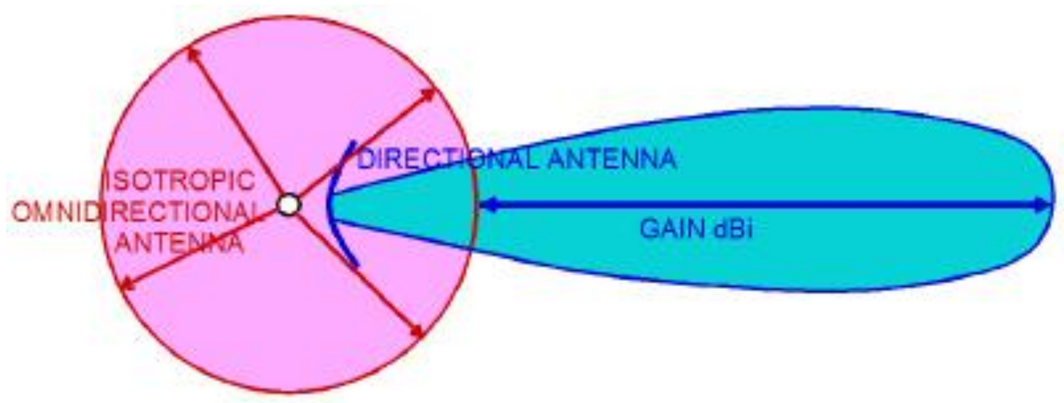
0 dBi

Antenna directivity, Gain, dBi

$$\text{Antenna Directivity} = \frac{max\ radiation\ intensity}{average\ radiation\ intensity}$$

$$\text{Antenna Gain} = \frac{max\ radiation\ intensity}{equivalent\ isotropic\ radiation\ intensity}$$

Gain includes resistive losses:
Values < 1.0 / 0 dBi are possible



dBi = Gain in dB relative to isotropic radiator

Antenna directivity, Gain, dBi

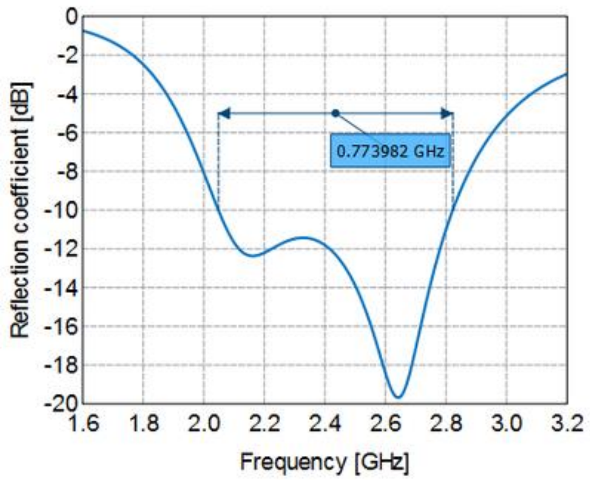
$$\text{Antenna Directivity} = \frac{max\ radiation\ intensity}{average\ radiation\ intensity}$$

$$\text{Antenna Gain} = \frac{max\ radiation\ intensity}{equivalent\ isotropic\ radiation\ intensity}$$

Examples:

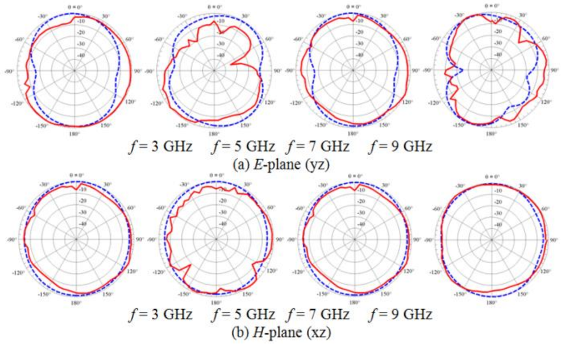
Isotropic radiator:	**0 dBi (reference)**
Dipole antenna	**2.15 dBi**
Typical TV antenna	**10-15 dBi**
Home satellite dish	**35-40 dBi**
Arecibo radio telescope (R.I.P)	**>70 dBi**

Antenna Bandwidth

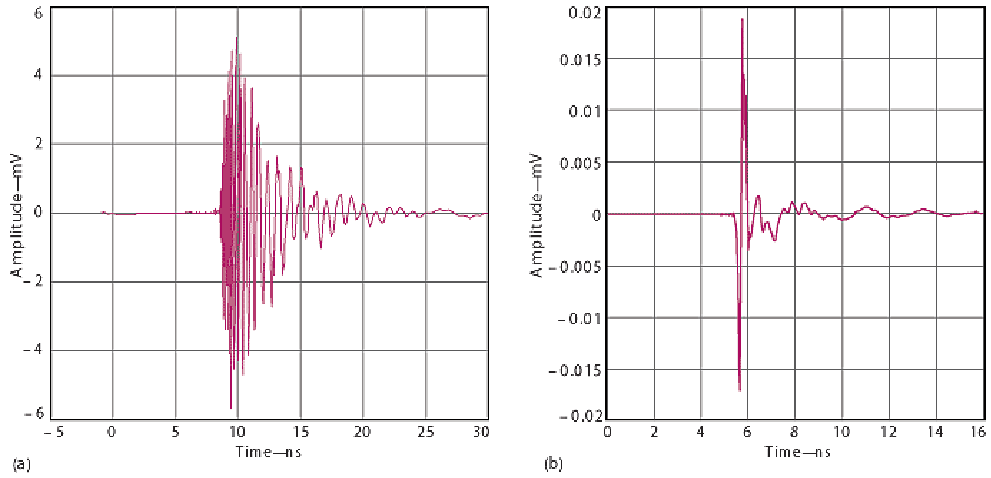


- **Impedance Bandwidth**
  - Matching to 50Ω System (reflection coefficient S11)
  - Typical requirement: **S11 ≤ -10 dB**

- **Radiation Pattern**
  - Frequency dependent Gain
  - Undesired nulls or peaks

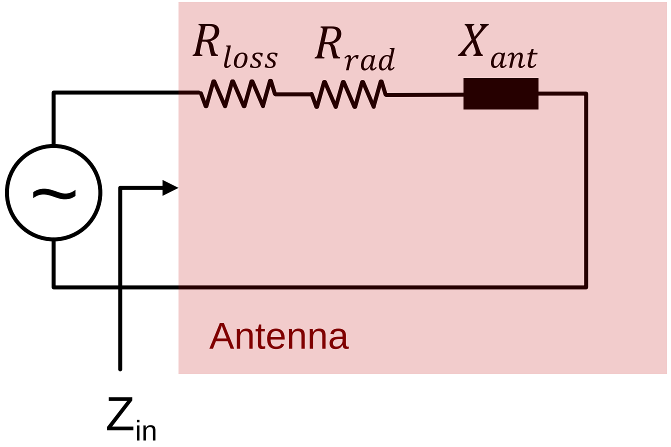


- **Phase response**
  - Pulse fidelity
  - Radar applications



Fundamental Limits: Impedance Bandwidth

- **Equivalent circuit of an antenna:**



R_{loss} Resistive & dielectric losses
R_{rad} Radiation resistance
X_{ant} Input reactance (capacitive or inductive)

Z_{in} Antenna impedance

Loss Resistance (R_{loss}):
Heating losses (undesired)

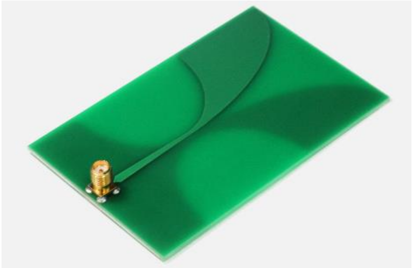
Radiation Resistance (R_{rad}):
Desired "loss" caused by radiation of electromagnetic waves

Lab instrument to determine antenna impedance: Vector network analyzer (VNA)

How to achieve a broadband response

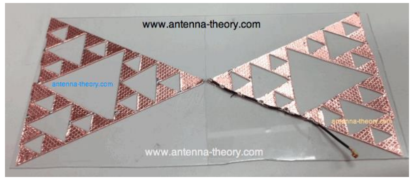
Tapered structures

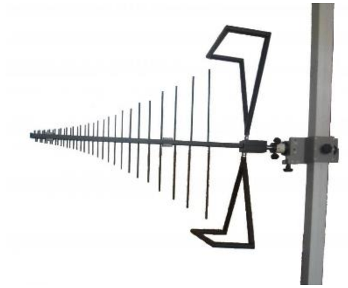
- Smooth impedance transition



Frequency independent structures

- Fractals
- Periodic elements



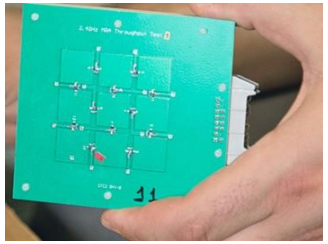


Multiband antenna

- Coupled resonators

Reconfigurable Antenna

- PIN diodes, varactors



Antenna Arrays and Adaptive Antennas

Antenna Arrays

What happens if several antennas are used simultaneously ?

- Superposition of several EM waves
- Constructive (in-phase) and destructive (out of phase) interference
- Direction dependent interference

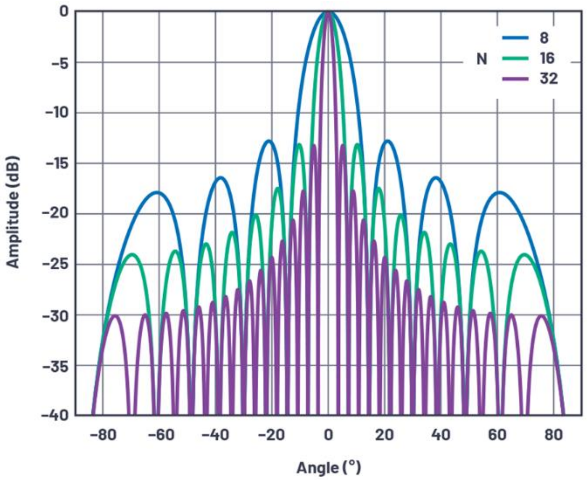
4-element helix antenna array

Antenna Arrays

- Clever arrangement of several (often low gain) antenna elements
- Array achieves higher gain than single element

Array Factor

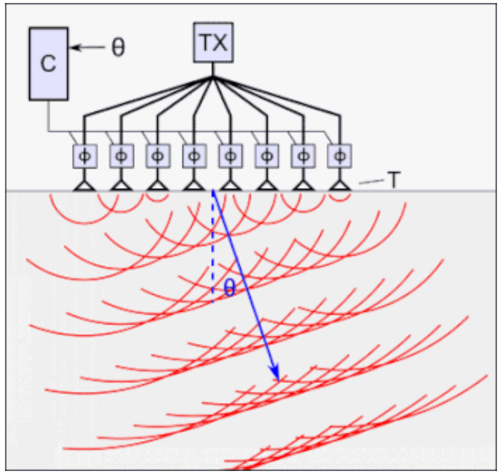
- Array gain relative to single element
- Depends on relative element spacing (in λ) and phase



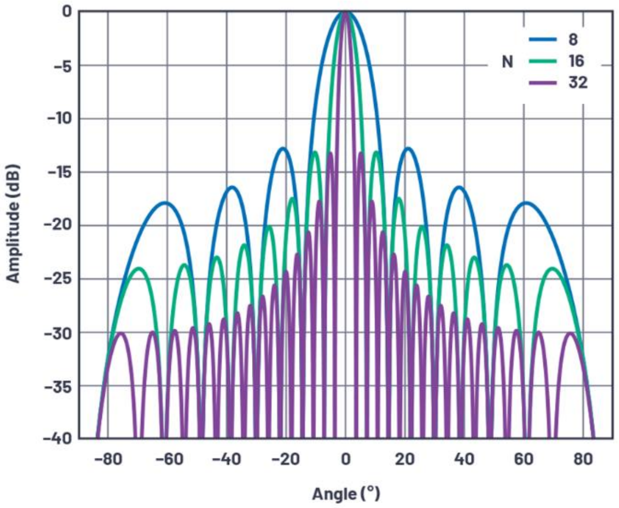
Array factor for λ/2 spaced antenna elements
(N = 8, 16 and 32)

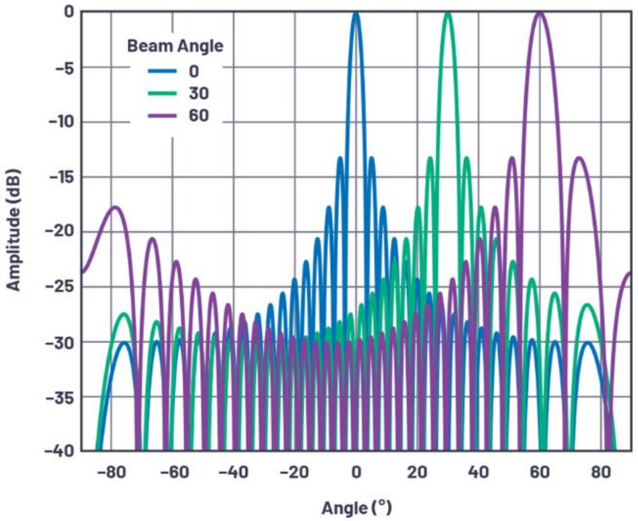
Phased Arrays & Beam Steering

Phased Array
- Antenna array allowing individual control of antenna elements
- Variable phase and amplitude for every single antenna
- Controllable electronically

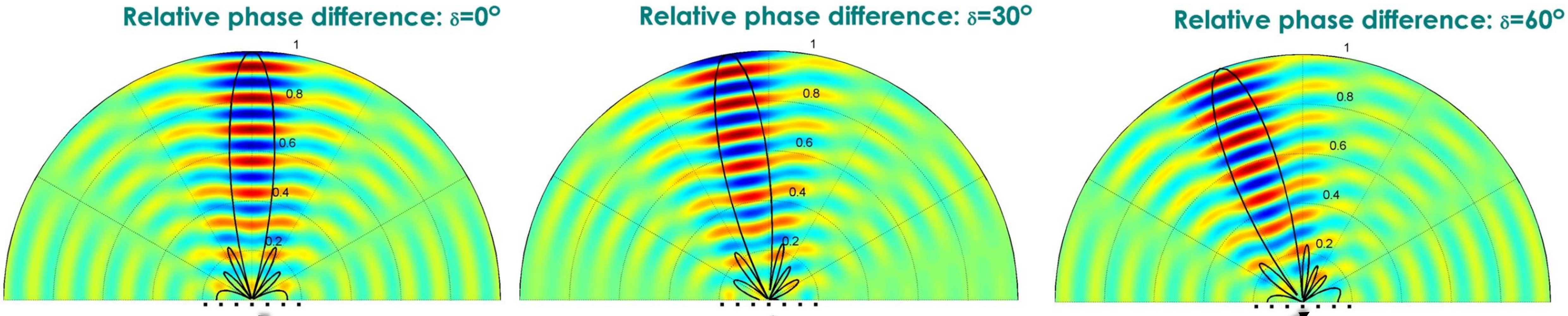


Beam Steering
- Time delay between adjacent antenna elements
  allow to (electronically) steer the direction of the main beam
- Scanning without moving
  mechanical parts





Phased Arrays & Beam Steering



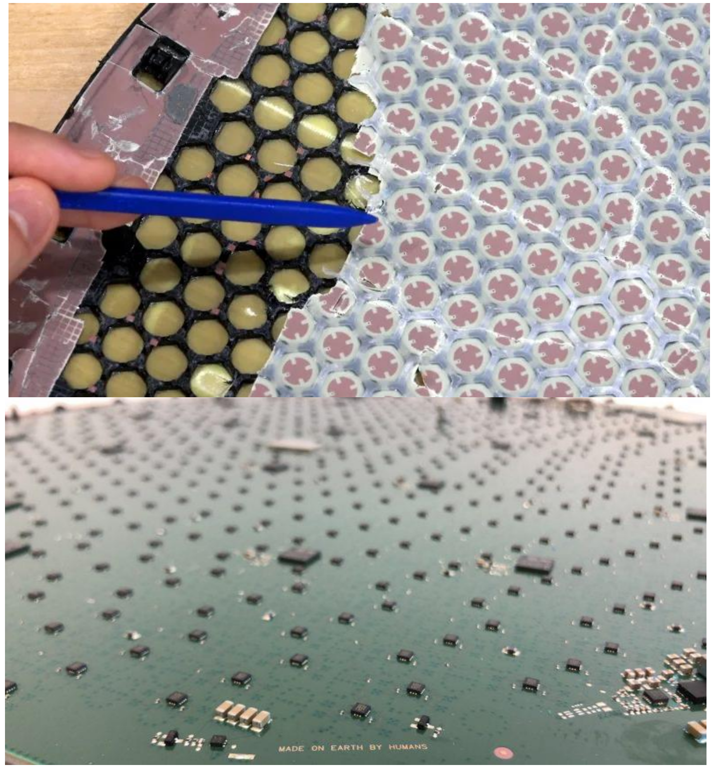
7 antenna elements; separation = λ/2

Phased Arrays & Beam Steering

Applications

- Radar
- 5G
- Radio astronomy
- Satellite communication (Starlink)

MiG-35 nose radar



Inside a Starlink antenna (1280 elements)

PAWS (US missile warning system from 1980):
2677 dipole elements

VLA (Very Large Array) radio telescope

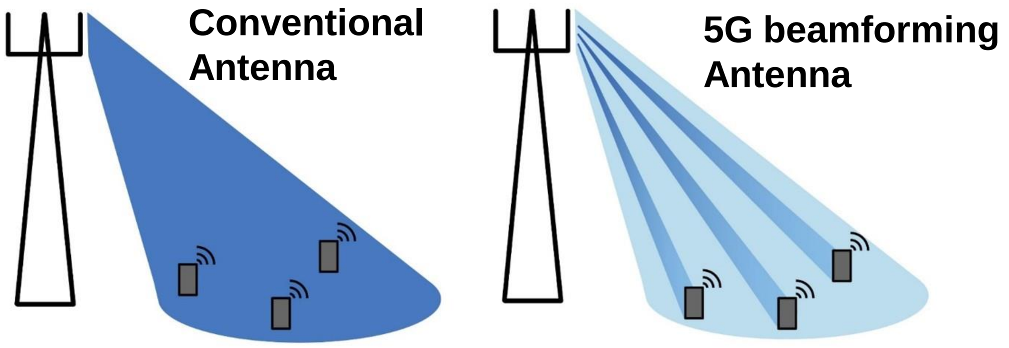
5G Mobile Network Infrastructure

5G introduces antenna arrays as integral part of the mobile standard

- Also known as “adaptive antennas”, “smart antennas”, “beamforming antennas” etc.

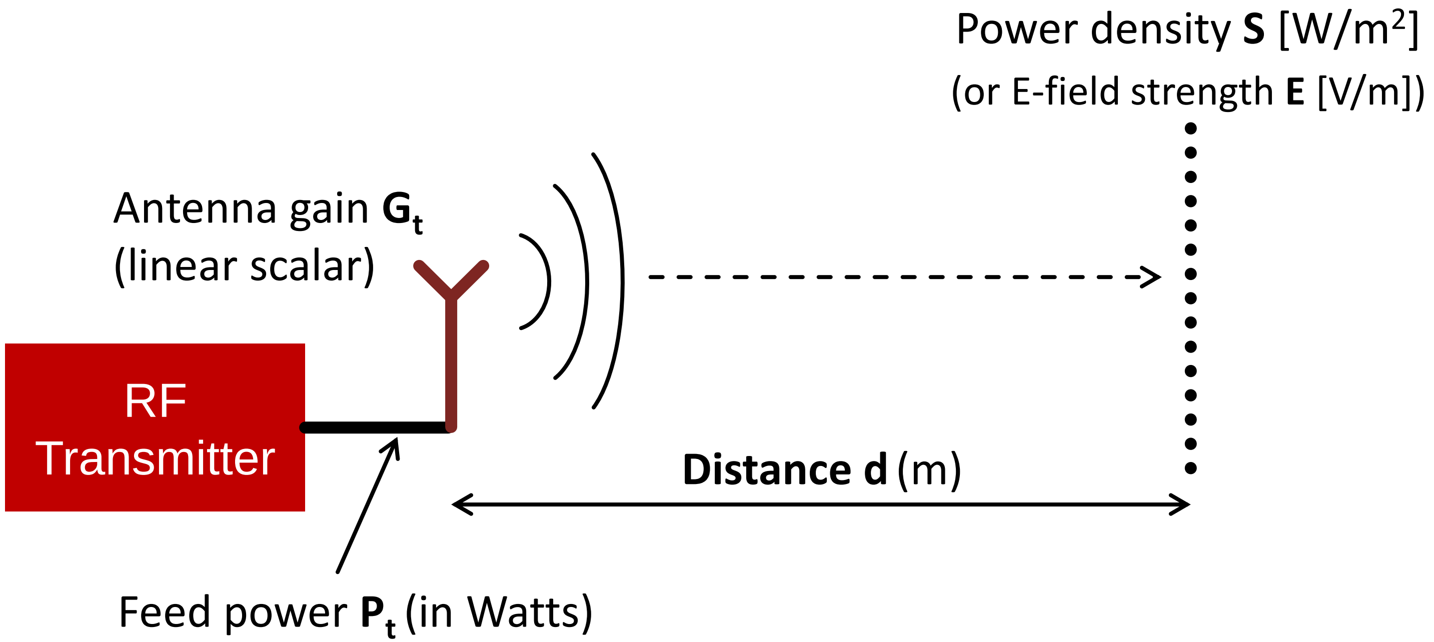
Higher efficiency: Mobile signal is selectively focused towards active user(s)

- Less Interference between users / antennas
- Lower transmission power required
- Broadcast beam (general info) and directional user beams



Important Formulas

Antennas: Power and field strength



$$S = G_t \cdot \left(\frac{P_t}{4\pi d^2}\right) = \frac{E^2}{Z_0}$$

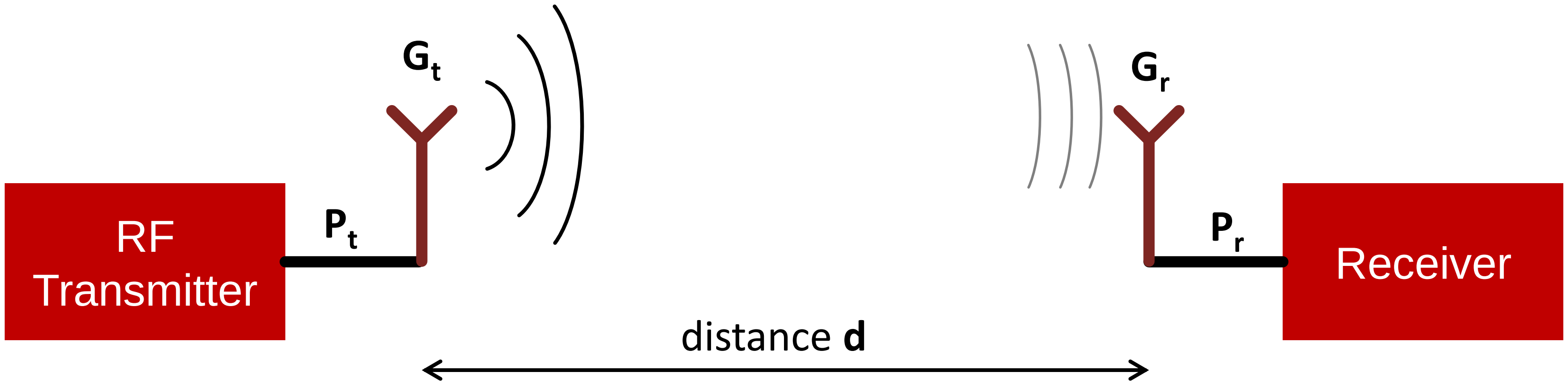
$$Z_0 = 377\ \Omega$$

$$E = \sqrt{\frac{P_t \cdot G_t \cdot Z_0}{4\pi \cdot d^2}}$$

Strength of electric Field component at distance *d* from antenna

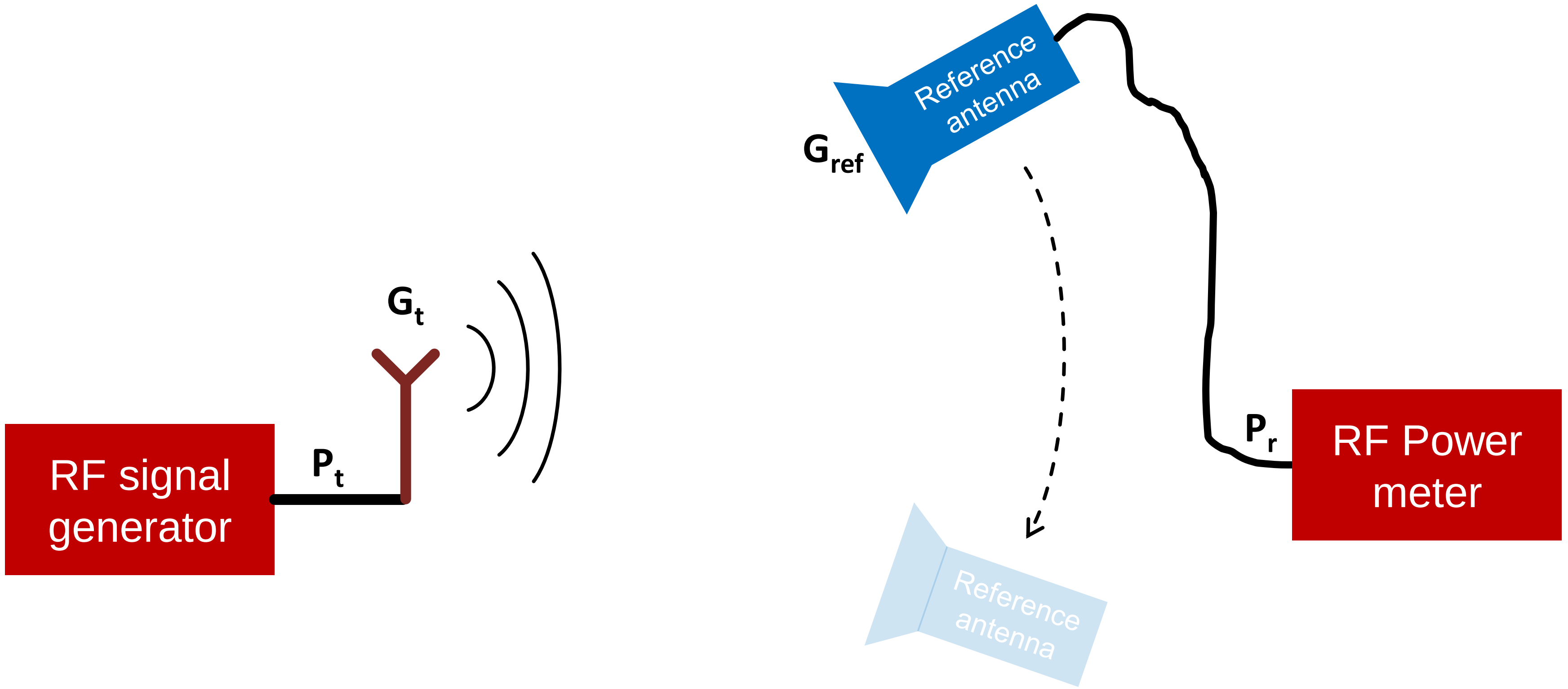
Friis transmission equation

Path Loss: $$\frac{P_r}{P_t} = Gt \cdot Gr \left(\frac{\lambda}{4\pi d}\right)^2$$

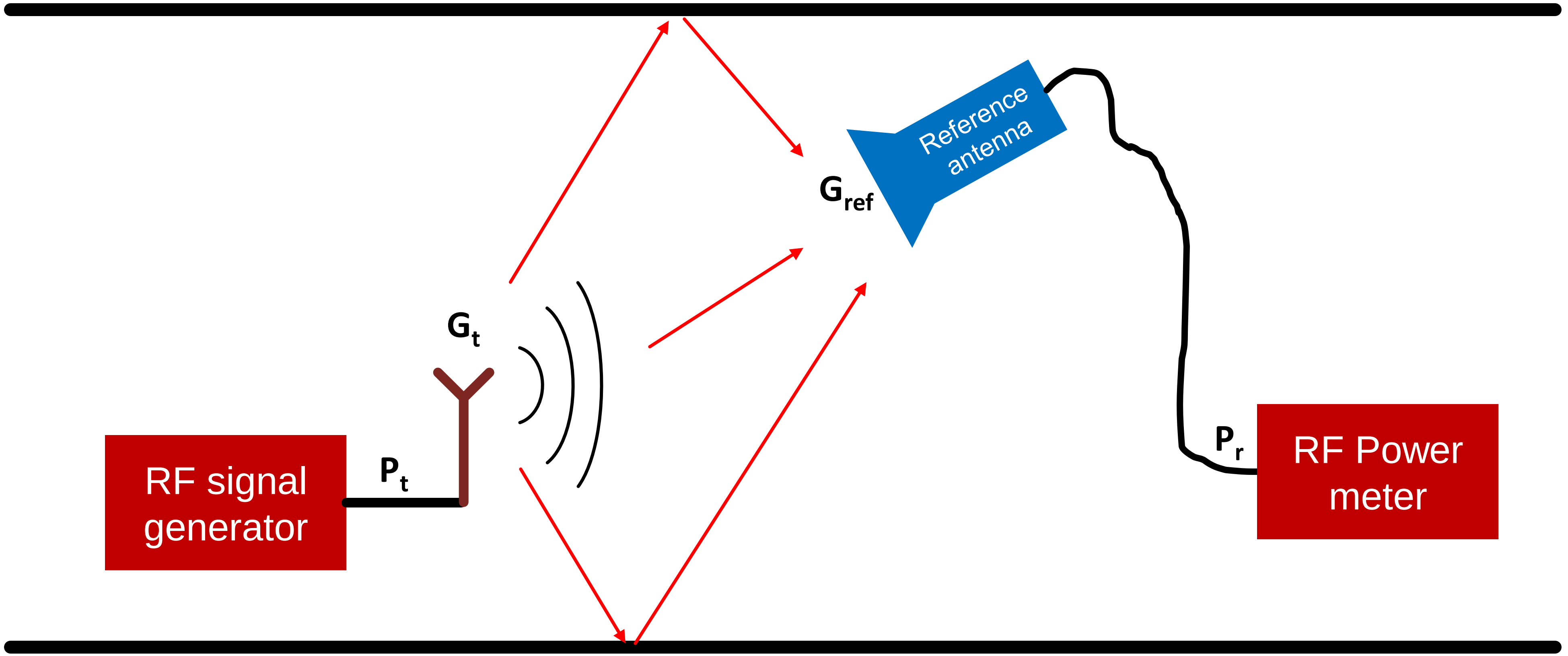


Reciprocity: Both G_t and G_r help to improve received power
Result is identical if the two antennas are swapped

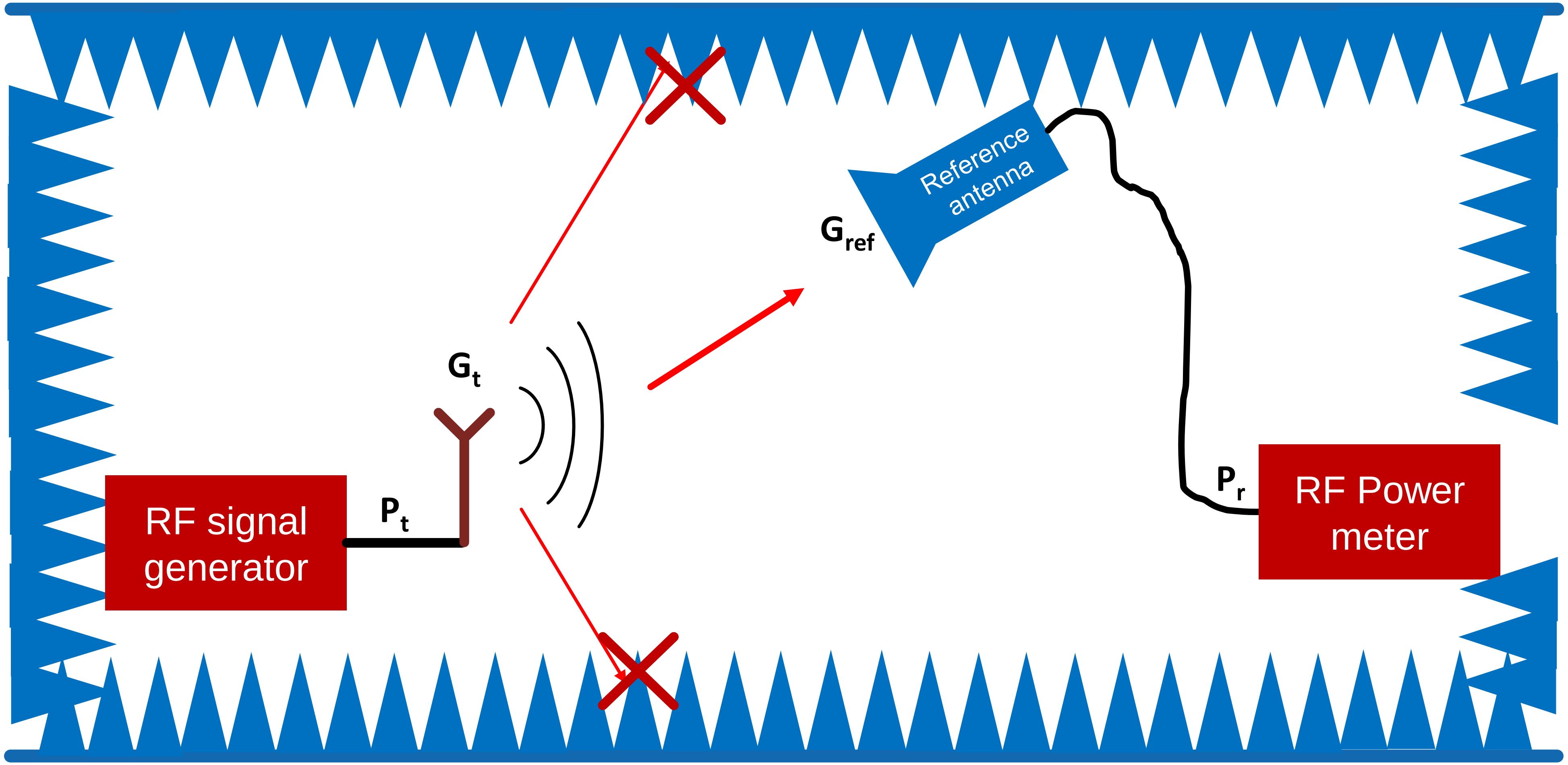
How to measure radiation pattern / directivity



How to measure radiation pattern/directivity

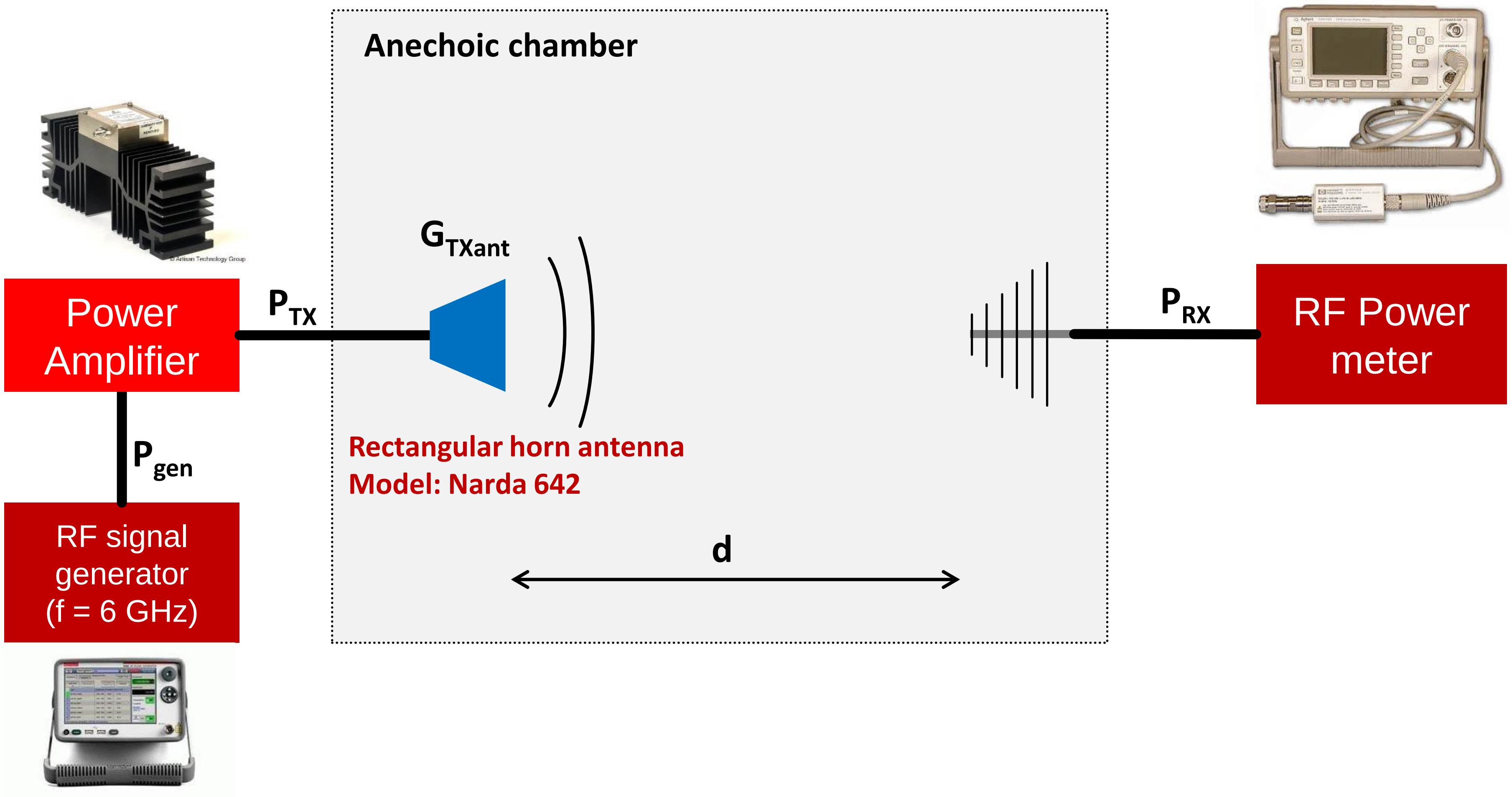


How to measure radiation pattern/directivity

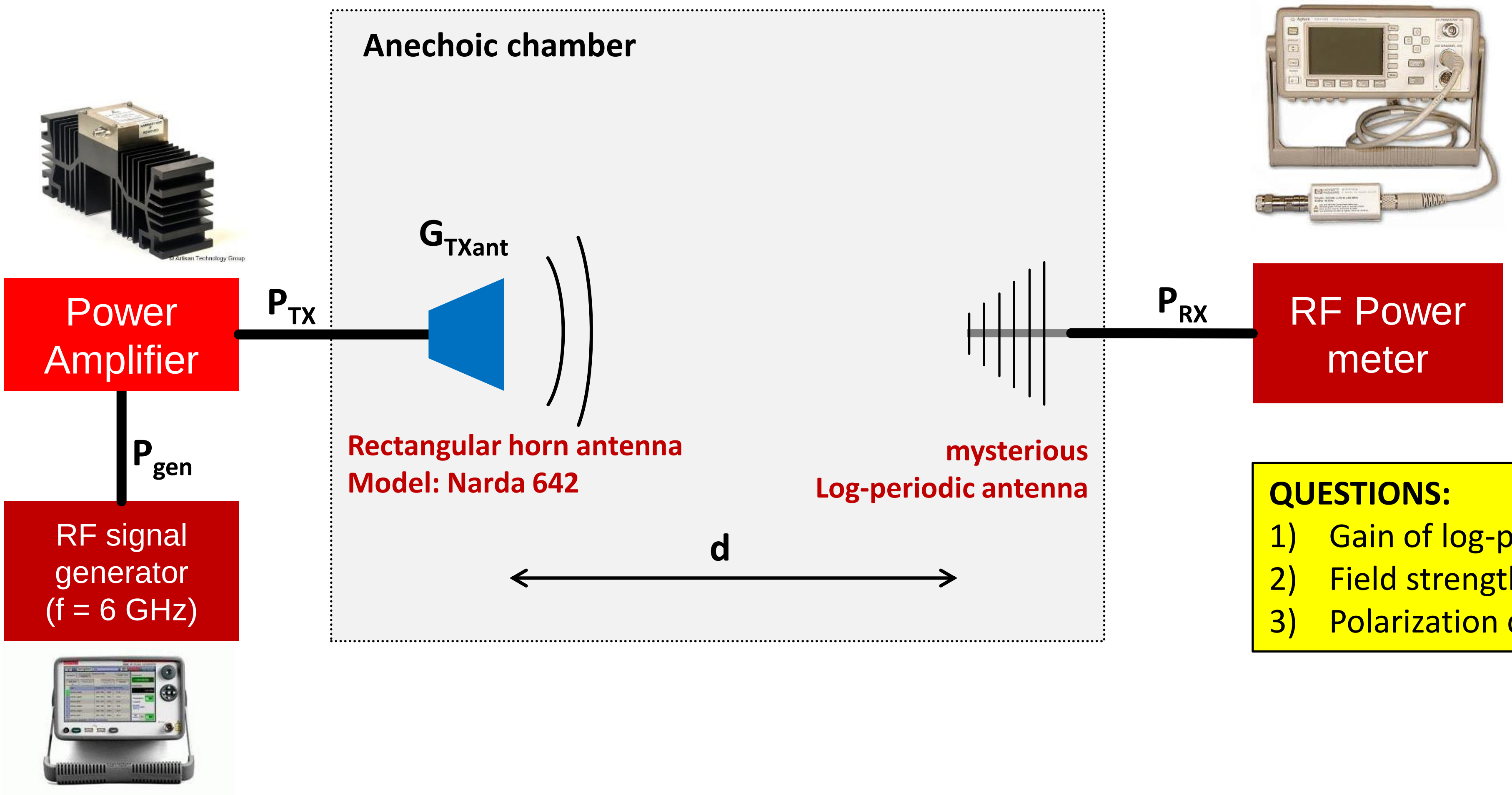


The Anechoic Chamber

Experiment: Measuring the gain of a log-periodic antenna



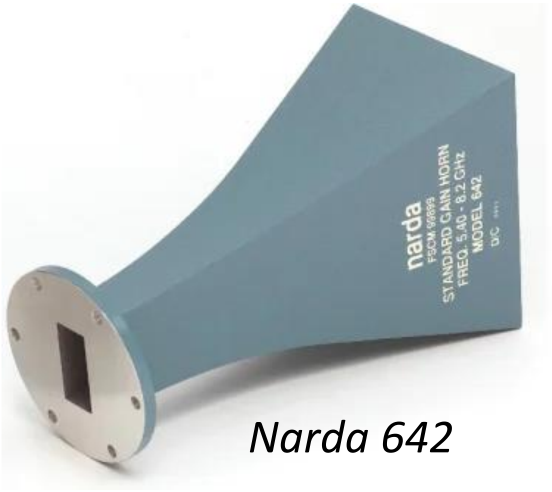
Experiment: Measuring the gain of a log-periodic antenna



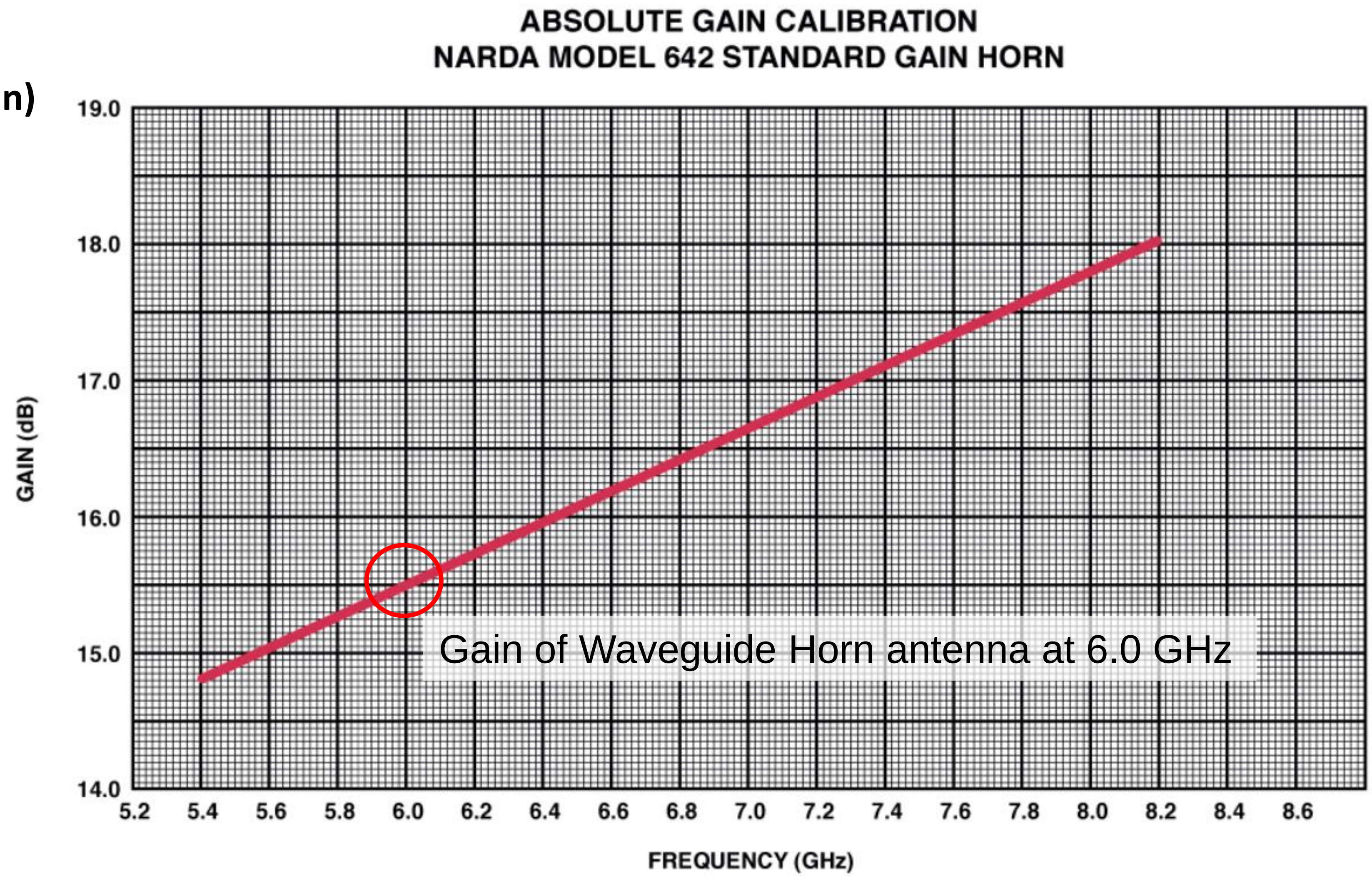
QUESTIONS:
1) Gain of log-periodic antenna at 6 GHz?
2) Field strength at RX location?
3) Polarization dependence?

Experiment: Measuring the gain of a log-periodic antenna

Transmitting antenna (calibrated gain)
- Narda Model 642
- Rectangular waveguide horn
- Gain at 6 GHz: 15.5 dBi



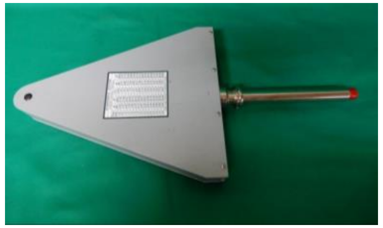
Narda 642



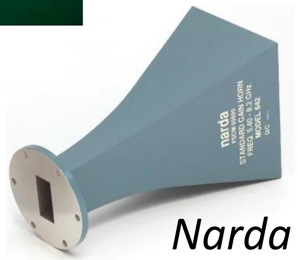
Experiment: Measuring the gain of a log-periodic & horn antennas

Measured Values (06.03.2025, anechoic chamber):

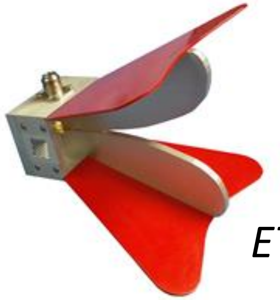
- Transmit Power: +30 dBm (1 Watt)
- Frequency: 6000 MHz
- Gain of Transmitter Antenna (Narda 642): 15.5 dBi
- Gain of Reference Antenna (Narda 642): 15.5 dBi
- Distance: 4.2 m



ESLP 9145



Narda 642



ETS-Lindgren 3117

Measurement Results:

Antenna Model	Type	RX power	RX power (rotated 90°)
ESLP-9145	Log-periodic antenna	-7.4 dBm	-26.8 dBm
Narda 642	Standard gain waveguide horn	1.2 dBm	-30.5 dBm
ETS-Lindgren 3117	Broadband ridged horn	-4.0 dBm	-37.5 dBm