ANTENNA MEASUREMENT

What to Measure

- Antenna Parameters
  - Circuit parameters
    - Impedance
    - Radiation resistance
    - Loss
  - Pattern parameters
    - Beam width
    - Side lobe level
    - Gain

How to Measure (Impedance)

- Network Analyzer
  - Calibration
  - Antenna environment
    - Anechoic chamber
    - Absorbers
- **IEEE Standard Test Procedures for Antennas**

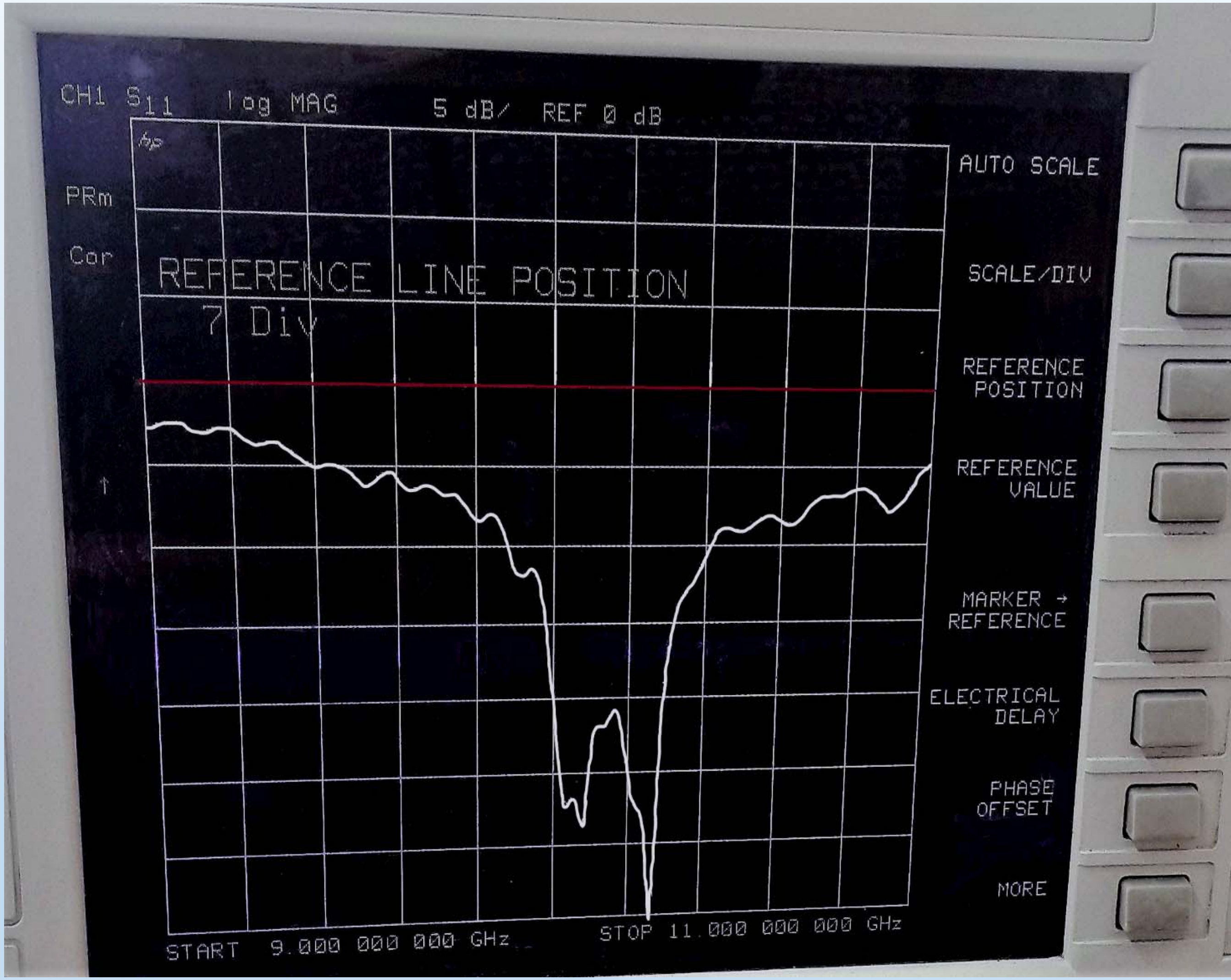
  IEEE Std 149™-1979 (R2008)

Return loss measurement

With small antennas, one is tempted to make the measurement quickly using the network analyzer in the laboratory, without paying much attention to the surroundings.

Ripples in S_{11}

Reflections are observed as ripple in the measurement. The signals reflected from the antenna and walls create an interference pattern.



Reflections can be avoided by simply pointing the antenna main beam towards the most distance point in the lab.

No ripples in s_{11}

Most antennas do not have ripples in their s_{11} characteristics. Any ripple is most probably an indicator of nearby objects.

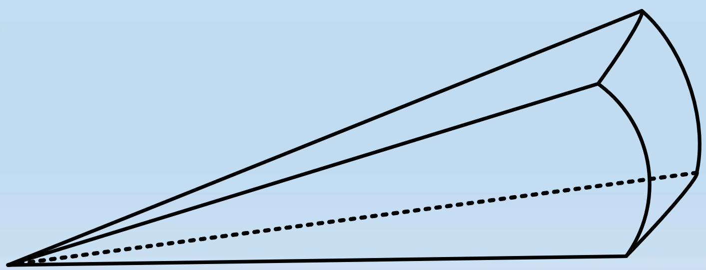
Antenna Radiation Parameters

- An antenna that radiates energy equally in all directions is called an **isotropic radiator** or an **omnidirectional radiator**.
- Such an antenna is a fictitious radiator.
- For the isotropic source, the power density at a distance R from the source will be

$$P = \frac{W_t}{4\pi R^2}$$

- It is generally more convenient to consider the power flow through unit solid angle which is called the **radiation intensity**.

$$U = \frac{W_t}{4\pi} = R^2 P$$

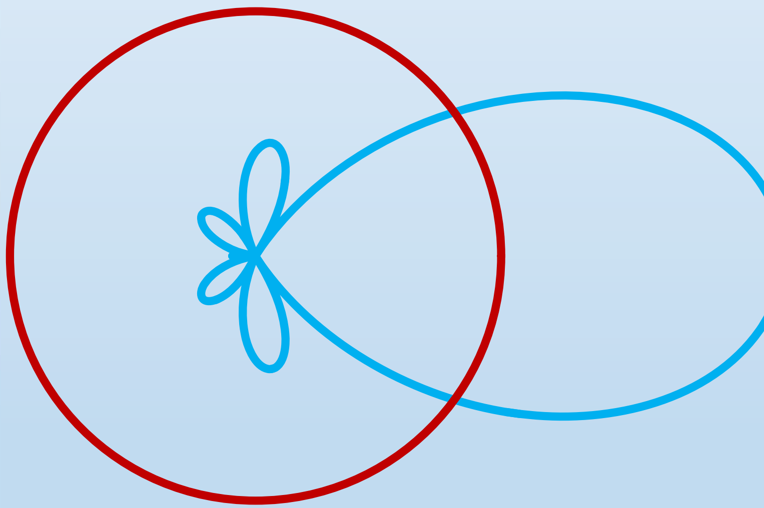


- The directivity of an antenna is defined as

$$D = \frac{U_m}{U_0} = \frac{\text{Maximum radiation intensity}}{\text{Average radiation intensity}}$$

$$D = \frac{4\pi U_m}{4\pi U_0} = \frac{4\pi U_m}{W_t} = \frac{4\pi(\text{Maximum radiation intensity})}{\text{Total radiated power}}$$

- The definition of directivity is based entirely on the shape of the radiated power pattern. The power input and antenna efficiency are not involved.



$$G = \frac{4\pi(\text{Maximum radiation intensity})}{\text{Total input power to the antenna}}$$

$$G = \eta D$$

- Directivity pattern and gain pattern of an antenna are defined in a similar manner.

$$D(\theta,\phi) = \frac{4\pi U(\theta,\phi)}{W_t} = \frac{4\pi(\text{radiation intensity in}(\theta,\phi)\text{ direction})}{\text{Total radiated power}}$$

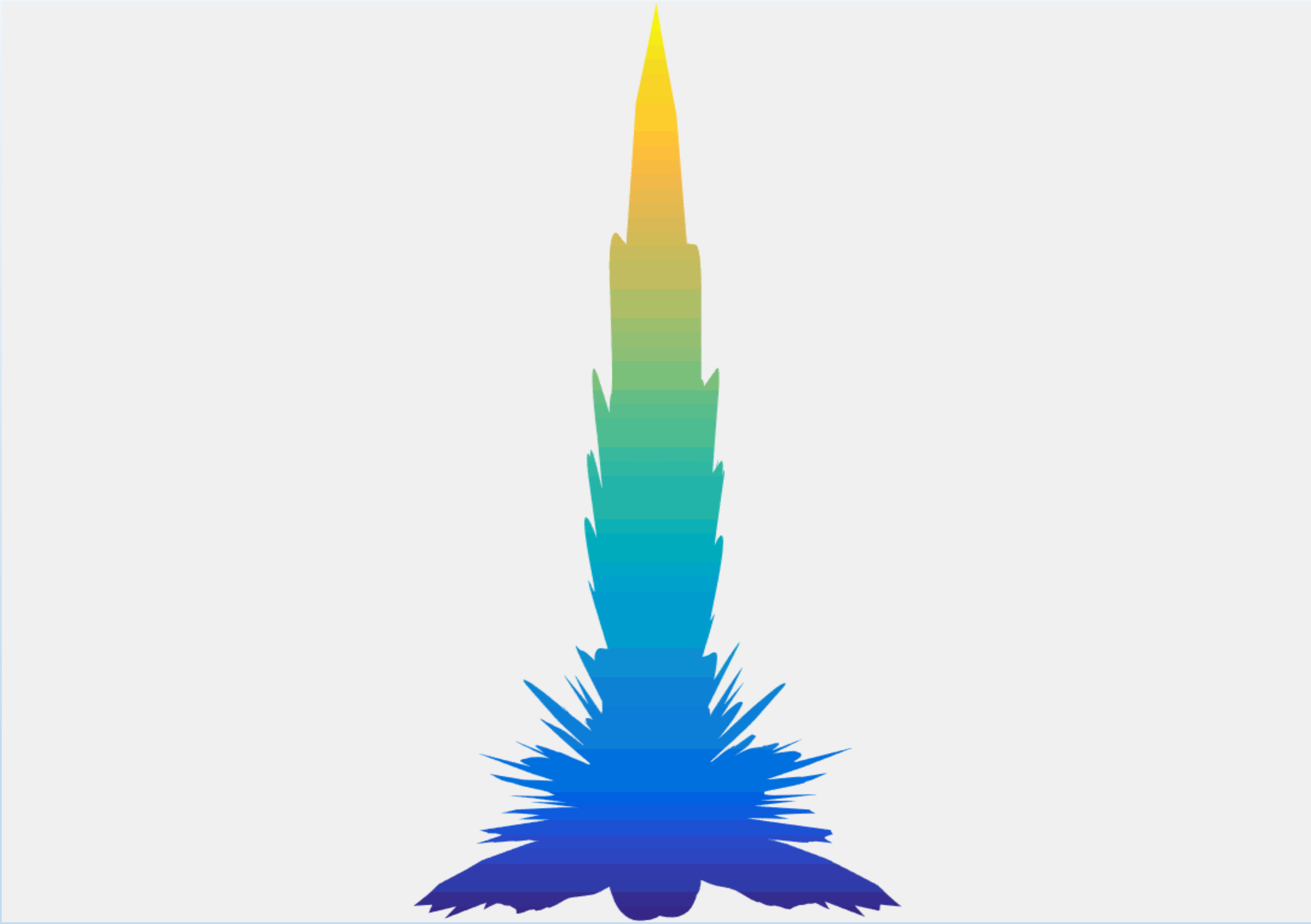
$$G(\theta,\phi) = \frac{4\pi(\text{radiation intensity in}(\theta,\phi)\text{ direction})}{\text{Total input power}}$$

- Antenna pattern measurement refers to the measurements performed to describe $G(\theta,\phi)$ or $D(\theta,\phi)$.
- These quantities are related to power by definition.
- Sometimes we need to know the fields (especially their direction, i.e. polarization as a function of directions.

- **Power Pattern** : If the radiation from an antenna is expressed in terms of Power per unit solid angle the radiation pattern is called “Power Pattern”.
- **Field Strength Pattern :** If the radiation from an antenna is expressed in terms of field strength E (Volt/Meter) the radiation pattern is called “Field Strength Pattern”.
  - Field strength pattern is typically related to the total field magnitude but may also be related to any component of the field.

3D Pattern

Antenna power pattern is a 3D quantity and is hard to measure and specify in all directions.



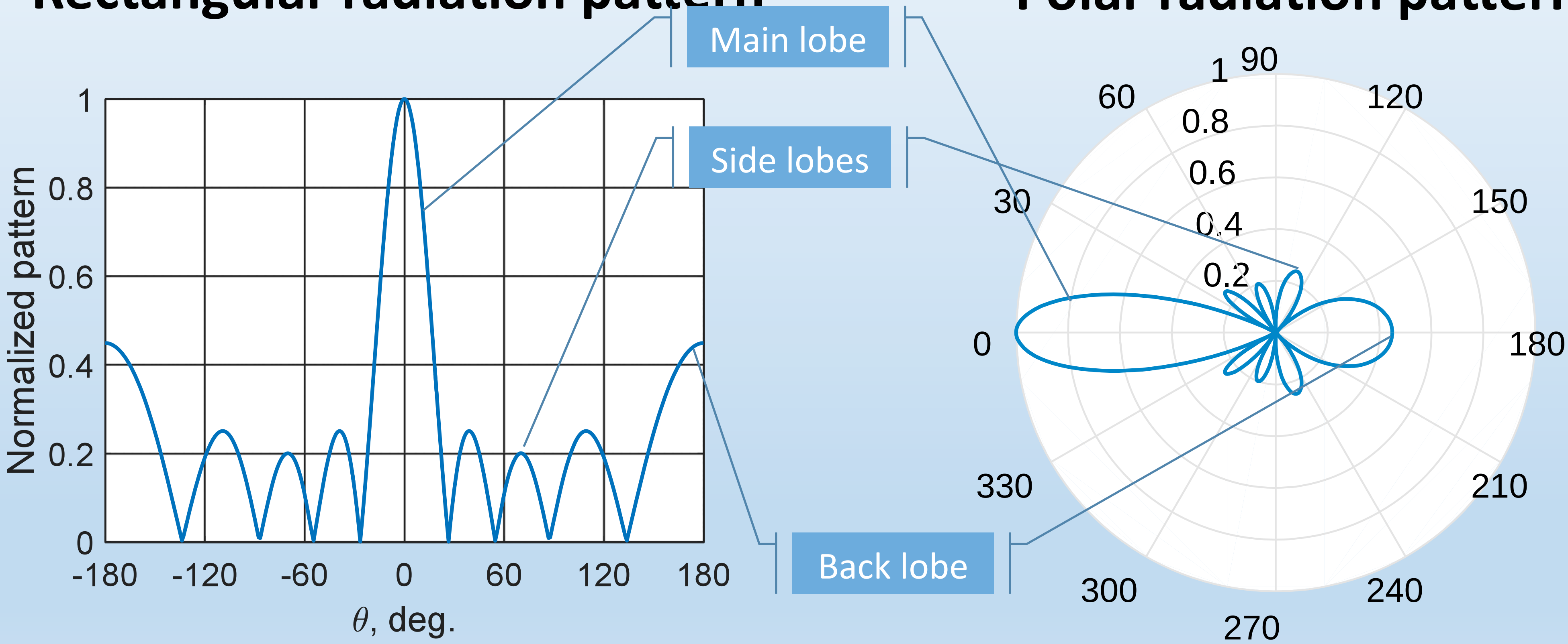
Principle planes and principle plane patterns

- **Antenna boresight** is the axis of maximum of a directional **antenna**. For most **antennas** the **boresight** is the axis of symmetry of the **antenna**.
- The **main lobe**, or **main beam** is the lobe containing the maximum power. This is the lobe that exhibits the greatest field strength.
- Two orthogonal planes that contain the antenna boresight axis are called the **principle planes**.

- If the antenna is linearly polarized, the two planes are chosen as the planes containing the electric and magnetic fields and called the $\boldsymbol{E}-$ **plane** and the $\boldsymbol{H}-$ **plane**.
- If the antenna has a specific positioning with respect to earth they are called **horizontal** and **vertical planes**.

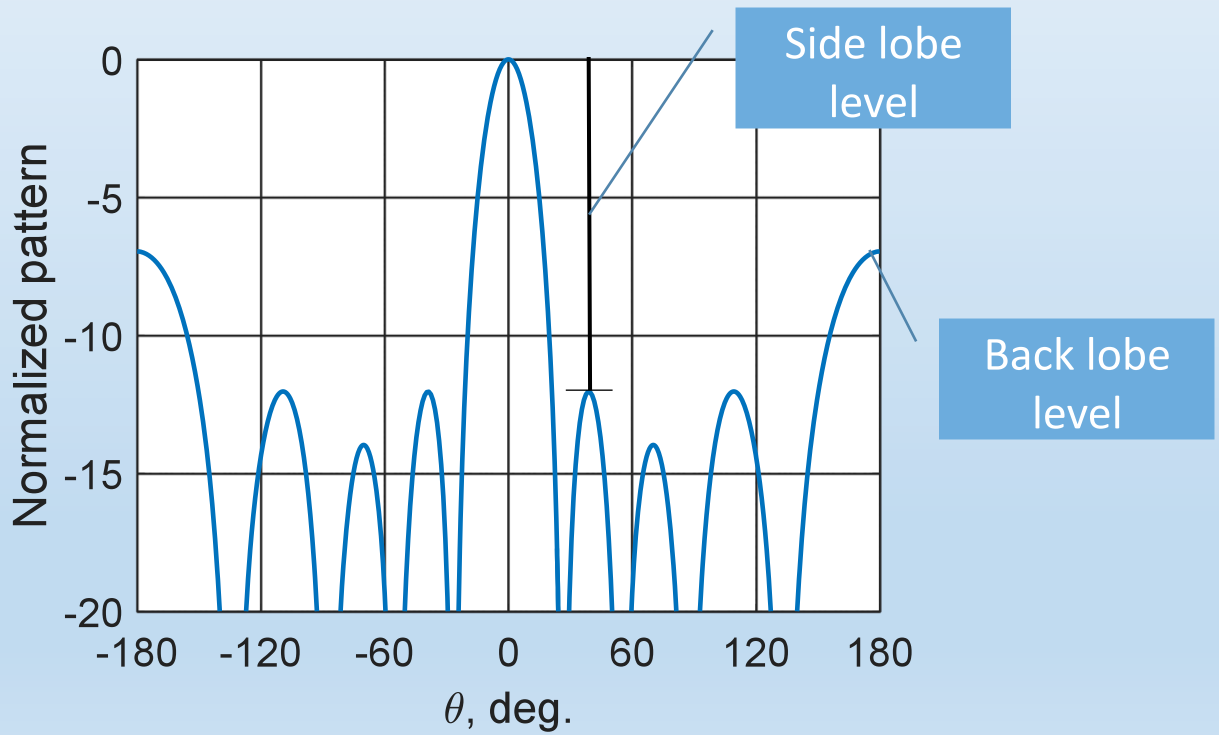
2D Patterns (normalized)

Rectangular radiation pattern **Polar radiation pattern**

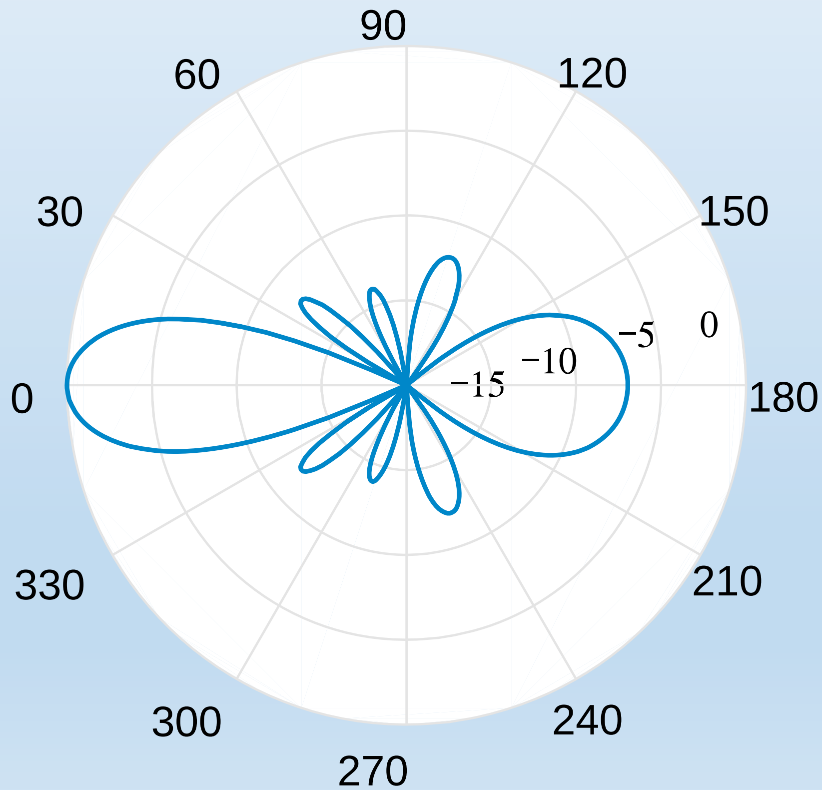


2D Patterns (dB)

Rectangular radiation pattern

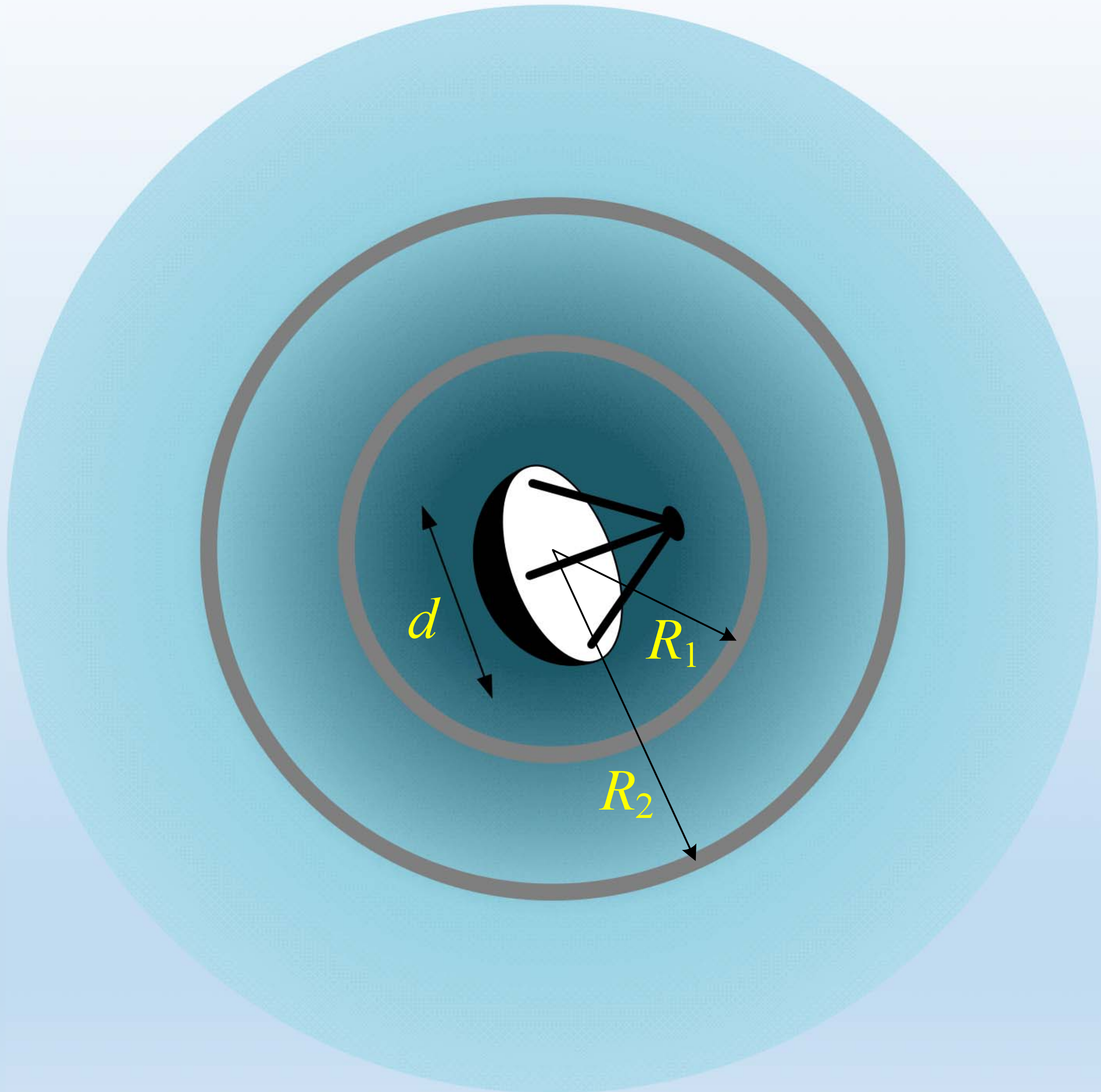


Polar radiation pattern



Antenna Field Regions

- Reactive Near Field
- Radiative Near Field
- Far Field



Antenna Field Regions (Near Field)

- **Reactive Near Field**
  - In the immediate vicinity of the antenna, we have the reactive near field. In this region, the fields are predominately reactive fields, which means the E- and H - fields are out of phase by 90^{o} to each other (for propagating or radiating fields, the fields are orthogonal (perpendicular) but are in phase).
  - This results in energy storage in the near field region and accounts for the reactive part of the antenna impedance.

$$R < 0.62\sqrt{\frac{d^3}{\lambda}}$$

Antenna Field Regions (Radiating Near Field)

- **Radiating Near Field (Fresnel) Region**
  - The radiating near field or Fresnel region is the region between the near and far fields. In this region, the reactive fields are not dominant; the radiating fields begin to emerge. However, unlike the Far Field region, here the shape of the radiation pattern may vary appreciably with distance.

$$0.62\sqrt{\frac{d^3}{\lambda}} < R < \frac{2d^2}{\lambda}$$

Antenna Field Regions (Far Field)

- **Far Field (Fraunhofer region)**
  - The far field is the region far from the antenna. In this region, the ***radiation pattern does not change shape with distance*** (although the fields still die off as $1/R$, the power density dies off as $1/R^2$). The fields are radiating TEM fields, E- and H - are orthogonal to each other and the direction of propagation and can be approximated as plane waves.

$$E(R,\theta,\phi) = \frac{e^{-jkR}}{R} D(\theta,\phi)$$

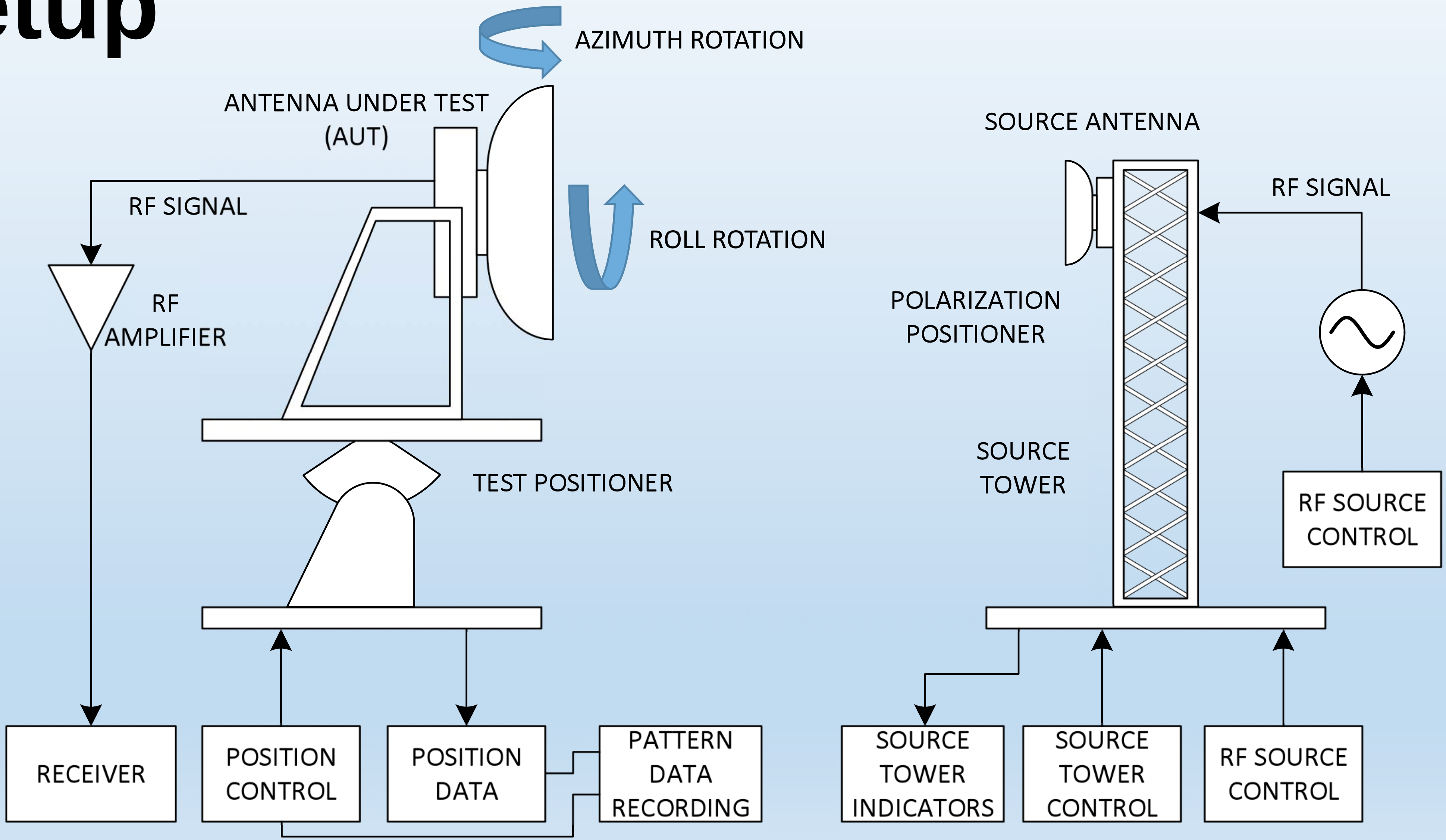
  - Rayleigh distance (d being the largest linear dimensio

$$\left.\begin{matrix} R \gg d \\ R \gg \lambda \end{matrix}\right\} \Rightarrow R > \frac{2d^2}{\lambda}$$

Antenna Reciprocity

- **Reciprocity** is one of the most useful (and fortunate) property.
- **Reciprocity** states that the receive and transmit properties of an antenna are identical.
- The radiation patterns in the transmit mode and in the receiving mode are identical.
- Reciprocity technically only applies for reciprocal antennas that are made of reciprocal materials. Non-reciprocal antennas are used in practice, but they are in the minority.
- Reciprocity implies that antenna pattern can be measured either in transmit mode or receive mode.

Antenna Pattern Measurement Setup



Antenna Ranges

- ***Antenna ranges*** are developed to measure the radiation characteristics of antennas independent of their operational environment.
- The antenna range consists of the appropriate ***instrumentation*** and the ***physical space*** required for the measurements.
- The ideal incident field for measuring the radiation characteristics of the test antenna is that of a ***uniform plane wave***. This is the ***far field*** requirement.
- In practice it is only possible to approximate such a field.

Types of antenna ranges

- Attempts to produce a uniform plane wave illumination on the AUT leads to the development of two basic types of ranges:

1. ***Free-space ranges*.**

   are designed in such a manner that all the effects of the surroundings are suppressed to acceptable levels.

2. ***Reflection ranges*.**

   are designed to judiciously use reflections in order to produce an approximated plane wave.

Free space ranges

Typical ranges that come under the free-space-range classification are:

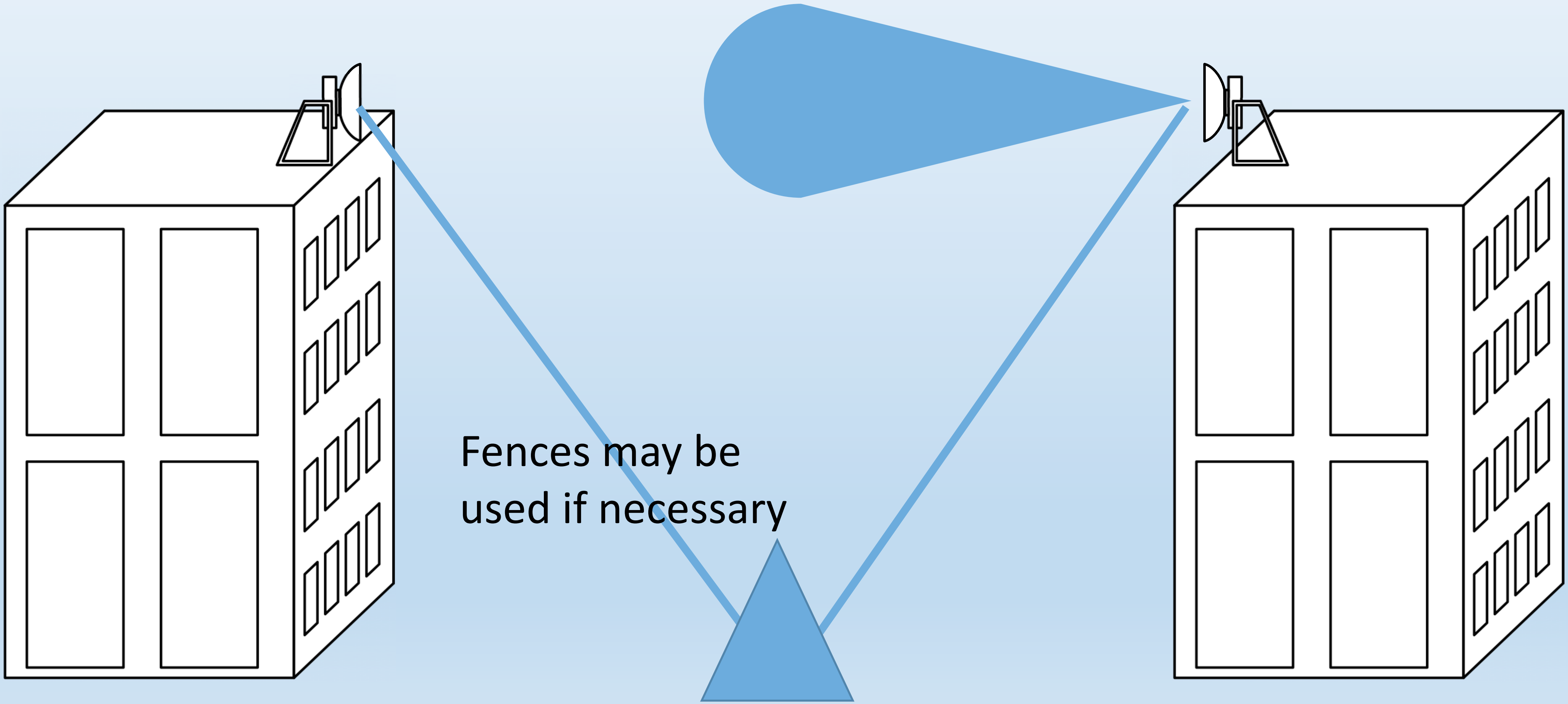
1) the **elevated range**,
2) the **slant range**,
3) the **compact range**,
4) and most **anechoic chambers**.

Elevated Range

The ***elevated ranges*** are those ranges in which the test and source antennas are located on towers, on adjacent mountain peaks, or on the roofs of adjacent buildings so that the effects of the surroundings are suppressed

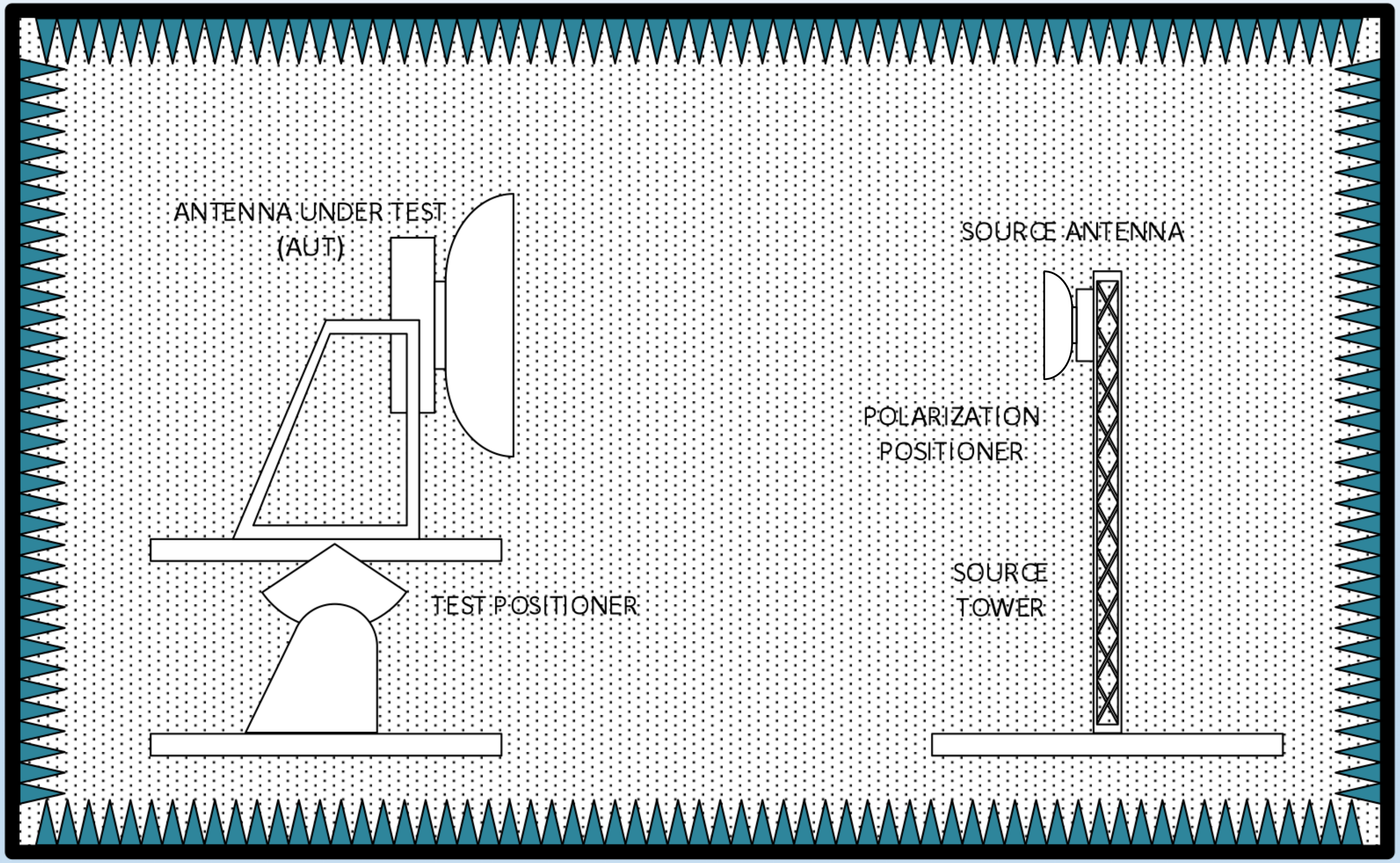
1) by careful choice of the source antenna with regard to directivity and side-lobe level
2) by clearance of the line of sight along the range surface
3) by redirection or absorption of energy reaching the range surface or obstacles that cannot be removed
4) by special signal-processing techniques such as modulation tagging of the desired signal
5) by use of short pulses

An elevated range

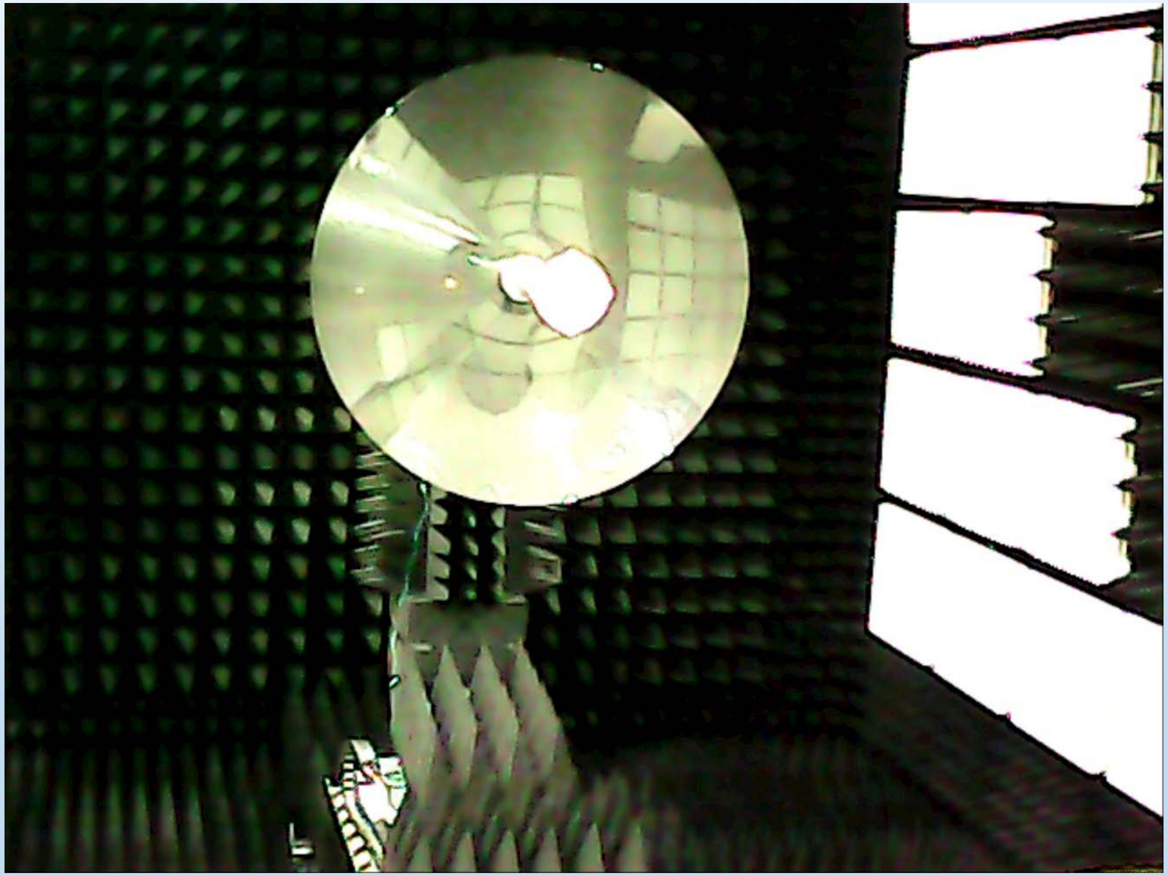


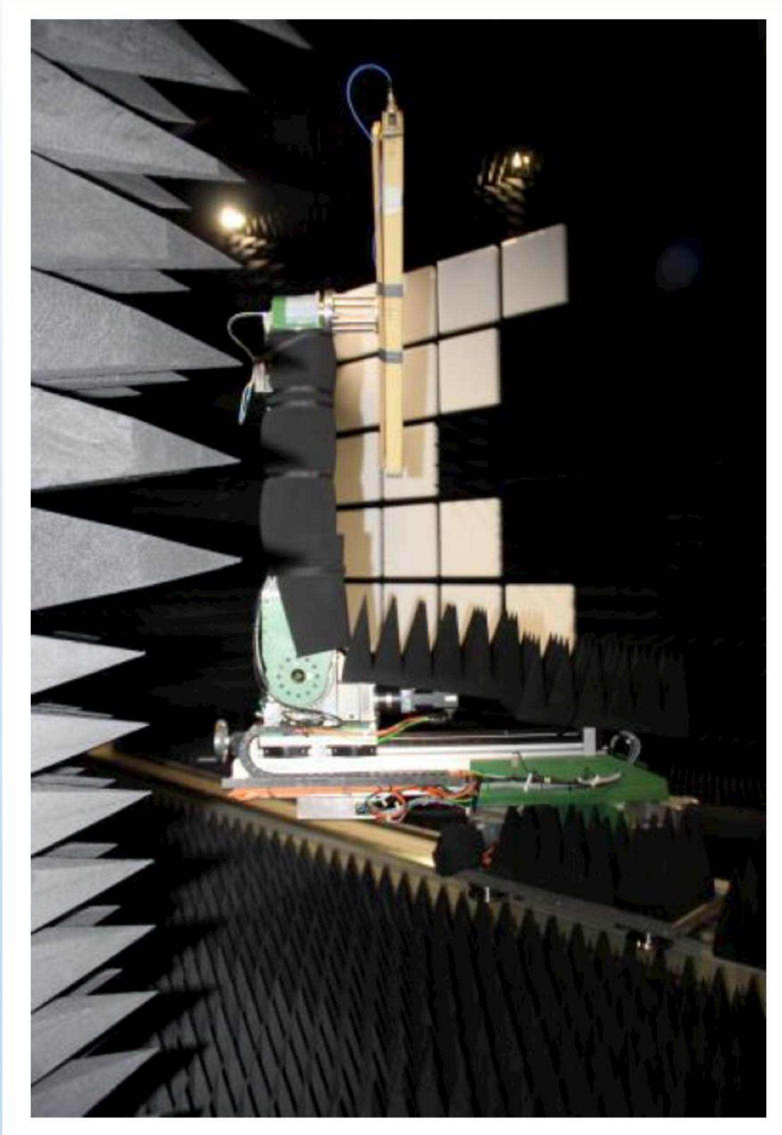
Anechoic chamber

- An *anechoic chamber* is a room designed to completely absorb reflections of electromagnetic waves. They are also isolated from waves entering from their surroundings.

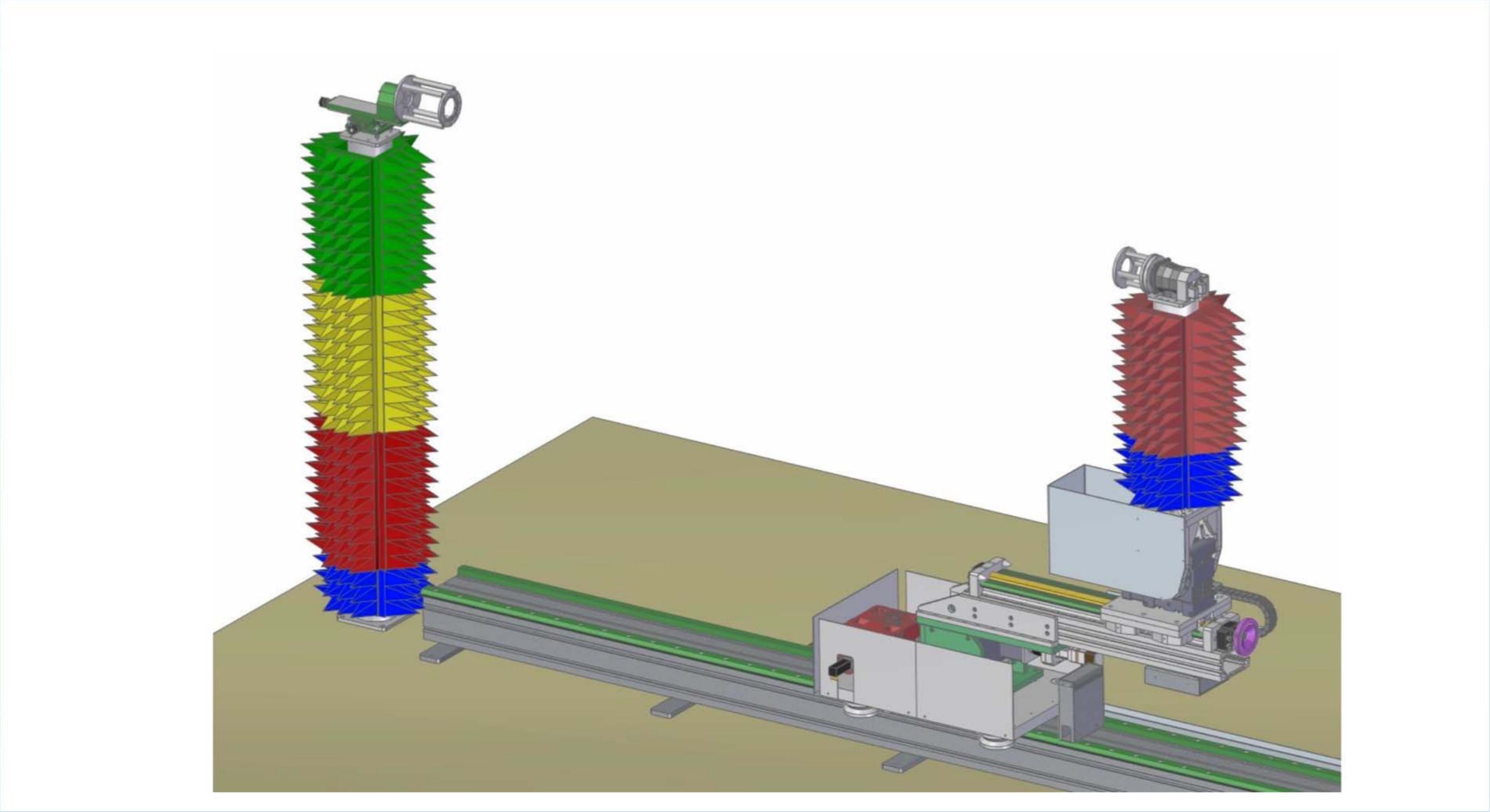


Anechoic chamber





Anechoic chamber



Antenna-Range Design Criteria

The important criteria for an antenna range are:

1) the coupling between source and test antennas
2) the transverse and longitudinal amplitude taper of the illuminating wave front
3) the phase curvature of the illuminating wave front
4) spatial variations in the illuminating wave front caused by reflections
5) interference from spurious radiating sources

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Coupling between source and test antennas

- If the AUT is in the ***reactive near field*** region of the source antenna, the test antenna may couple to the reactive field, and for some types of measurements this produces an error.
- Acceptable distance is

$$R > 10\lambda$$

- The re-radiative coupling or mutual coupling between source and AUT is also of concern.
- For this case, part of the energy received by the AUT is re-radiated back toward the source and vice versa, resulting in multiple reflections.
- This level is quite low, but it can cause a measurable error in the level of the signal observed near the peak of the AUT's major lobe.

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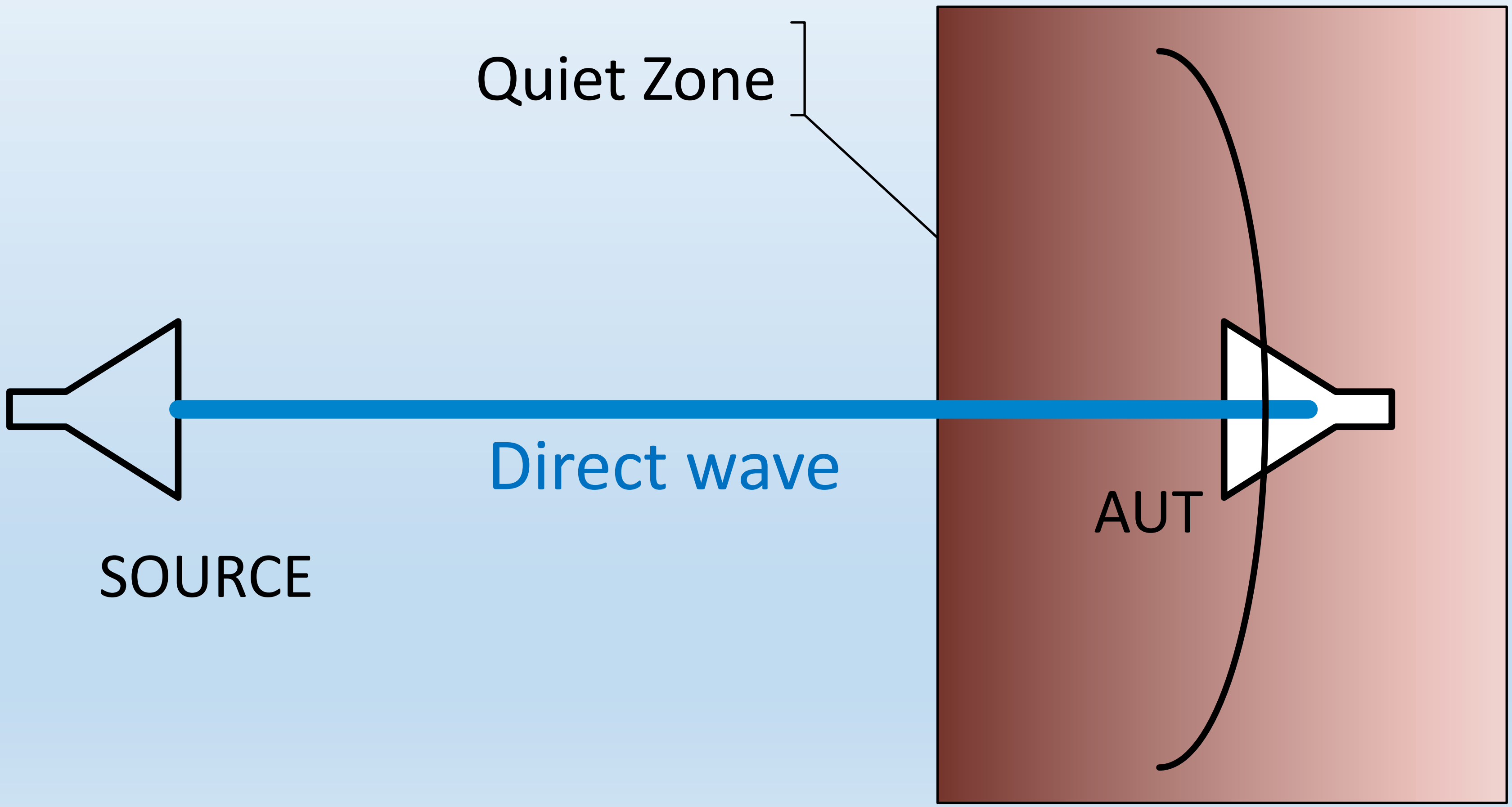
Transverse and longitudinal amplitude taper of the illuminating wave front



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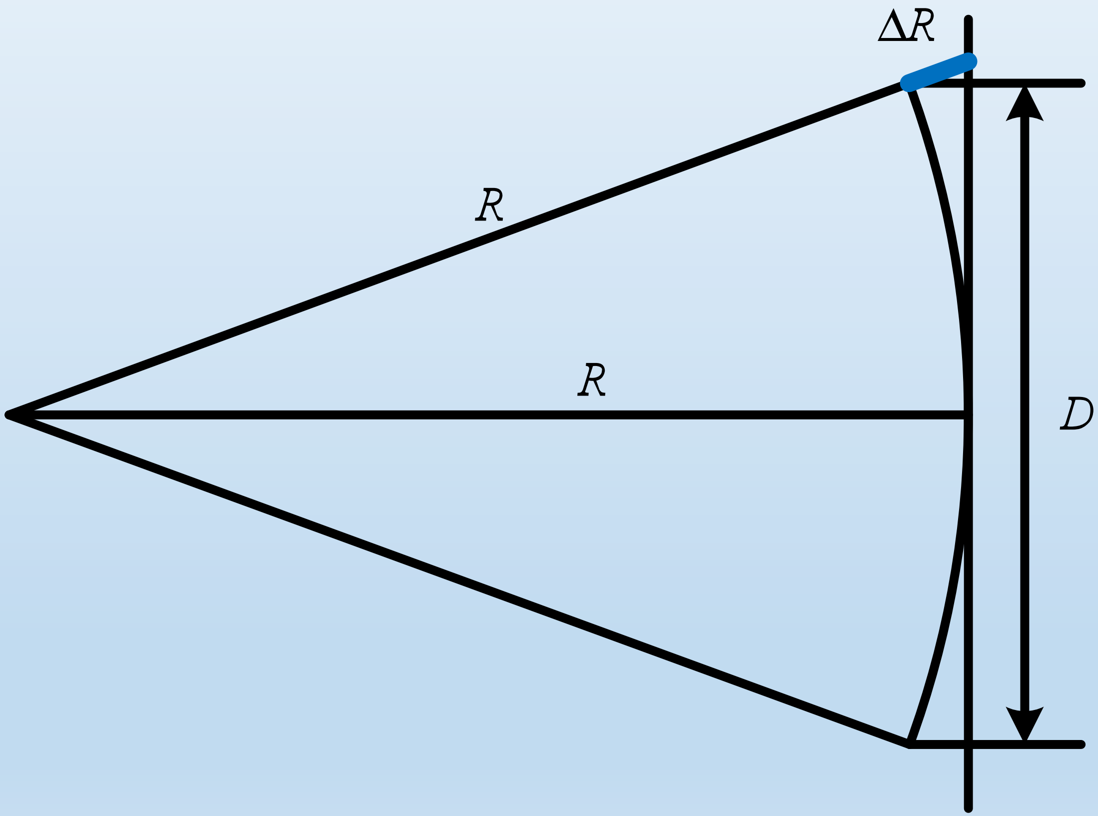
Phase curvature of the illuminating wavefront



- $$\Delta R = \sqrt{R^2 + \left(\frac{D}{2}\right)^2} - R = \frac{\lambda}{16}$$

implies

$$R = \frac{2D^2}{\lambda}$$

Equivalently, the phase variation on the wavefront is limited to $\pi/16$ rad. or 22.5^{o}.

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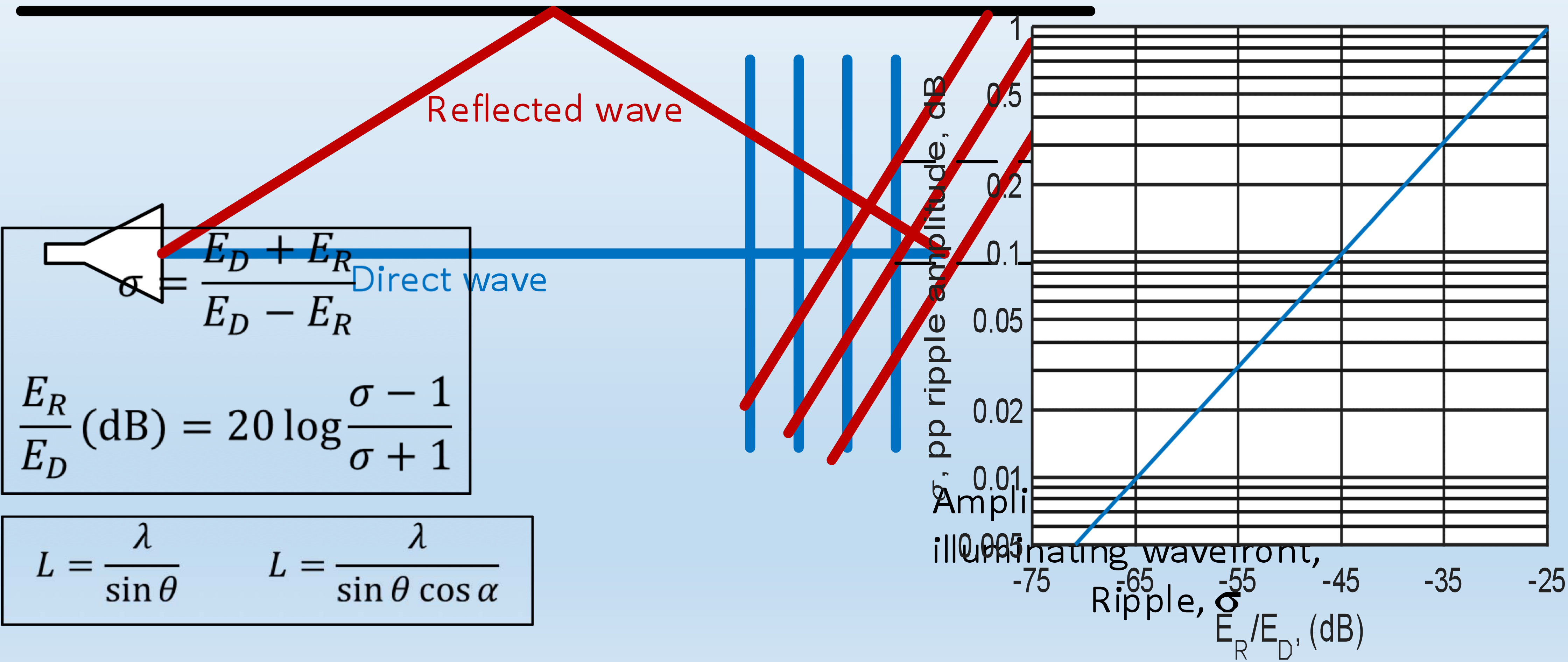
Effect of reflections on the wave front

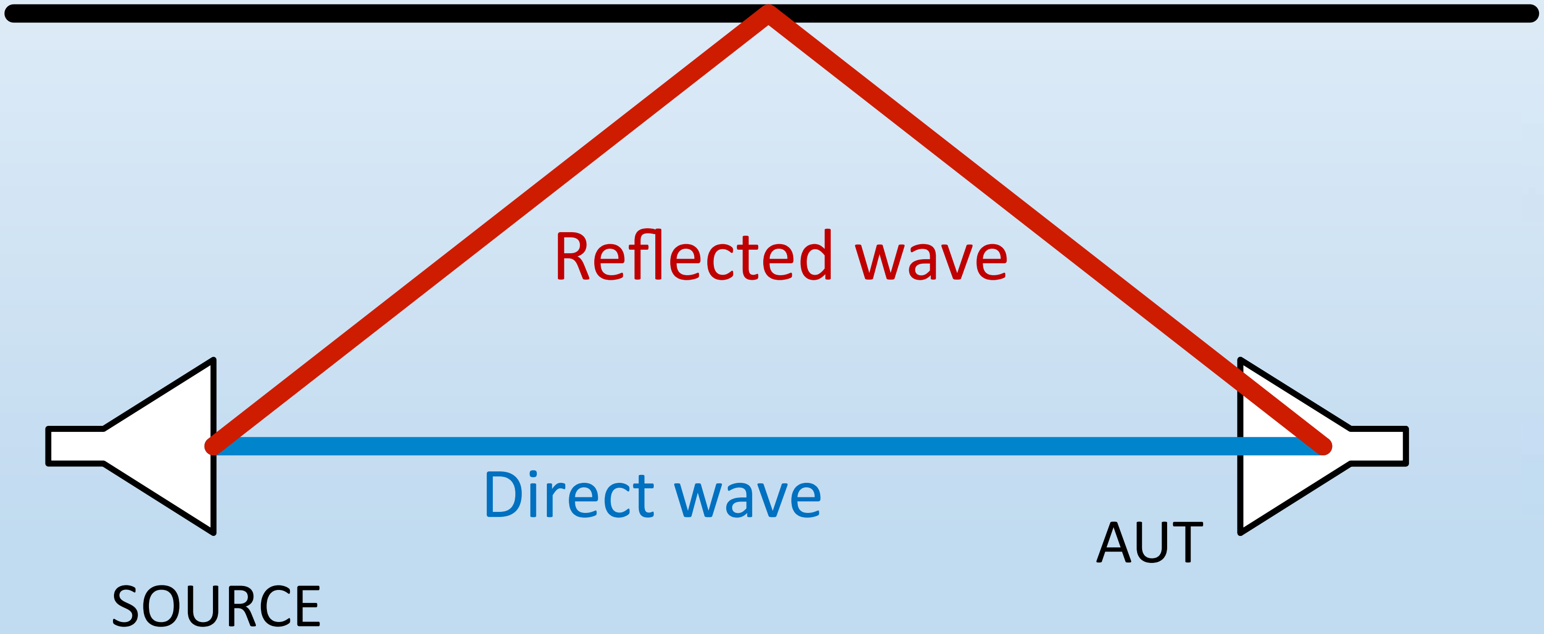


$$\sigma = \frac{E_D + E_R}{E_D - E_R}$$

$$\frac{E_R}{E_D}(\mathrm{dB}) = 20 \log \frac{\sigma - 1}{\sigma + 1}$$

$$L = \frac{\lambda}{\sin\theta} \qquad L = \frac{\lambda}{\sin\theta \cos\alpha}$$

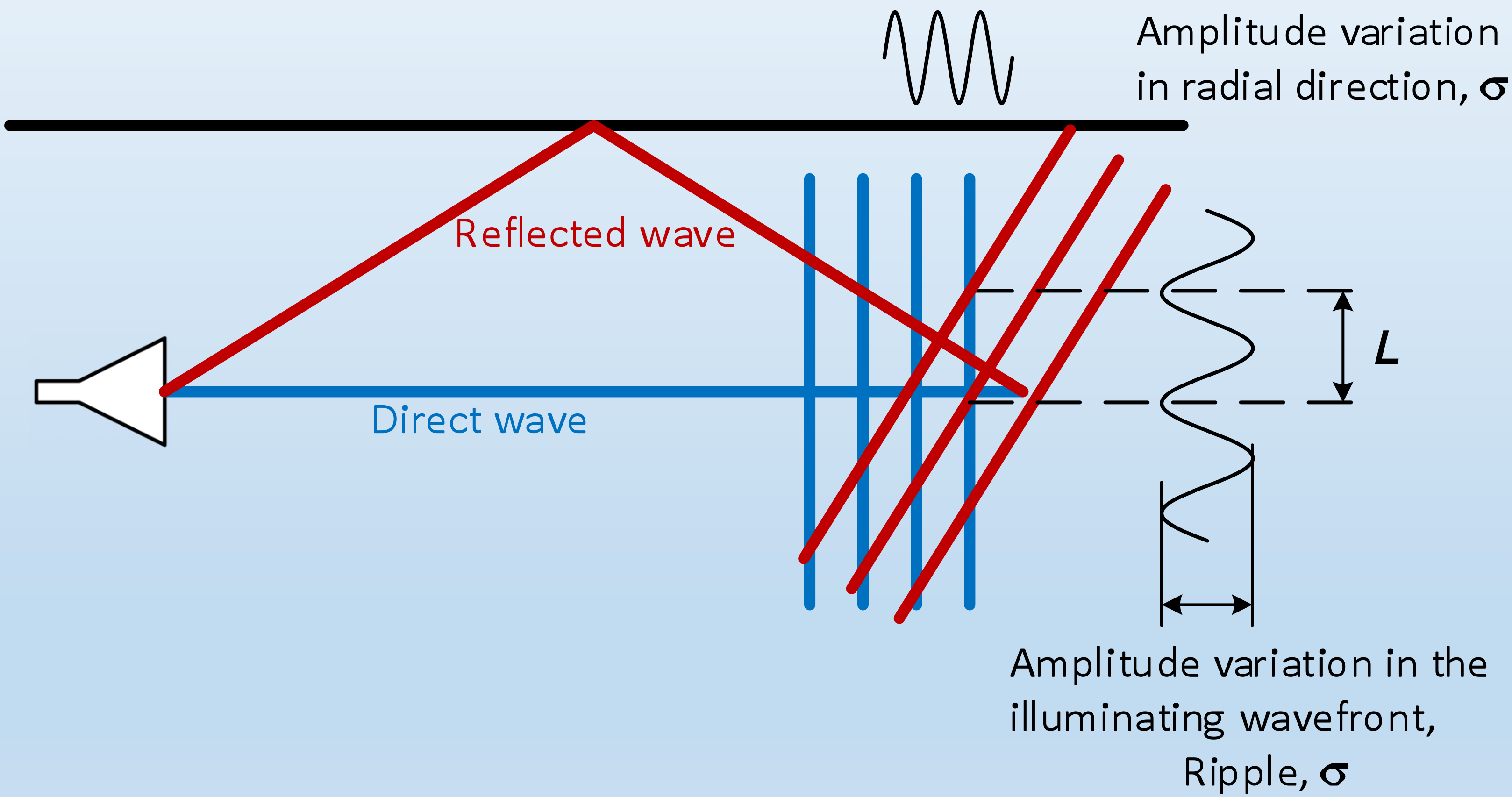
Effect of reflections on the AUT pattern



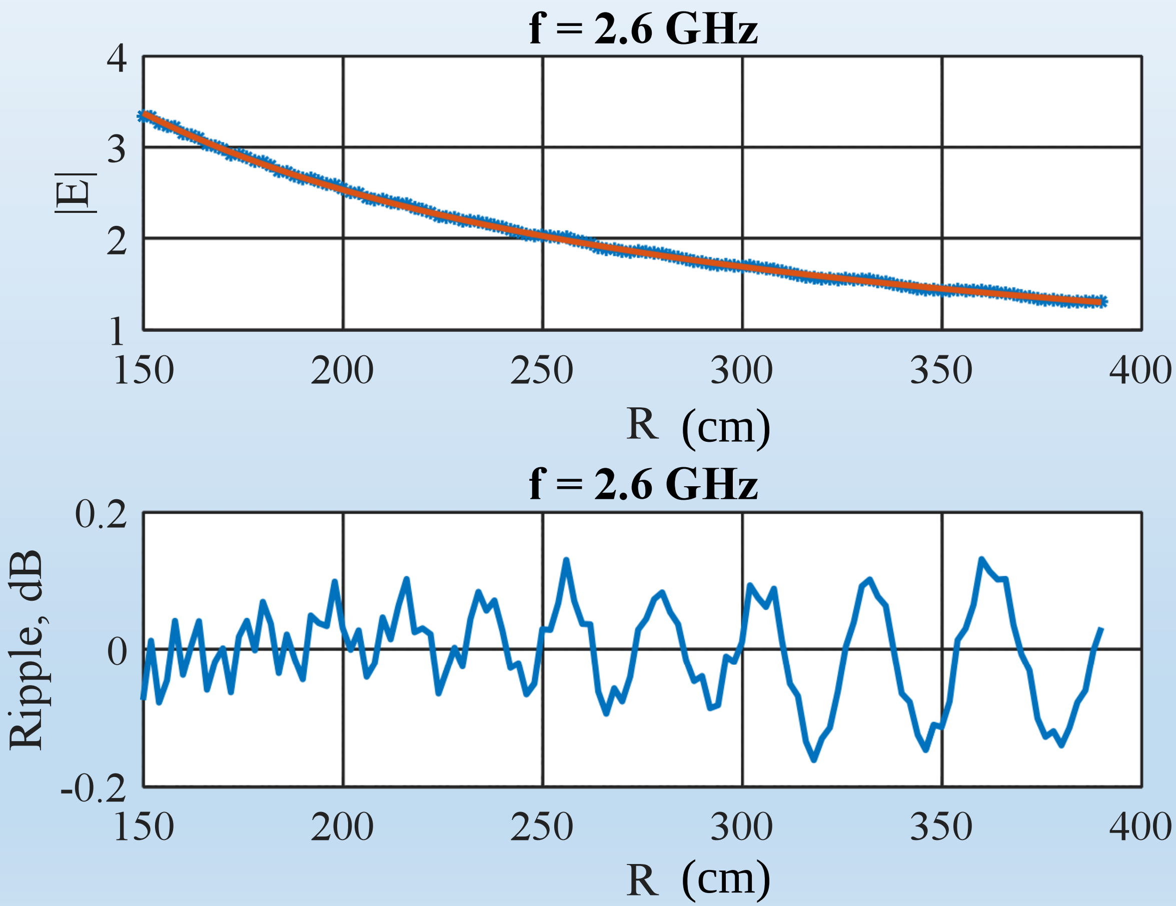
$$E_{rec}(0) = E_D G_o + E_R G(-$$
$$\approx E_D G(0)$$

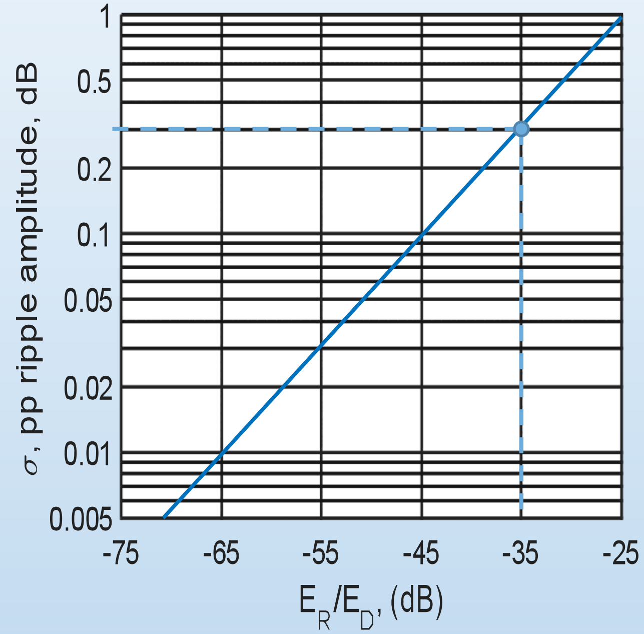
$$E_{rec}(\theta) = E_D G(\theta) + E_R$$
$$\overset{?}{\approx} E_D G(\theta)$$

Amplitude variation in radial direction



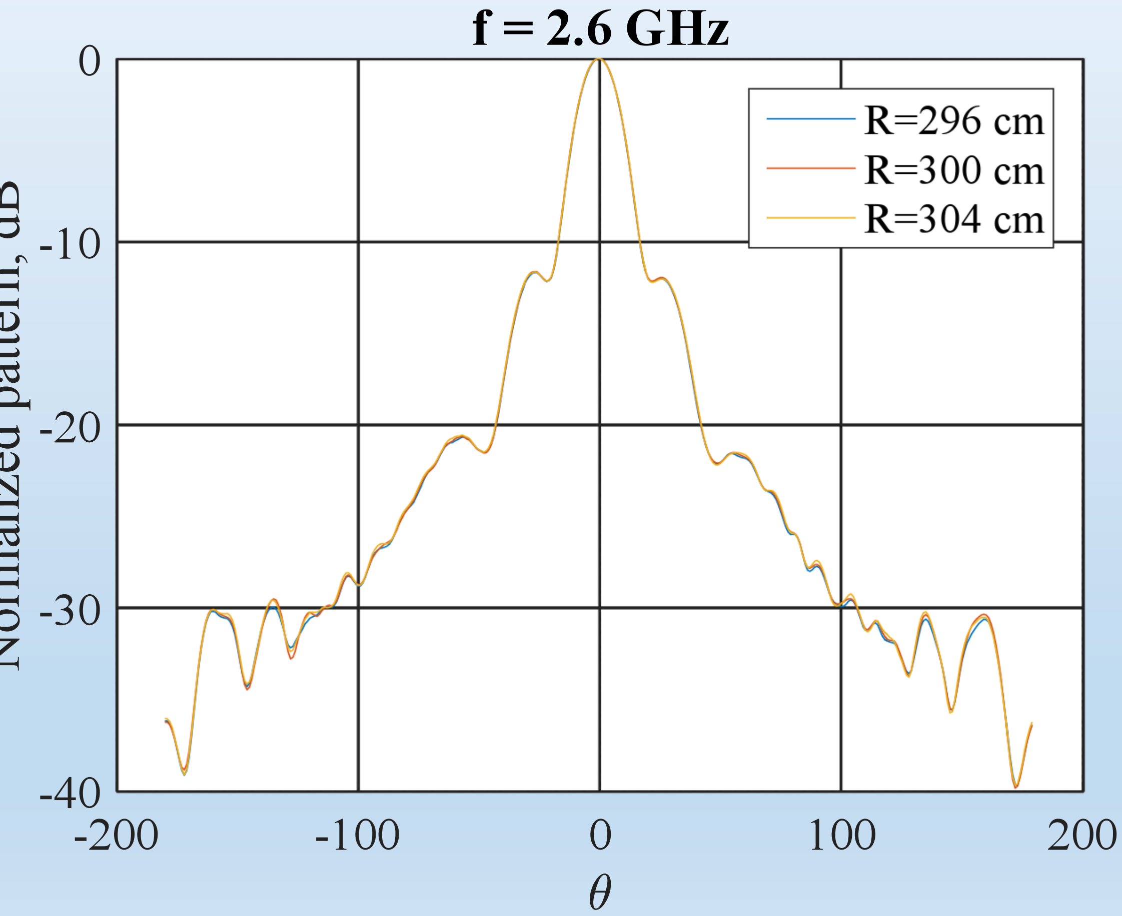
Field strength variation with distance (2.6 GHz)

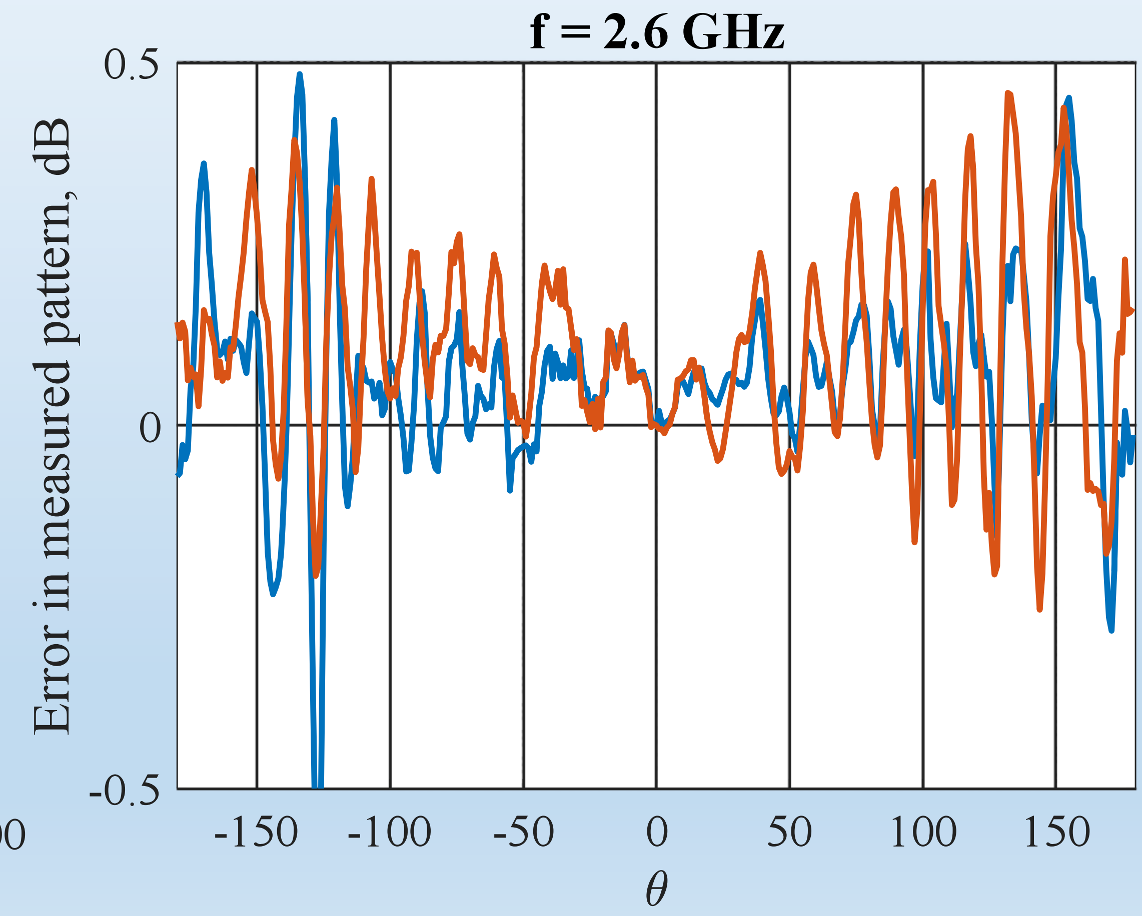




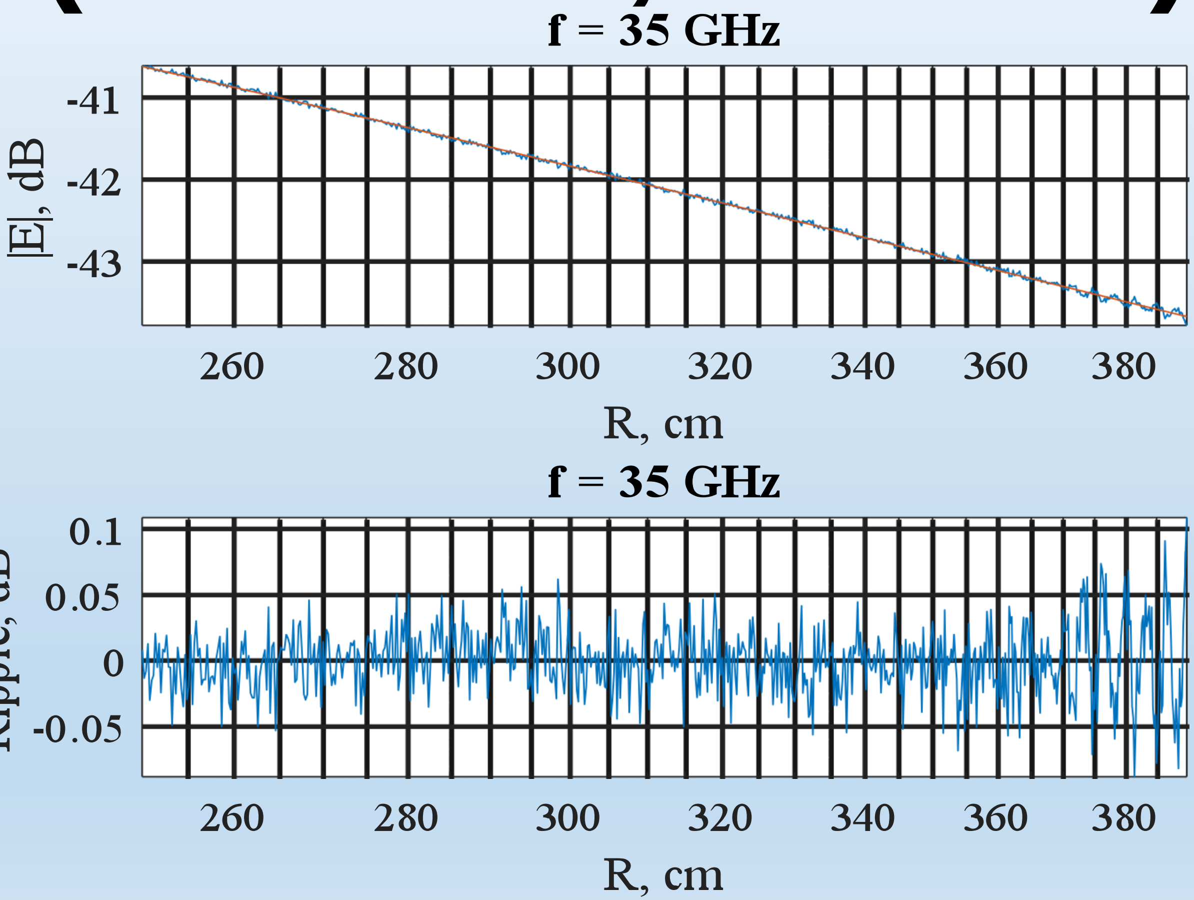
- $\sigma = 0.3 \text{ dB} \Rightarrow \dfrac{E_R}{E_D} = -35 \text{ dB}$

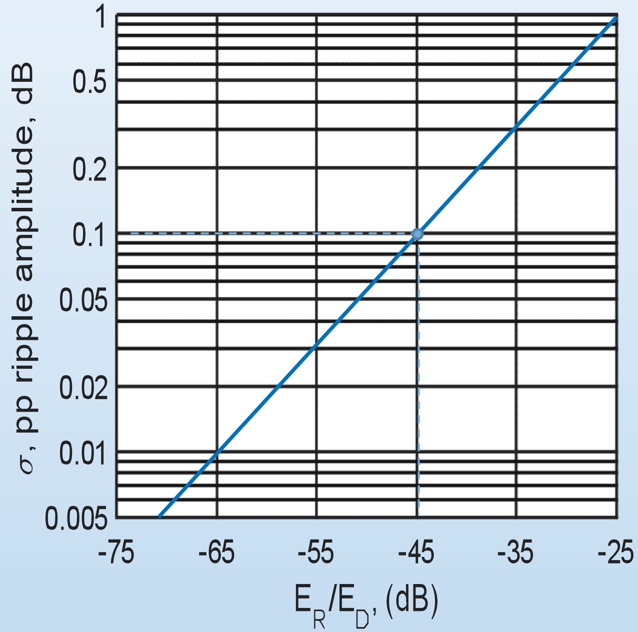
Pattern measurement at three distances





Field strength variation with distance (Ka Band, 35 GHz)

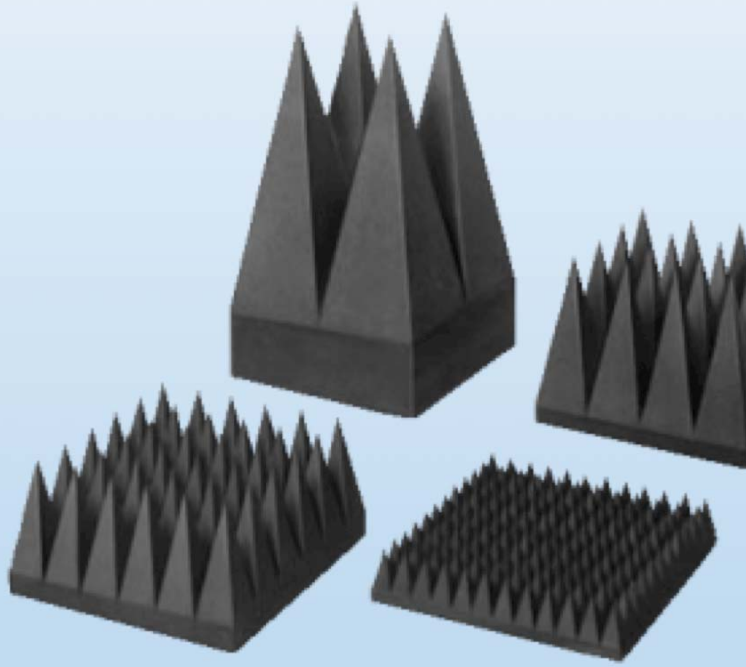




$$\sigma = 0.1\ \text{dB} \Rightarrow \frac{E_R}{E_D} = -45\ \text{dB}$$

TYPICAL ABSORPTION CHARACTERISTICS (VERTICAL INCIDENCE)

Material name	0.3 GHz	0.5 GHz	0.8 GHz	1 GHz	3 GHz	5 GHz	10 GHz	30 GHz	50 GHz
IS-005A	—	—	—	—	15	20	30	50	50
IS-012A	—	—	20	20	30	40	55	55	55
IS-015A	—	—	20	20	35	40	55	55	55
IS-023A	—	—	23	30	45	50	55	55	55
IS-030A2	—	—	30	35	45	50	55	55	55
IS-045	—	30	35	40	45	50	55	55	55
IS-060	—	32	37	42	50	55	55	55	55
IS-075	25	35	40	45	55	55	55	55	55
IS-100	30	40	45	50	55	55	55	55	55



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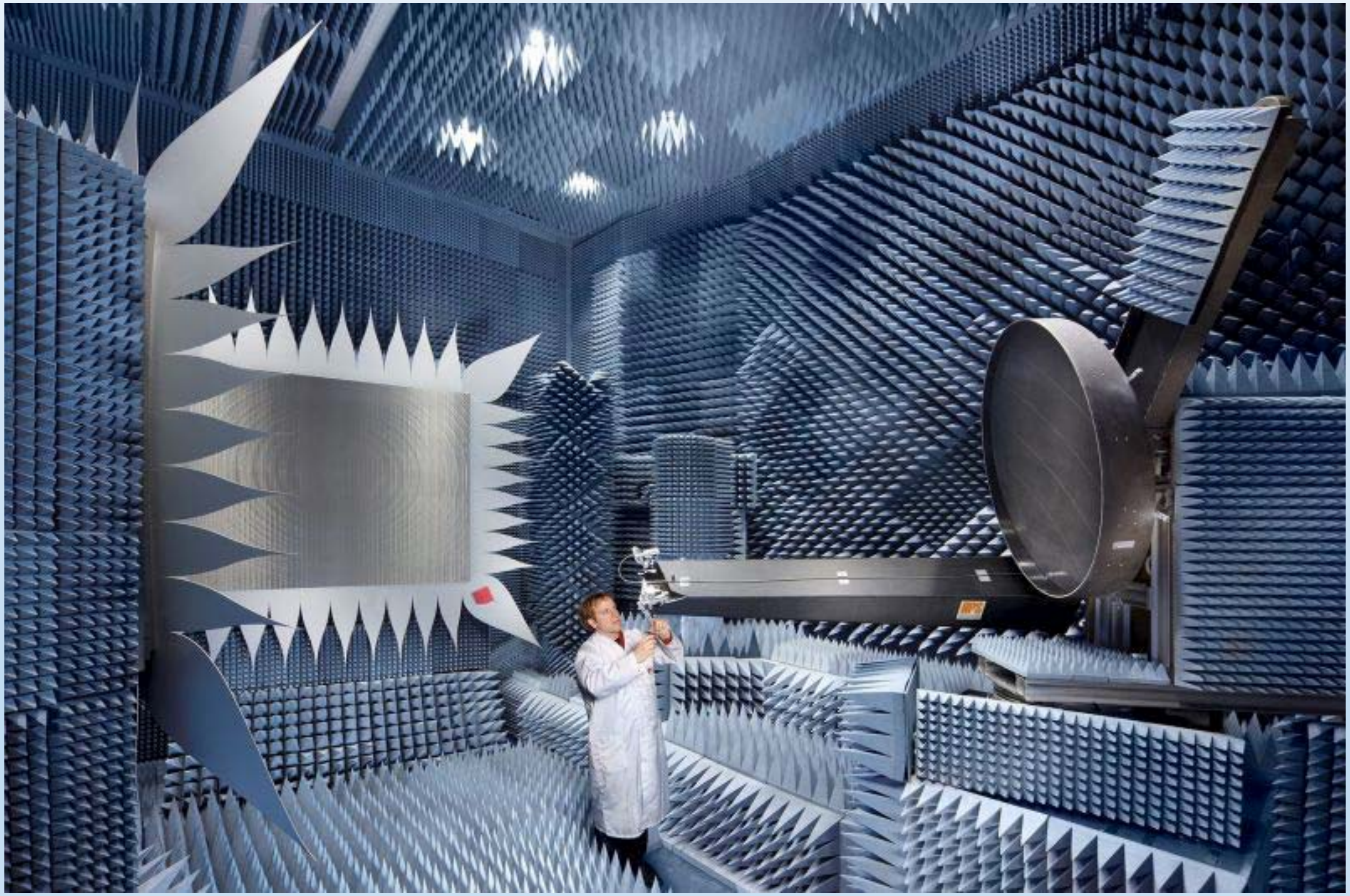
5) **interference from spurious radiating sources**

Interference from spurious radiating sources

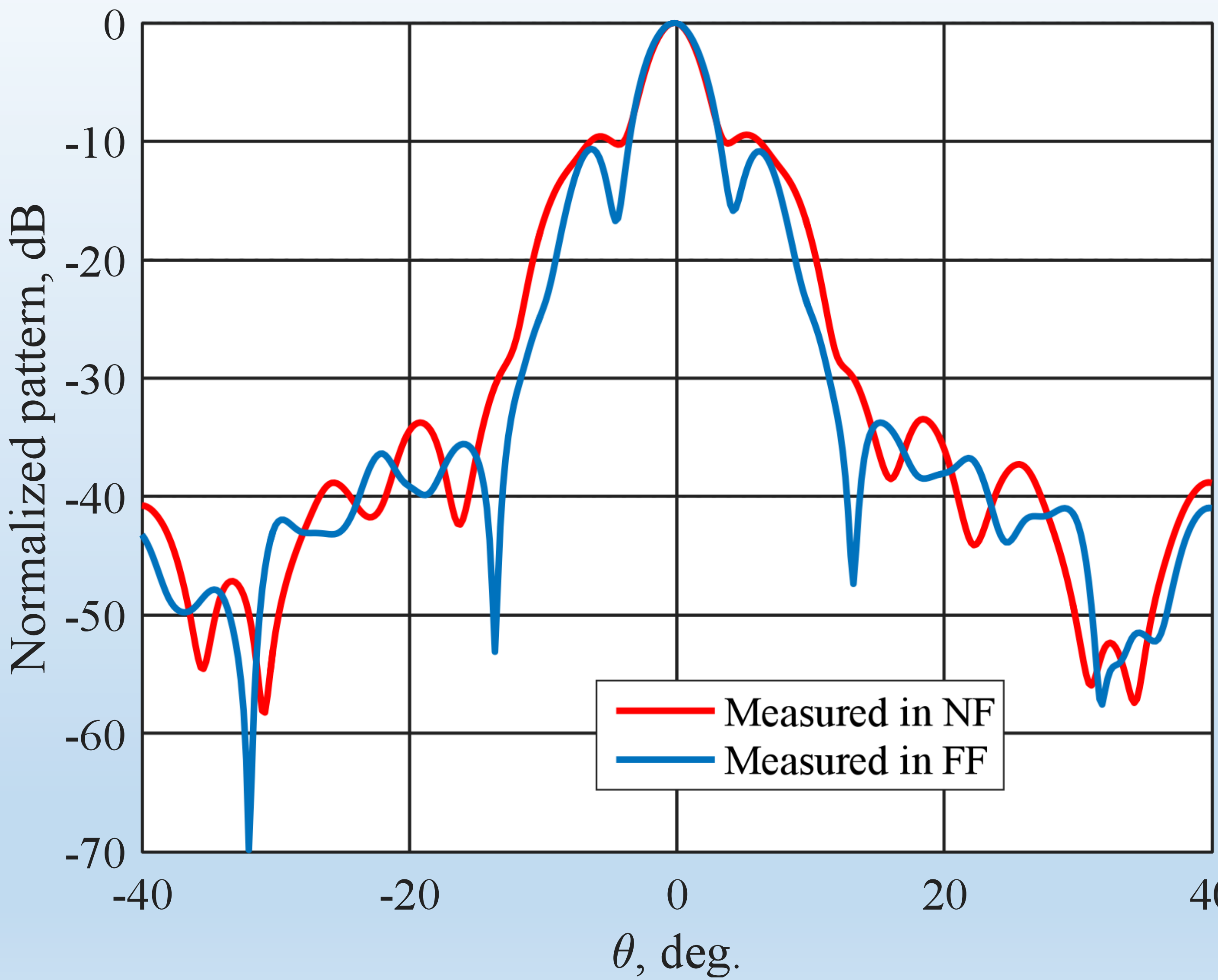
- Anechoic chambers are isolated from the outside world by metallic walls
- Only the source antenna is in the chamber.
- External sources are suppressed typically by about 120 dB (by a factor of 10^6 in field strength).
- In open regions, undesired sources may be suppressed by using a narrow receiver filter.

Compact range



- **COMPENSATED COMPACT TEST RANGE AT THE MUNICH UNIVERSITY OF APPLIED SCIENCES**
- http://www.compactrange.de/

- If the far field conditions are not satisfied:
  - The nulls in the pattern are filled
  - Main lobe is not much affected but side lobes are in error.

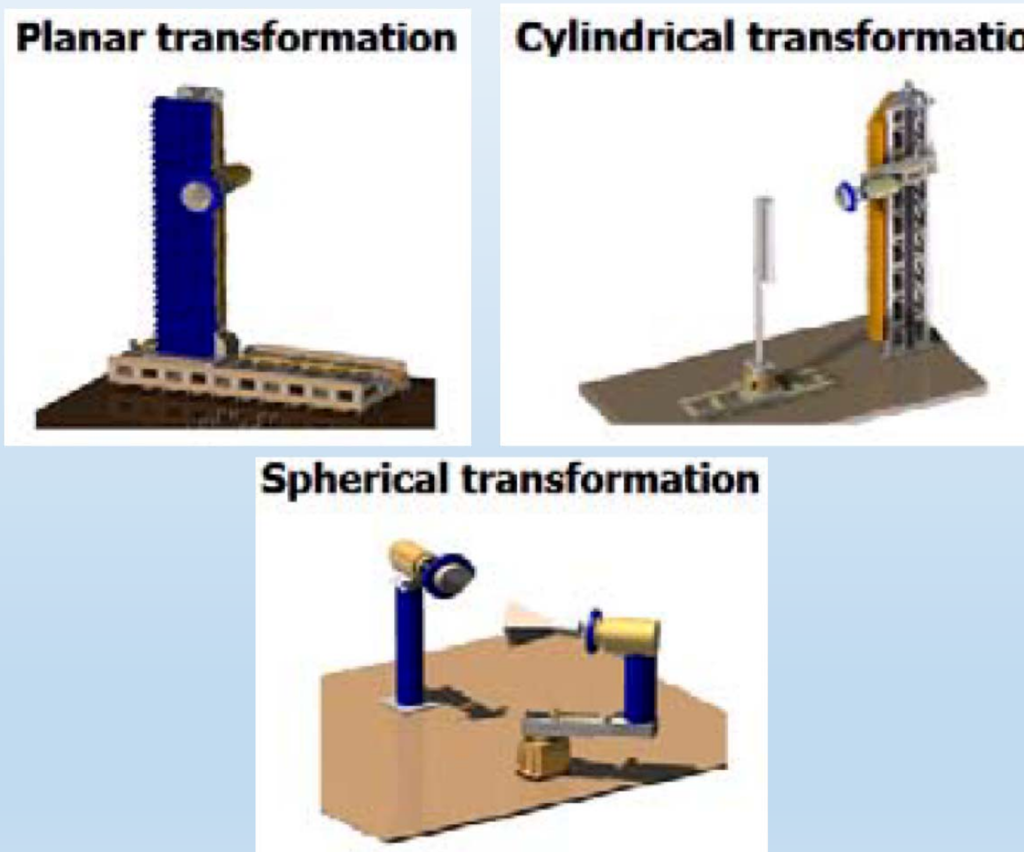


Near field measurement

- Measurements are done in the ***radiating near field*** of AUT.
- The complex (phase and amplitude) vector field is sampled over a ***well defined surface***.
- The measured data are processed to obtain an angular spectrum of plane, cylindrical, or spherical waves appropriate to the measurement surface employed.
- The angular spectrum is corrected for the effects of the measuring probe, and far-field parameters such as power gain, relative pattern, and polarization are calculated from the corrected spectrum.

Near field measurement

- The field of the test antenna is represented by a superposition of
  - plane waves for a planar measurement surface,
  - cylindrical waves for a cylindrical surface,
  - spherical waves for a spherical measurement surface.
- The output voltage of the probe as it moves over the surface is expressed in terms of the probe response which is known, the basis fields of the test antenna, and the effect of the orientation and motion of the probe.



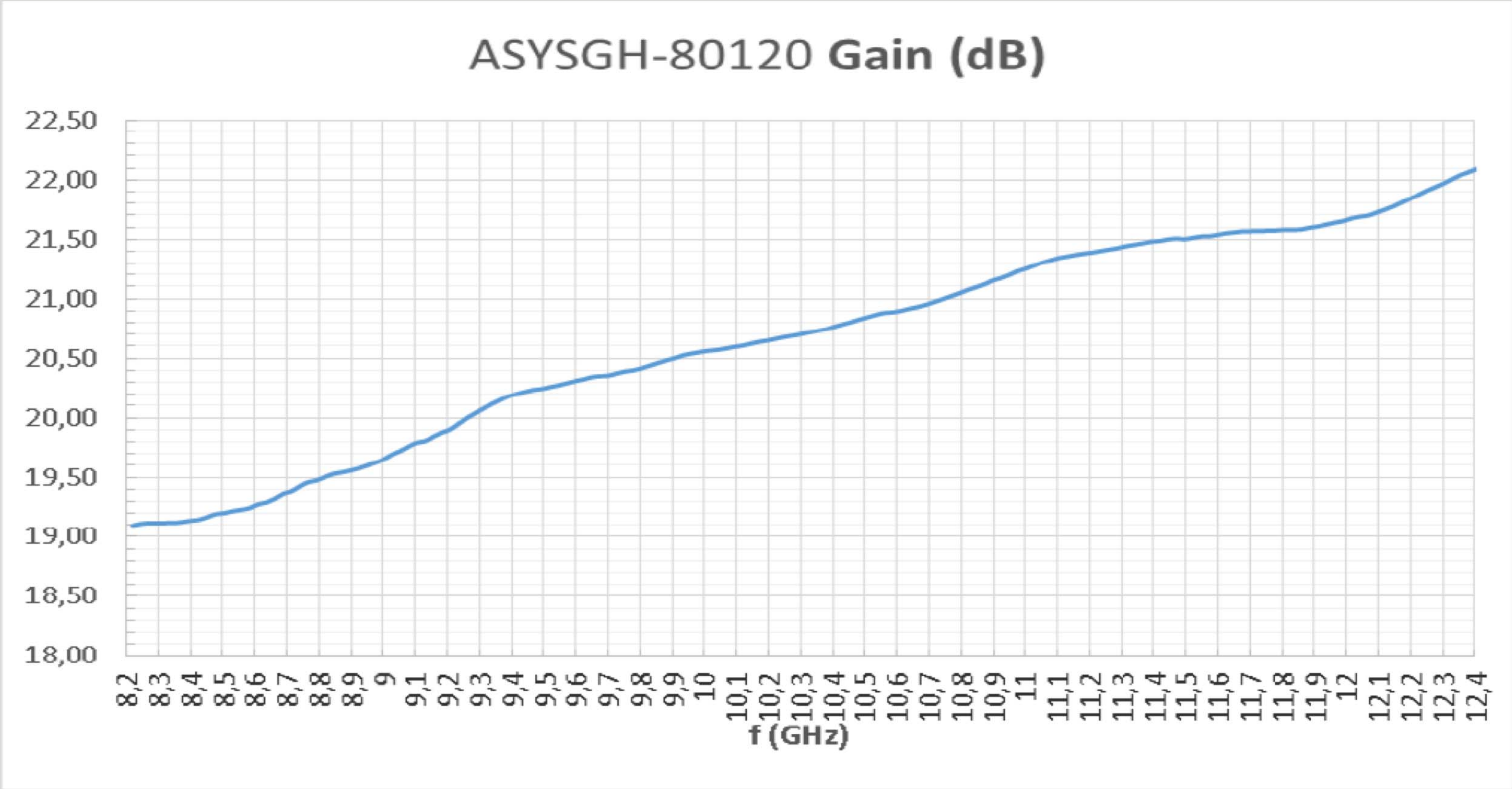
Gain Measurement

- **Gain-Transfer Measurements**
  - ***Measurement of Linearly Polarized Antennas***
    - $(G_T)_{dB} = (G_S)_{dB} + 10\log_{10}\frac{P_T}{P_S}$
    - $(G_S)_{dB}$ is the power gain of the gain-standard antenna,
    - P_T is the power received with the test antenna,
    - P_S is the power received with the gain-standard antenna.
  - ***Measurement of Circularly and Elliptically Polarized Antenna***
    - $(G_T)_{dB} = (G_{TV})_{dB} + (G_{TH})_{dB}$

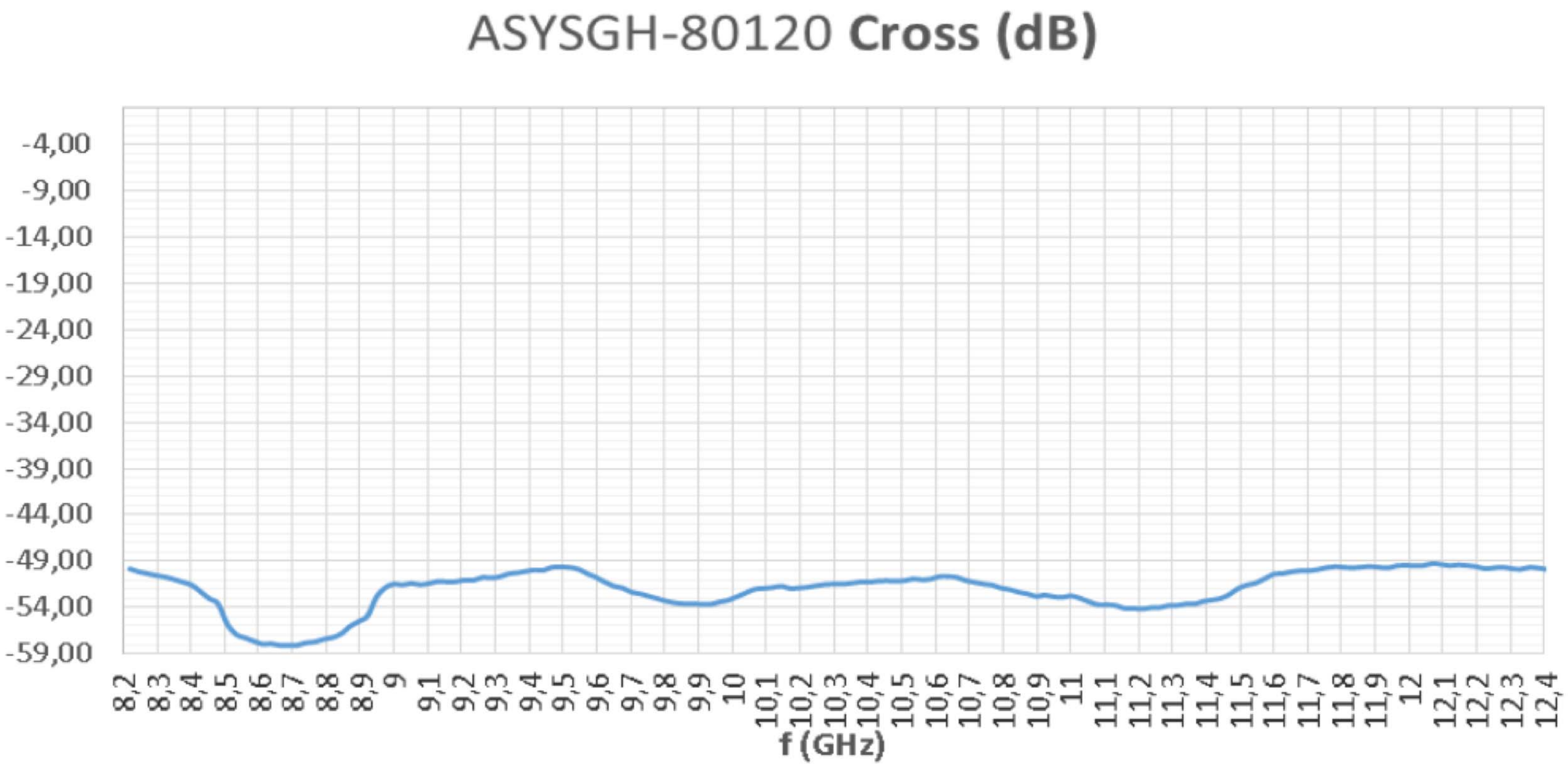
Gain Standard Antenna

ASYSGH-80120

Freq (GHz)	Gain (dB)	Crosspolar (dB)
8,2	19,096	-49,843
8,65	19,321	-58,079
9,1	19,793	-51,401
9,55	20,275	-49,887
10	20,563	-52,846
10,45	20,805	-51,117
10,9	21,153	-52,806
11,35	21,467	-53,636
12,4	22,093	-49,885



ASYSGH-80120 Gain (dB)
22,50
22,00
21,50
21,00
20,50
20,00
19,50
19,00
18,50
18,00
8,2 8,3 8,4 8,5 8,6 8,7 8,8 8,9 9 9,1 9,2 9,3 9,4 9,5 9,6 9,7 9,8 9,9 10 10,1 10,2 10,3 10,4 10,5 10,6 10,7 10,8 10,9 11 11,1 11,2 11,3 11,4 11,5 11,6 11,7 11,8 11,9 12 12,1 12,2 12,3 12,4
f (GHz)



ASYSGH-80120 Cross (dB)
-4,00
-9,00
-14,00
-19,00
-24,00
-29,00
-34,00
-39,00
-44,00
-49,00
-54,00
-59,00
8,2 8,3 8,4 8,5 8,6 8,7 8,8 8,9 9 9,1 9,2 9,3 9,4 9,5 9,6 9,7 9,8 9,9 10 10,1 10,2 10,3 10,4 10,5 10,6 10,7 10,8 10,9 11 11,1 11,2 11,3 11,4 11,5 11,6 11,7 11,8 11,9 12 12,1 12,2 12,3 12,4
f (GHz)

Other topics

- Measurement of the Electrical Properties of Radomes
- Power-Handling Measurements
- Environmental Factors
- Radiation hazards

Radiation hazards (WHO)

- **Are there any health effects?**

  A large number of studies have been performed over the last two decades to assess whether mobile phones pose a potential health risk. To date, no adverse health effects have been established as being caused by mobile phone use.

http://www.who.int/mediacentre/factsheets/fs193/en/

The Interphone Study Group summarized its findings as follows:

- "A reduced odds ratio (OR) related to ever having been a regular mobile phone user was seen for glioma [OR 0.81; 95% confidence interval (CI) 0.70-0.94] and meningioma (OR 0.79; 95% CI 0.68-0.91), possibly reflecting participation bias or other methodological limitations. No elevated OR was observed ≥10 years after first phone use (glioma: OR 0.98; 95% CI 0.76-1.26; meningioma: OR 0.83; 95% CI 0.61-1.14). ORs were < 1.0 for all deciles of lifetime number of phone calls and nine deciles of cumulative call time. In the tenth [highest] decile of recalled cumulative call time, ≥1640 h, the OR was 1.40 (95% CI 1.03-1.89) for glioma, and 1.15 (95% CI 0.81-1.62) for meningioma; but there are implausible values of reported use in this group. ORs for glioma tended to be greater in the temporal lobe 10 than in other lobes of the brain, but the CIs around the lobe-specific estimates were wide. ORs for glioma tended to be greater in subjects who reported usual phone use on the same side of the head as their tumor than on the opposite side."

Exposure Limits (US)

Occupational

All exposures averaged over 0.1 hour (6 minutes)

Frequency Band	S (mW/cm^2)
30 – 100 MHz	1
100 – 300 MHz	1
0.3 – 3 GHz	f/300
3 – 15 GHz	f/300
15 – 30 GHz	5
30 – 300 GHz	5

Non-occupational

All exposures averaged over 0.5 hour (30 minutes)

Frequency Band	S (mW/cm^2)
30 – 100 MHz	0.2
100 – 300 MHz	0.2
0.3 – 3 GHz	f/1500
3 – 15 GHz	f/1500
15 – 30 GHz	f/1500
30 – 300 GHz	5

f : MHz

Exposure Limits (Turkey)

Frequency Band	S (mW/cm^2)
10 – 400 MHz	2
0.4 – 2 GHz	f/200
2 – 60 GHz	10

f : MHz

- Dynamic range of network analyzer and power requirements.
- A picture that shows a noisy measurement
- The dynamic range of the network analyzer