Component characterization

relative measurements

Outline

• Introduction
• Reflectometry
  • SWR measurements
  • Coupler reflectometry
• Measurement of transfer functions
• The network analyser
**Introduction : an example**

P1 = 10 ± 1.2 mW
P2 = 9 ± 1.1 mW
P1 - P2 = 1 ± 2.3 mW
P2/P1 = 0.9 mW

Thus relative measurement are needed

**Component characteristics**

- A component is defined by its scattering matrix
- An "s" parameter is the ratio between two signals
- This ratio should be obtained by comparison, not by computations in order to minimize errors
- Two distinct cases: reflexion and transmission
Reflexion measurements

\[ s_{ji} = \frac{b_j}{a_i} \]

Transmission measurements

\[ s_{ji} = \frac{b_j}{a_i} \]
Comparative measurements

• Search of minima and maxima
• Combining signals (sum or difference)
• Obtention of zeros and substitution measurements
• Coherent frequency change and low frequency measurements

A short interlude: detectors

point diode  Schottky diode
Thus, for $u = u_1 \cos \omega t$

The current will have a continuous term given by

$$I_c = I_s \left[ \frac{(\alpha u_1)^2}{4} + \frac{(\alpha u_1)^4}{64} + \frac{(\alpha u_1)^6}{2304} + \ldots \right]$$

Thus $I_c$ is proportional to $P$: Quadratic detector
The detector itself has a low pass equivalent circuit
Detectors: modulation

On the generator side:
- RF signal
- Modulator
- 1 kHz or 27.8 kHz square signal

On the detector side:
- Detection process
- Modulated detection

Modulated detection graph:
- Modulated RF signal
- Frequency components:
  - $f_{RF}$
  - $f_m$
Detectors: modulation

- Advantages:
  - the band pass filter is tunable, and can be very selective
  - The amplifiers are coupled in AC and not in DC, which takes care of the drift problems

- Do not forget to adjust the frequency of the filter or of the modulating signal!

Measurement of the reflexion coefficient
The good old method: the VSWR meter

The voltage along a transmission line can be expressed as the sum of an incident and a reflected wave.

\[ U_i = \sqrt{Z_{ci}} a_i + b_i = \sqrt{Z_{ci}} (a_i + s_{ii} a_i) \]

\[ U_i(z) = \sqrt{Z_{ci}} a_i(z) \left[ 1 + s_{ii} e^{2 j \beta z} \right] \]

\[ |U_i(z)| = \sqrt{Z_{ci}} |a_i(z)| \left[ 1 + |s_{ii}| \cos(\varphi + 2\beta z) \right]^2 + |s_{ii}|^2 \sin^2(\varphi + 2\beta z) \]

\[ |U_i(z)| = \sqrt{Z_{ci}} |a_i(z)| \left[ 1 + |s_{ii}|^2 + 2|s_{ii}| \cos(\varphi + 2\beta z) \right] \]

VSWR: definition

Extrema of \( |U_i| \):

\[ U_{\text{max}} = \sqrt{Z_{ci}} |a_i| \left( 1 + |s_{ii}| \right) \quad \text{at} \quad \varphi + 2\beta z_i = 2n\pi \]

\[ U_{\text{min}} = \sqrt{Z_{ci}} |a_i| \left( 1 - |s_{ii}| \right) \quad \text{at} \quad \varphi + 2\beta z_i = (2n + 1)\pi \]

\[ \text{ROS} = \text{VSWR} = \frac{U_{\text{max}}}{U_{\text{min}}} = \frac{1 + |s_{ii}|}{1 - |s_{ii}|} \]
Measurement of the VSWR

- vary z
- vary $\beta$ (thus the frequency)
- vary both
Slotted line
Slotted line
Slotted line

![Graph showing slotted line waveforms and parameters](image)
slotted line

The slot mode

coaxial slotted line

Measurement procedure

• Find a maximum of the voltage by moving the probe in the line
• Adjust the needle on the display to the max. by adjusting the gain
• Move to a minimum
• Read the VSWR on the display

• Take care to stay in the quadratic zone of the detector. If it is not possible, use a substitution procedure with a precision tunable attenuator!
Phase measurement

we know that the minimum at $z_c$ corresponds to $\phi=\pi$. Thus $\beta z_c=n\pi$.

The phase $\phi$ of the unknown reflection coefficient is then given by

$$\phi=2\beta(z_c-z_m)+(2n-1)\pi=4\pi\left(z_c-z_m\right)/\lambda_g + \pi \pm 2n\pi$$

Special case of large VSWR

$$\text{vswr} \approx \frac{\lambda_g}{\pi d}$$
Modern reflectometry

- Using one coupler
- Using two couplers

The microwave coupler: a short reminder
Outline

- Theoretical approach
- Ideal coupler
- Real coupler
- Applications:
  - Hybrid ring
  - Hybrid coupler

4-port scattering matrix

General

\[
\begin{bmatrix}
    s_{11} & s_{12} & s_{13} & s_{14} \\
    s_{21} & s_{22} & s_{23} & s_{24} \\
    s_{31} & s_{32} & s_{33} & s_{34} \\
    s_{41} & s_{42} & s_{43} & s_{44}
\end{bmatrix}
\]

adapted and reciprocal

\[
\begin{bmatrix}
    0 & s_{12} & s_{13} & s_{14} \\
    s_{12} & 0 & s_{23} & s_{24} \\
    s_{13} & s_{23} & 0 & s_{34} \\
    s_{14} & s_{24} & s_{34} & 0
\end{bmatrix}
\]
flow chart

adapted and reciprocal and lossless 4-port

\[
\begin{bmatrix}
0 & s_{12}^* & s_{13}^* & s_{14}^* \\
{s_{12}^*} & 0 & s_{23}^* & s_{24}^* \\
{s_{13}^*} & s_{23}^* & 0 & s_{34}^* \\
{s_{14}^*} & s_{24}^* & s_{34}^* & 0
\end{bmatrix}
\begin{bmatrix}
0 \\
{s_{12}} \\
{s_{13}} \\
{s_{14}}
\end{bmatrix}
= \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
What does it mean?

\[ s_{13}^* s_{14} + s_{23}^* s_{24} = 0 \quad (\text{line 3 column 4}) \quad x s_{14}^* \]
\[ s_{13}^* s_{23} + s_{14}^* s_{24} = 0 \quad (\text{line 1 column 2}) \quad x s_{23}^* \]

\[ s_{13}^* \left( |s_{14}|^2 - |s_{23}|^2 \right) = 0 \]

1st solution: \( s_{13} = 0 , s_{14} \neq 0 , s_{23} \neq 0 \)

thus: \[ s_{13}^* s_{14} + s_{23}^* s_{24} = 0 \Rightarrow s_{24} = 0 \]
\[ s_{13}^* \left( |s_{14}|^2 - |s_{23}|^2 \right) = 0 \]

**2nd solution:** \[ |s_{14}| = |s_{23}| \]

**selection of reference planes:** \[ s_{14} = s_{23} = j\beta \]

\[ |s_{12}|^2 + |s_{13}|^2 + |s_{14}|^2 = 1 \]  
(line 1 x column 1)

\[ |s_{13}|^2 + |s_{23}|^2 + |s_{34}|^2 = 1 \]  
(line 3 x column 3)

Thus: \[ s_{12} = s_{34} = \alpha \quad \text{with adequate ref. planes} \]

---

\[ s_{12}^*s_{24} + s_{13}^*s_{34} = 0 = \alpha \left( s_{24} + s_{13}^* \right) \]  
(line 1 x column 4)

\[ s_{13}^*s_{14} + s_{23}^*s_{24} = 0 = \beta \left( s_{13}^* - s_{24} \right) \]  
(line 3 x column 4)

\[ \alpha = 0, \beta = 0 \]

\[ s_{13} = s_{24} = 0 \]
Ideal coupler

\[
\begin{bmatrix}
0 & s_{12}^* & 0 & s_{14}^*
s_{12}^* & 0 & s_{23}^* & 0 \\
0 & s_{23}^* & 0 & s_{34}^*
s_{14}^* & 0 & s_{34}^* & 0
\end{bmatrix}
\begin{bmatrix}
0 & s_{12} & 0 & s_{14} \\
0 & s_{12} & 0 & s_{23} \\
0 & s_{23} & 0 & s_{34} \\
0 & s_{14} & 0 & s_{34}
\end{bmatrix}
= \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[|s_{12}|^2 + |s_{14}|^2 = 1\]
\[|s_{12}|^2 + |s_{23}|^2 = 1\]
\[|s_{23}|^2 + |s_{34}|^2 = 1\]
\[|s_{14}|^2 + |s_{34}|^2 = 1\]
\[s_{12} s_{23}^* + s_{14} s_{34}^* = 0\]
\[s_{12} s_{14}^* + s_{23} s_{34}^* = 0\]

\[|s_{12}| = |s_{34}| = \alpha\]
\[|s_{14}| = |s_{23}| = \beta\]
\[\alpha^2 + \beta^2 = 1\]

\[
\begin{align*}
\phi & = \alpha e^{j\varphi} \\
\eta & = \alpha e^{j\eta} \\
\psi & = \beta e^{j\psi} \\
\theta & = \beta e^{j\theta}
\end{align*}
\]

with \((\varphi + \eta) = \pi + (\psi + \theta) + 2n\pi\)

and \(\alpha > \beta\) by convention
symmetric coupler

\[ \psi = \theta = \frac{\pi}{2} \]

\[
\begin{bmatrix}
0 & \alpha & 0 & j\beta \\
\alpha & 0 & j\beta & 0 \\
0 & j\beta & 0 & \alpha \\
j\beta & 0 & \alpha & 0
\end{bmatrix}
\]

asymmetric coupler

\[ \psi = 0, \theta = \pi \]

\[
\begin{bmatrix}
0 & \alpha & 0 & \beta \\
\alpha & 0 & -\beta & 0 \\
0 & -\beta & 0 & \alpha \\
\beta & 0 & \alpha & 0
\end{bmatrix}
\]
Summary: ideal coupler

Coupling: \( LC = -20 \log_{10} \beta \)
Attenuation: \( LA = -20 \log_{10} \alpha \) \( \alpha \geq \beta \)

Isolation: \( LI_{31} = -20 \log_{10} |s_{31}| \)
Isolation: \( LI_{24} = -20 \log_{10} |s_{24}| \)
Directivity: \( LD_{13} = LI_{13} - LC = -20 \log_{10} |s_{31}|/\beta \)
Directivity: \( LD_{24} = LI_{24} - LC = -20 \log_{10} |s_{24}|/\beta \)

real coupler

- \( \alpha \geq \beta \)
- Attenuation: \( LA = -20 \log_{10} \alpha \)
- Coupling: \( LC = -20 \log_{10} \beta \)
- Isolation: \( LI_{31} = -20 \log_{10} |s_{31}| \)
- Isolation: \( LI_{24} = -20 \log_{10} |s_{24}| \)
- Directivity: \( LD_{13} = LI_{13} - LC = -20 \log_{10} |s_{31}|/\beta \)
- Directivity: \( LD_{24} = LI_{24} - LC = -20 \log_{10} |s_{24}|/\beta \)
example: 10 dB waveguide coupler

example: magic T
example: magic T combined with 10 dB coupler

Example: E Band 10 dB coupler
### Example

<table>
<thead>
<tr>
<th>LC [dB]</th>
<th>$\beta$</th>
<th>$\alpha$</th>
<th>LA [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>0.01</td>
<td>0.99995</td>
<td>0.0004</td>
</tr>
<tr>
<td>30</td>
<td>0.0316</td>
<td>0.9995</td>
<td>0.004</td>
</tr>
<tr>
<td>20</td>
<td>0.1</td>
<td>0.995</td>
<td>0.04</td>
</tr>
<tr>
<td>10</td>
<td>0.316</td>
<td>0.948</td>
<td>0.45</td>
</tr>
<tr>
<td>3</td>
<td>0.707</td>
<td>0.707</td>
<td>3</td>
</tr>
</tbody>
</table>

### Directivity: measure of quality

- Microstrip hybrid coupler: 30 dB
- Multihole waveguide couplers: 40 dB
- Waveguide couplers used in metrology: 50-60 dB
Couplers used in measurement

Reflectometry

- with 1 coupler
  - amplitude measurements
- with 2 couplers
  - precision measurements
  - phase and amplitude measurements
1 coupler reflectometry

\[ b_3 = s_{21} s_{32} a_1 \]

\[ \frac{b_3}{b_{3c}} = -s_{ii} \]

\[ b_{3c} = -s_{21} s_{32} a_1 \]
• $s_{ii}$, $s_{13}$, $s_{24} << 1$, but non equal to zero
• we need:
  • coupling $LC = -20\log\beta$
  • isolation $LI_{13} = -20\log|s_{13}|$
  • $LI_{14} = -20\log|s_{24}|$
• The quality of the coupler is given by:
  • directivity $LD_{13} = LI_{13} - LC = -20\log|s_{13}|/\beta$
  • $LD_{24} = LI_{24} - LC = -20\log|s_{24}|/\beta$

1 coupler reflectometry

$$b_3 = a_1(s_{21}s_{ii}s_{32} + s_{31})$$
$$b_{3c} = a_1(-s_{21}s_{32} + s_{31})$$
1 coupler reflectometry

- $s_{31}$ is non negligible at the numerator if $s_{ii} \ll 1$
- $s_{31}$ is negligible at the denominator if the couple is of good quality:
  $$\frac{b_3}{b_{3c}} = -s_{ii} - \frac{s_{31}}{s_{21}s_{32}}$$
- The phases of the signals are not known

$$\frac{b_3}{b_{3c}} \leq \frac{s_{31}}{s_{21}s_{32}} \leq s_{ii} \leq \frac{b_3}{b_{3c}} + \frac{s_{31}}{s_{21}s_{32}}$$

- For a weak coupling (LC large) $S21 \approx 1$
- The error term is directly the directivity of the coupler:
  $$\frac{b_3}{b_{3c}} - \frac{s_{31}}{s_{21}s_{32}} \leq s_{ii} \leq \frac{b_3}{b_{3c}} + \frac{s_{31}}{s_{21}s_{32}}$$

- $\text{LD [dB]} \quad |s_{31}/s_{32}|$
  - 10 \quad 0.3162
  - 20 \quad 0.1
  - 30 \quad 0.03162
  - 40 \quad 0.01
  - 50 \quad 0.003162
  - 60 \quad 0.001
2 coupler reflectometry

\[
\frac{b_s}{b_r} = \frac{A s_{ii} + B}{C s_{ii} + D}
\]

\[
A = s_{21}s_{32} - s_{31}s_{22}
\]

\[
B = s_{31}
\]

\[
C = s_{21}s_{42} - s_{41}s_{22}
\]

\[
D = s_{41}
\]

Use adapters to put \( B = C = 0 \)

\[
\frac{b_s}{b_r} = s_{21}s_{ii}s_{32}
\]

\[
\frac{b_s}{b_r} = s_{41}
\]
2 coupler reflectometry

ratiometer

A

zero detector

A

2 coupler reflectometry
2 coupler reflectometry

Transmission measurements

(Attenuation measurements)
Transmission measurements

- Attenuation (very common)
- Phase (more seldom)

Causes of attenuation

- Absorption in the component
- Mismatch of the component
**Attenuation**

\[ LA = -10 \log \left( \frac{P_2}{P_1} \right) \text{ dB} \]

**Attenuation : example**

\[ LA = -10 \log \left( \frac{P_2}{P_1} \right) \text{ dB} \]

**a) Rg = 20 \Omega**

\[ P_1 = \left( \frac{100}{20 + 30} \right)^2 \times 30 = 120W \]

\[ P_2 = \left( \frac{100}{20 + 30 + 100} \right)^2 \times 30 = \frac{40}{3}W \]

\[ LA = 10 \log 9 = 9.5 dB \]
Attenuation: example

\[ LA = -10 \ \text{Log}(P_2/P_1) \ \text{dB} \]

b) \( R_g = 70 \ \Omega \)

\[ R_1 = \left( \frac{100}{70+30} \right)^2 30 = 30W \]
\[ P_2 = \left( \frac{100}{70+30+100} \right)^2 30 = \frac{30}{4} W \]
\[ LA = 10 \text{Log}4 = 6dB \]

Effet od the mismatch of the source and the load
Methods

- Direct measurement
- Substitution measurement
- Measurement through reflection measurement
- Method using couplers
Direct measurement

- The detector should be adapted (use attenuator or isolator)
- The detector should be quadratic (limited dynamic range)
- The connexions should be reproductible (sometimes difficult)
- The generator should deliver a signal which is stable over time

Cheap, but not very precise and quite limited !!!

Substitution measurements

- The precision attenuator (rotative blade) allows a measurement precision of 1-2%, over a 60 dB dynamic range
- Only for waveguides
- No precision attenuators for coaxial cables
Measurement through reflection measurement

1) the device is matched but reciprocal

\[ \rho = \frac{b_1}{a_1} = s_{21}^2 \rho_{cc} = s_{21}^2 \]

\[ LA = -10 \log |\rho| + 10 \log |\rho_{cc}| = -10 \log |\rho| \]

\[ \varphi = \frac{1}{2} \arg(\rho) - \frac{1}{2} \arg(\rho_{cc}) \pm n\pi = \frac{1}{2} \arg(\rho) + \frac{\pi}{2} \pm n\pi \]

2) the device is mis-matched but reciprocal

\[ \rho = \frac{b_1}{a_1} = s_{11} + \frac{s_{21}^2 e^{-j\psi}}{1 - s_{21} e^{-j\psi}} \]

\( f(\psi) \) is a circle on the Smith chart
Attenuation measurement

Same principle than reflectometry

Network analyser measurements
Microwave measurements

Analog NWA
Analog NWA

Calibration: the old analog way
Calibration: the old analog way

Digital Network Analyser
Errors

- 1. Systematic errors:
  - Component imperfections
  - Time invariant and predictable
  - Can be characterized and taken into account mathematically during the measurements
- 2. Random errors:
  - Vary randomly with time
  - Cannot be eliminated with calibration
  - Due to noise, connexion repetability, cables (flexion), etc.
- 3. Errors linked to drift:
  - Due to variations in the instrument after calibration
  - Due mainly to temperature shift
  - Can be eliminated by a new calibration
Errors and calibration: the 12 error terms

F: forward
R: reverse

D: directivity
X: isolation
T: transmission
R: reflection
L: match of the load
SOLT calibration (Short, Open, Load, Trough)

**UNCORRECTED RESPONSE**
- Convenient
- Generally not accurate
- No errors removed

**ONE-PORT**
- Easy to perform
- Use when highest accuracy is not required
- Removes frequency response error

**FULL TWO-PORT**
- For reflection measurements
- Need good termination for high accuracy with two-port devices
- Removes these errors: Directivity, Source match, Reflection tracking

**ENHANCED-RESPONSE**
- Combines response and 1-port
- Corrects source match for transmission measurements

Source: Agilent application note Nr 5965-7709E

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SOLT calibration: 1port model

**To solve for error terms, we measure 3 standards to generate 3 equations and 3 unknowns**

- Assumes good termination at port two if testing two-port devices
- If using port 2 of NA and DUT reverse isolation is low (e.g., filter passband):
  - assumption of good termination is not valid
  - two-port error correction yields better results

Source: Agilent application note Nr 5965-7709E
SOLT calibration: 1-port model

Data before 1-port calibration

Data after 1-port calibration

SOLT calibration: 2-port model

Each actual S-parameter is a function of all four measured S-parameters.
Analyzer must make forward and reverse sweep to update any one S-parameter.
Luckily, you don’t need to know these equations to use network analyzers!!!

Source: Agilent application note Nr 5965-7709E
TRL (Trough, Reflect, Line) calibration

- Used for non coaxial or non waveguide measurements
- 16 measurements for 12 unknown parameters
- => redundancy! We need not to know the standards very precisely

+ Measurements of incident signals
+ Measurements of isolations with matched loads

Antenna measurement
What is an antenna?

- An antenna transforms a guided wave to a radiated wave
- An antenna is a link between Krichhof’s world (circuit) and Maxwell’s world (fields)
- An antenna is a spatial filter and a spectral filter
- An antenna is a one port device
- An antenna is a two port device
Circuit characteristics

• Frequency response of the antenna (antenna bandwidth)
• Input impedance of the antenna
• Reflection coefficient of the antenna

Can be measured using S parameter measurements or Power measurements

Antenna characterisation using power measurements

Note: we still need A coupler!
Matching measurement using a SA:

- Measure first the reflected power in the absence of the antenna (open circuit = max reflection), or better using a short circuit.
- In the presence of the antenna, we measure the difference of reflected power, which corresponds to the transmitted (radiated) power.
Circuit measurements using an NWA

- The antenna input reflection coefficient is measured after a usual 1 port calibration procedure.
Sources of errors

- Systematic errors (can be calibrated out)
- Random errors (noise, connexions, cables, etc.)
- Drift errors (can also be taken care off)
- Errors specific to antennas: spurious radiation

The importance of the environment
The solutions

- Anechoic chamber
- Outdoor ranges

Anechoic chamber

Rectangular Anechoic Chamber
Outdoor ranges

Field characteristics

- Radiation pattern
- Directivity
- Gain
- Polarization
- Radiation efficiency

Most of these measurements imply the Measurement of an attenuation coefficient (transfer function)
Reminders

- Radiated power per solid angle (Far field):
  \[ P_{\Omega}(\theta, \phi) d\Omega \]

- Gain (with respect to an isotropic radiator):
  \[ G(\theta, \phi) = \frac{P_{\Omega}(\theta, \phi)}{P_f} \]

- Maximum gain:
  \[ G_{\text{max}} = \max [G(\theta, \phi)] \]

Principle

Mesured:
- \( kP_f \), \( P_r \)

Known:
- \( k \), \( L \) et \( \lambda \)

\[ G_1G_2 = \frac{P_r}{P_f} \left( \frac{4\pi L}{\lambda} \right)^2 \]
Several solutions

- Known $G_1$
- Use two identical antennas ($G_1 = G_2$)
- Do three measurements using three antennas ($G_1 G_2$, $G_1 G_3$, $G_2 G_3$), :

$$G_1 = \sqrt{\frac{G_{12} G_{13}}{G_{23}}}, \quad G_2 = \sqrt{\frac{G_{12} G_{23}}{G_{13}}}, \quad G_3 = \sqrt{\frac{G_{13} G_{23}}{G_{12}}}$$

Radiation pattern

$$r(\theta, \phi) = \frac{G(\theta, \phi)}{G_{\text{max}}} \quad \Rightarrow \quad 0 \leq r \leq 1$$

Principle:
- You need two antennas or one antenna and a known reflector
- You need to be in the far field

$$L \geq \frac{2d^2}{\lambda}$$
Far field (variation of the phase over the range)

Usual criterion: $\Delta \varphi$ smaller than $\pi/8$

Amplitude variation over the range

- Usually up to 0.5 dB amplitude variation is tolerated over the aperture of the antenna under test
Errors due to refelction

- A interfering field which is 30 dB below the direct path signal can cause a variation of ±0.25 dB in the measured maximum gain and can seriously affect the measured sidelobe structure of the pattern.
- Thus: use a directive transmitting antenna, an anechoic chamber or an outdoor range.

Elevated outdoor range

- Variations in the amplitude of the field incident over a test aperture must also be restricted for accurate far-zone measurements.
- For range geometries employing comparatively large transmitting and test tower heights (i.e., elevated range geometries), it is advisable to restrict amplitude taper to the order of 1/4 dB or less by using the following criterion:

\[
d_t \leq \frac{2R}{4D}
\]
With

- $d_t =$ transmitting antenna diameter
- $\lambda =$ wavelength
- $R =$ range length
- $D =$ maximum test aperture dimension
- $H > 6D$

Ground reflection test ranges

Constructive interference with the ground reflected signal is used. Good for low directive antenna test.
Ground reflection test ranges

In these expressions:

- **R** = range length
- **D** = test aperture diameter
- **λ** = wavelength
- **h_r** = height of the center of the test aperture
- **h_t** = height of the center of the transmitting antenna
- **d_t** = transmitting antenna diameter

\[
R \geq \frac{2D^2}{\lambda}
\]

\[
h_r \geq 3.3D \quad \text{Vertical-plane amplitude taper 1/4 dB}
\]

\[
h_t = \frac{2R}{4h_r} \quad \text{Peak of first interference lobe at } h_t
\]

\[
d_t \leq \frac{2R}{4D} \quad \text{Horizontal-plane amplitude taper } \leq 1/4 \, \text{dB}
\]

Anechoic chambers

Rectangular Anechoic Chamber

\[
L \geq \frac{2d^2}{\lambda}
\]
Anechoic chambers

- Large chambers needed for large antennas (directive antennas)
- Large chambers needed for high frequencies

Expensive

Solutions

- Near field measurements, then near to far field transform
- Compact ranges
Near field ranges

- Planar
- Cylindrical
- Spherical

Planar near field ranges

- **Planar Near-Field Method** – With planar near-field scanning, the probe usually is scanned in X and Y linear coordinates over the aperture of the test antenna. A large planar scanner is used to move the probe over a very accurate plane located in front of the test antenna’s aperture. Once aligned to the scan plane, the test antenna is not moved during the collection of the nearfield data. Planar near-field provides limited angular coverage of the test antenna’s field due to the truncation caused by the scanner’s dimensions.
**Cylindrical near field ranges**

- **Cylindrical Near-Field Method** – For this method the probe typically is scanned in one linear dimension using a single axis linear positioner. The test antenna is stepped in angle on a rotary axis oriented parallel to the linear axis. The resulting scan describes a cylindrical surface around the test antenna. Cylindrical near-field scanning can provide complete angular coverage of the test antenna’s field in one plane. The orthogonal plane has limited angular coverage due to truncation caused by the finite length of the linear scanner.

**Spherical near field ranges**

- **Spherical Near-Field Method** – Spherical near-field scanning normally involves installing the test antenna on a spherical scanning positioner. The probe antenna is normally fixed in space. The test antenna is normally scanned in one angular axis and stepped in an orthogonal angular axis. The resulting data is collected over a spherical envelope surrounding the test antenna. Full or nearly-full coverage of the test antenna’s radiating field can be evaluated with this type of near-field system.
Compact Antenna Test Range

Advantages of compact ranges

- Anechoic
- Reasonable size for directive antennas
- Reasonable cost
Typical instrumentation

- The good old way
- Outdoor ranges
- Indoor ranges

The old way (using power measurements)
Typical outdoor setup

- Avoid long cables for RF signals (put the front end of the receiver as close to the antenna under test as possible, and the source close to the transmitting antenna)
Examples of setups

- UPM compact range
- SATIMO near field range
UPM compact range

Measurements

- Measurement freq.: 12 GHz
- Measurement type: Far field
- Scan axis: $\theta$
- Scan range: $-179^\circ \leq \theta \leq 179^\circ$
- Scan increment: 0.075° for $-30^\circ \leq \theta \leq 30^\circ$
  0.5° for $-179^\circ \leq \theta \leq 179^\circ$
- Step axis: $\phi$
- Step range (cm): 0°, 45°, 90°, 135°
- Probes: Corrugated conical horn

Satimo spherical near field range

High gain antenna test system (2)

Mobile system:
- Frequency: 3.0 – 3.5 GHz
- Gain: app. 30-35 dB
- SLL: down to 40dB below peak
- 61 dual polarized probe array (3° spacing)
Satimo near field range

Measurement accuracy specification

- Measurement repeatability within +/- 0.1 dB
- Gain error at bore sight within +/- 0.3 dB
- The error level in dB on side lobes below 40 dB below the peak should be better than +/- 2.0 dB (1σ 0> confidence level of 68.27%).
- Acceptance testing: comparison with reference measurements in compact test range, Intespace (F).