Antenna pattern corrections

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• Slides are based on D.Sc. Ville Viikari’s lecture slides in ESoA Course, ”Antenna measurements at millimetre and submillimetre wavelengths,” in May 2009.
Compact Antenna Test Ranges

- Surface accuracy requirement of the collimating element depends on the wavelength: very difficult to build satisfactory collimating element at submm wavelengths
- Measurement accuracy requirements are difficult to achieve
Antenna Pattern Measurement

- Antennas are designed to operate in far field
- Antenna pattern is recorded by rotating the AUT in the plane wave
- In compact range, the plane wave volume is called quiet-zone
- The pattern measurement accuracy depends on the quiet-zone quality
- General criteria for the quiet-zone quality:
  - Amplitude ripple ±0.5 dB peak-to-peak
  - Phase ripple ±5° peak-to-peak
Measurement Accuracy of a CATR

- Spurious signals caused by:
  - Range reflections
  - Leakage of the range feed
  - Edge diffraction
  - Collimating element manufacturing errors
- Spurious signal level should be 10 dB lower than the side-lobe level of the AUT
- Spurious signals can be decreased:
  - Physically by improving the range
  - Virtually by using correction techniques
Pattern Measurement in Distorted Quiet-Zone

Pattern measurement in ideal quiet-zone

Pattern measurement in distorted quiet-zone

Spurious plane wave

True pattern

AUT

Measured pattern

-α

α

Spurious side lobe

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Antenna Pattern Correction Techniques

- Correction is based on some additional information:
  1. Measured quiet-zone field
  2. Impulse (or frequency) response of the test range
  3. Spatial response of the test range
  4. Antenna size and oversampling in antenna pattern measurement
- Most of the techniques are developed for microwave frequencies
- Some methods are presented in more detail in the following
  - Deconvolution
  - Time gating
  - Antenna pattern comparison
  - Feed scanning APC
  - Adaptive array correction
  - Mathematical absorber reflection suppression
Deconvolution Technique

• The measured antenna pattern can be assumed to be

\[
P_{\text{meas}}(\theta) = P_{\text{true}}(\theta) \otimes S(\theta)
\]

where \( P_{\text{true}} \) is the true pattern, \( S \) is the angular spectrum of the range.

• By finding \( S \), the true pattern of the AUT can be calculated from the measured pattern.

• Two ways to measure \( S \):
  1. By measuring an antenna pattern of a reference antenna, whose pattern is exactly known, and by using above equation.
  2. By sampling the electrical field in the quiet-zone using planar scanner.
Plane Wave Spectrum of the Test Range

\[ E(x) = \int S(k_x) e^{jk_x x} \, dk_x \]

\[ k_x = k \sin(\theta) \]

\[ E[n] = \sum_{m} S[m] e^{j\xi} d x m n \]

Plane wave components caused by spurious signals

Quiet-zone field

Desired plane wave

Ripple caused by extraneous plane wave components
Problems with Deconvolution Technique at Submm Wavelengths

- Quiet-zone scanning is as challenging as near-field measurement
  - One could measure the near field of the AUT as well, no CATR needed
- No reference antennas, whose antenna pattern is known, are available
- Also the phase of the antenna pattern has to be measured
  - Measuring phase may be difficult and positiong errors may be too large
- When used, the two-dimensional antenna pattern has to be measured
  - Measuring two-dimensional pattern may be too time consuming
- Seems very impractical technique at submm wavelengths
Other Techniques Utilizing the Measured Quiet-Zone Field

• Test-zone field compensation

• D. A. Leatherwood and E. B. Joy:
  “Plane wave, pattern subtraction, range compensation”
  – Quiet-zone field is probed on a sphere enclosing the AUT
  – Based on spherical-wave representation

• The quiet-zone probing on a sphere is extremely difficult and time consuming if full sampling is performed
  – Does not seem practical at high frequencies
Time Gating

- Transmitter
- AUT
- Reflector
- Spurious signal path
- Straight signal path
- Received signal
- Gate
- Gated signal
- Time
**Time Gating**

- **Hard gating:** measurements are done in time domain
  - Pulsed signal is transmitted and RF-switch is used on the receiver side
- **Soft gating:** measurements are done in frequency domain
  - Gate is applied computationally
  - More information since no information has gated out at the measurement
  - Gate function can be changed later
- **Measurement time may be shorter with hard gating**
- **Spatial resolution (and correction accuracy) depends on the pulse width (duration) \( \tau \)**
- **The pulse width is limited by AUT dimensions \( D_{AUT} \) and bandwidth \( B \) of range, AUT and measurement equipment**
Other Time And Frequency Techniques

• Frequency shift
  – Measurements at different frequencies are averaged

• Matrix-pencil and oversampled Gabor-transform
  – Time domain response is solved from the frequency response
    with the matrix-pencil or the oversampled Gabor-transform
    methods

• Channel equalization
  – Based on channel model of tapped delay lines and channel
    equalization
Applicability of Time And Frequency Techniques at Submm Wavelengths

• Seem practical, only a possibility to change the frequency is needed
• Frequency shift is the simplest method
• Other methods require that the frequency can be swept
• Different frequencies can be measured fast with a network analyzer
• The spatial resolution (and the correction accuracy) depends on the bandwidth
  – At submillimeter wavelengths the required bandwidth is relatively small
• Channel equalization requires a possibility to modulate the signal
  – May be challenging to implement
Antenna Pattern Comparison (APC)

- Antenna pattern is recorded several times at different locations in the quiet-zone.
- Measured patterns are superimposed
  - Corrected pattern is an average of measured patterns
  - Range reflections are determined from the deviations between patterns
- Quiet-zone has to be large enough
- Possibility to move the AUT required
- Technique is a bit laborious
Feed Scanning Based APC

- Range feed is moved instead of AUT
- Range feed is usually much lighter than the AUT
- Quiet-zone quality need to be taken into account when moving the feed
Feed Scanning Based APC

Measured in non-distorted QZ
Measured in distorted QZ
Feed scanning APC
APC
Adaptive Array Correction

- Different measurements are combined to form a virtual array
- Array factor is modulated so, that it has constant gain towards to desired signal and high attenuation to other directions
- Computationally more complicated than the APC
Example of a Synthesized Array Pattern

**Uniform weighting**

**Adaptive weighting**

Signal to interference = -20 dB  
Signal to interference = 10 dB
Results with Adaptive Array Correction Technique

Antenna patterns

Error in the corrected patterns
Other Spatial Techniques

• Novel APC (NAPC)
  – Based on a circle fitting algorithm

• Virtual array
  – AUT is displaced as a function of the rotation angle

• Adaptive array technique based on the MUSIC
  – Multipath signals are separated with the MUSIC algorithm
Applicability of Spatial Techniques at Submm Wavelengths

- Antenna pattern comparison seems practical
  - Only a possibility to move the AUT is needed
  - Time consuming if compared to frequency techniques
- Feed scanning APC seems practical
  - Only a possibility to move the range feed is required
- Other techniques require more sophisticated translation stage for the AUT
- The translation stage does not need to be very accurate if the position of the AUT can be measured precisely
  - Seems possible methods
- In the virtual array method very precise translation stage is needed
  - More challenging to implement
- Adaptive array strategy and the NAPC may be sensitive to far-field assumption
  - Far-field conditions are not likely satisfied
Mathematical Absorber Reflection Suppression (MARS)

- Developed for spherical near-field measurements
- Requires:
  1. Information on antenna size (minimum sphere that encloses the antenna)
  2. Oversampled radiation pattern
- Minimum sphere gives information on maximum number of modes that can derive from the antenna
- Higher order modes must derive from the measurement facility
- Can also be used in CATRs for eliminating distortions deriving from the antenna rotation stage
Range Evaluation Techniques

- Range evaluation techniques are used to determine the measurement accuracy in the evaluated range.
- Gives information on locations of distortion signals
  - Range improvement
- Antenna pattern correction techniques give information also on range quality
- Probed quiet-zone field data can also be used to locate distortion signals
  - Distortion location estimation – near-field focusing
  - Direction-of-arrival estimation – spectral techniques
  - Time-of-arrival estimation – spectral techniques
Near-field focusing (NFF)

\[ I(\rho, z, f) = \left| \sum_{m=1}^{M} h(\rho_m, 0, f) w(\rho_m) e^{j2\pi d(\rho, z, \rho_m)/c} \right| \]

\[ d(\rho, z, \rho_m) = \sqrt{(\rho - \rho_m)^2 + z^2} \]

- The phase of the probed data is adjusted to focus the probe data in the image domain
- Stray signal sources are found in the local maxima of \( I \)
- Desired plane wave has a planar wave front
  - It does not focus to a single point
- Planar wave front has to subtracted from the probe data
Direction-of-Arrival

- Plane wave spectrum is calculated from the probe data
  - Fourier transform
  - MUSIC
  - ...
- The local maxima in the spectrum give the direction of the stray signal sources
- Far field conditions are assumed
  - Does not hold for submm ranges
- The desired planar wave front may hide stray signals
  - The desired plane wave can be subtracted from the probe data
- Probe data also in time- or frequency domain
  - Time-of-arrival can be calculated in addition to the direction
Conclusions

• Hologram and reflector based CATRs are potential methods for characterizing submm wave antennas
• Measurement accuracy need to be improved for measuring very low side lobe levels
• Physical improvement may be difficult or impossible
• Measurement accuracy can be improved also with pattern correction techniques
• Most of the techniques are developed for lower frequencies
• Some of the techniques seem applicable at submm wavelengths
• Correction is based on:
  1. Measured quiet-zone field
  2. Impulse (or frequency) response of the test range
  3. Spatial response of the test range
  4. Antenna size and oversampled antenna pattern
References


