Basic Concepts of Antenna Characterization and Applications in EMC Measurement

Zhong Chen
Director of RF Engineering
ETS-Lindgren, Inc.

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Goal of the presentation

- Promote a deeper understanding of some of the practical EMC antenna terms beyond basic definitions
  - Antenna Factor
  - Mismatch
  - Balance
  - Phase center
  - Cross-polarization rejection
- Provide an overview of antenna calibration using the Standard Site Method (SSM)

Antenna Factor

- It is a receiving transducer factor

$$AF = \frac{E}{V}$$

Incident E field

Voltage on a 50 ohm load connected to antenna

- It has a unit of (m^{-1}).
- In dB: **E(dB uV/m) = V (dB uV) + AF (dB/m)**
- **It assumes the antenna is connected to a 50 ohm load (a typical receiver)**

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Antenna Factor

- AF is normally provided by a calibration lab
- The E field reading is the incident E field from the **boresight direction**.
- AF is directly related to the **realized gain**.
  - Includes mismatch
  - Includes ohmic loss
- Is NOT a suitable parameter to describe antenna when used in a complicated environment where fields are coming from many directions, e.g., in a reverb chamber.

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Gain and AF – Two Peas in the Same Pod

- $P_r = P_{inc} A_e$ (A_e- effective aperture)
- $A_e = \frac{g_{realize} \lambda^2}{4\pi}$

Realized Gain/ include mismatch and loss

$$\Rightarrow P_r = P_{inc} \frac{g_{realize} \lambda^2}{4\pi}$$

- $P_r = \frac{V^2}{50}$

50 ohm system

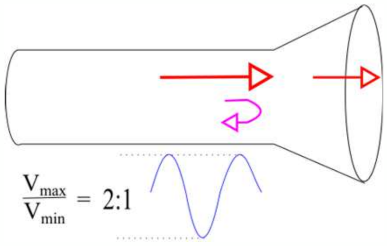
- $P_{inc} = \frac{E^2}{377}$

Plane wave /far field

$$\Rightarrow AF = \frac{E}{V} = \frac{9.73}{\lambda \sqrt{g_{realize}}}$$

Mismatch

- In a 50 ohm system, reflection coefficient (Γ) and VSWR all describe how well the antenna is matched to the 50 ohm system.



- VSWR = 2:1
- => |Γ|= (VSWR-1)/(VSWR+1)=1/3 (reflected voltage is 1/3 level)
- => (1- $|\Gamma|^2$) = 89% of the power delivered to the load, 11% reflected

AF ≡ Realized Gain

- Goal of AF calibration is to obtain the free-space far field realized gain.
- To emphasize:
  - AF includes mismatch and ohmic loss, so no additional correction is needed for system calculation
  - AF is for boresight direction only with the antenna pointing to the direction of the incoming field
  - It only has a clear definition for farfield plane wave incident wave
  - It assumes the receiver is a 50 ohm load
  - AF assume the antenna is in receive mode. By reciprocity, AF can be converted to realized gain, and transmit property can be derived.

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- In most EMC applications, antennas are NOT used in free space. For example, for < 1 GHz radiated measurements, standards stipulate:
  - Antenna is over a conducting ground.
  - Antenna scans from 1 -4 m in height to avoid nulls
- AF as used is an **approximate** transducer factor to convert voltage reading to the incident field strength from near boresight directions.
- Note the field measured is the **sum** of the direct wave and reflected wave. With height scanning, Measured E field can almost double the direct incident field (when the ground reflection adds in phase).

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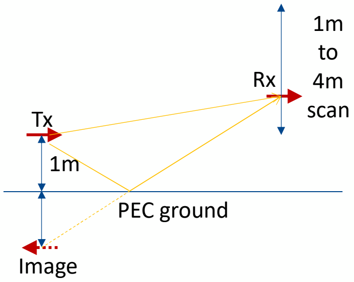
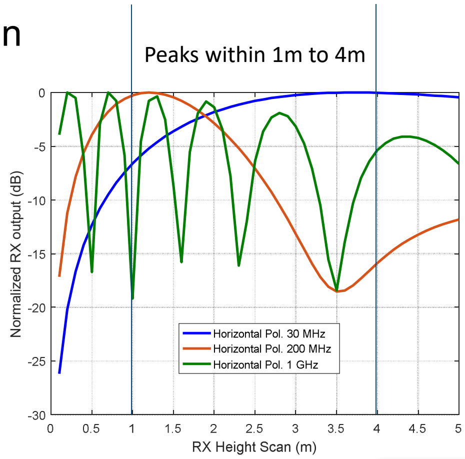
Why 4m Height?

- Catching the peak of the summation of the direct wave and the ground reflecting wave

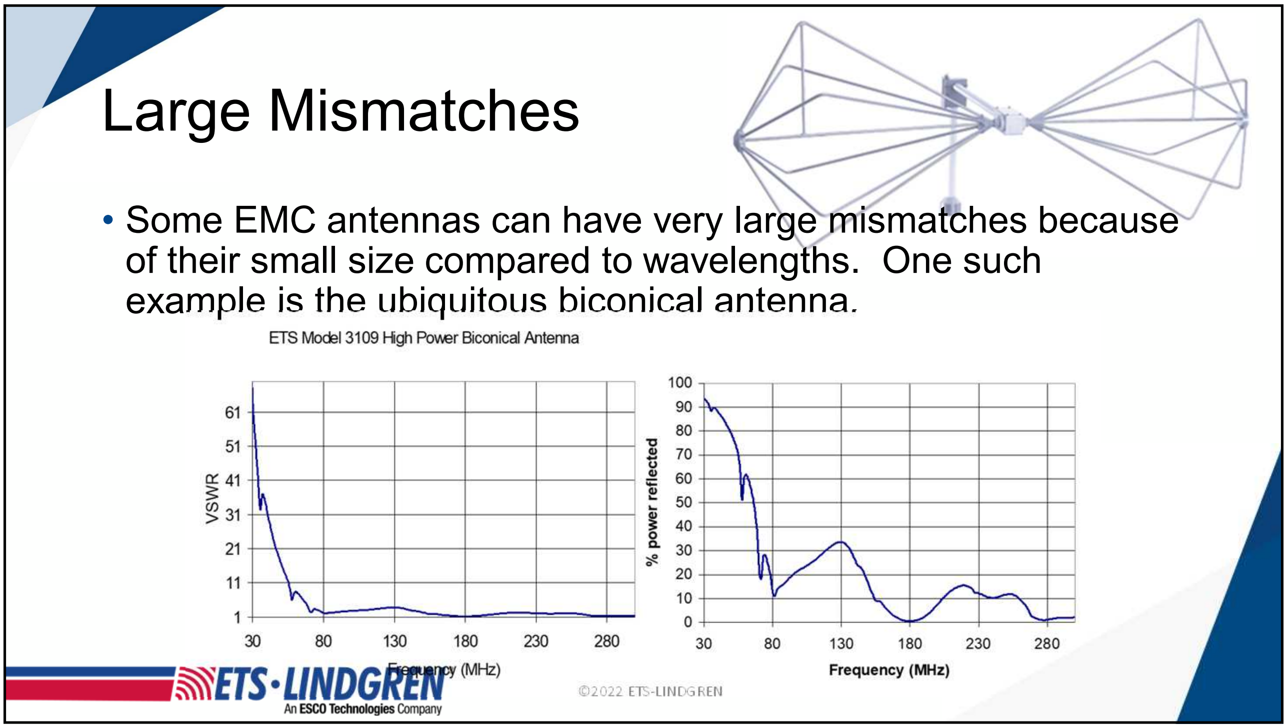
Two dipoles separated by 3 m over ground





Antenna Pattern & Beamwidth

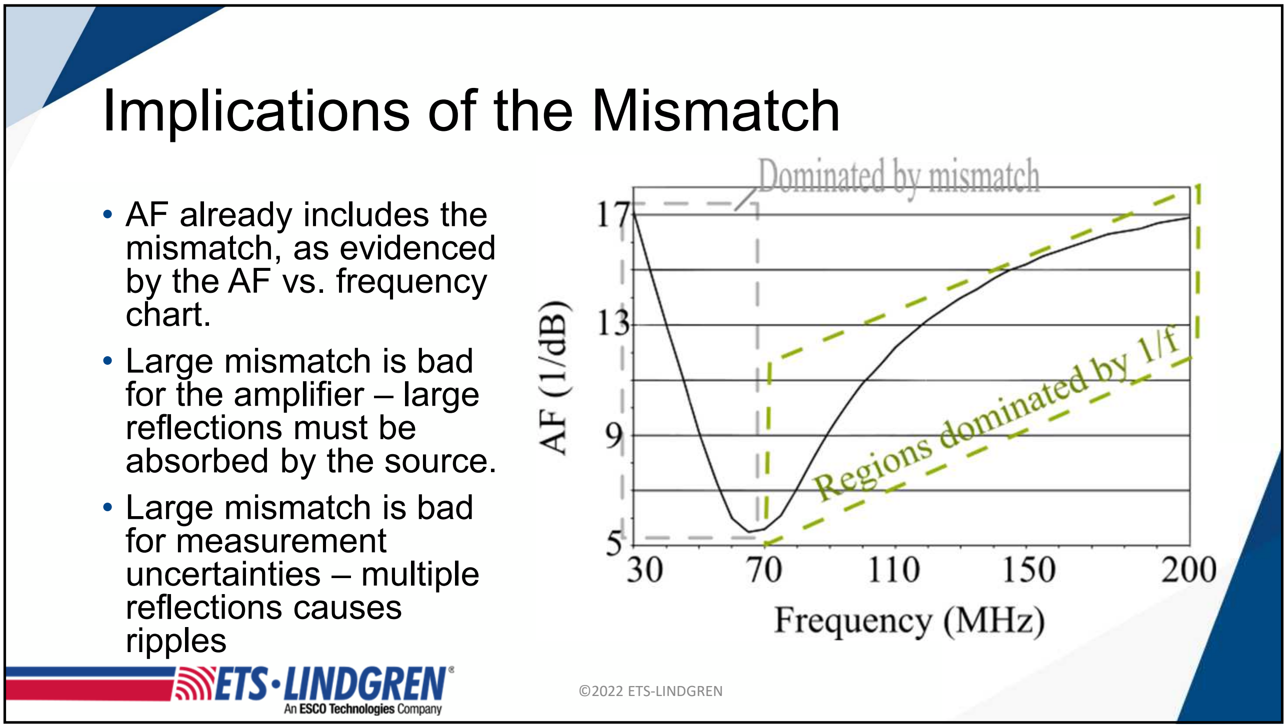
- Typical EMC antennas are low gain, and broad beam by design (one reason is EUT coverage; another is the conducting ground)
- At a given frequency, low gain antenna = large AF = low voltage output to the receiver
- Recall $AF = \frac{E}{V} = \frac{9.73}{\lambda\sqrt{g}}$
- For an antenna with a constant gain (vs. freq), AF increases with frequency. It means that the system is less sensitive at higher frequencies.
- Pre-amp is often needed to combat the loss of sensitivity at high frequencies



Large Mismatches

- Some EMC antennas can have very large mismatches because of their small size compared to wavelengths. One such example is the ubiquitous biconical antenna.

ETS Model 3109 High Power Biconical Antenna



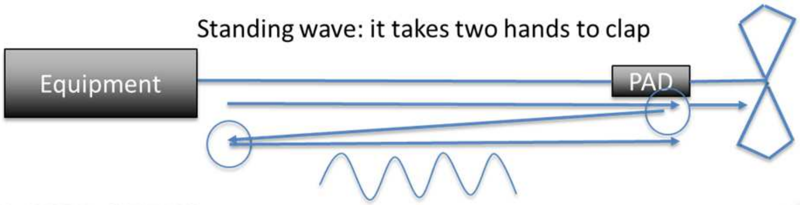
Implications of the Mismatch

- AF already includes the mismatch, as evidenced by the AF vs. frequency chart.
- Large mismatch is bad for the amplifier – large reflections must be absorbed by the source.
- Large mismatch is bad for measurement uncertainties – multiple reflections causes ripples

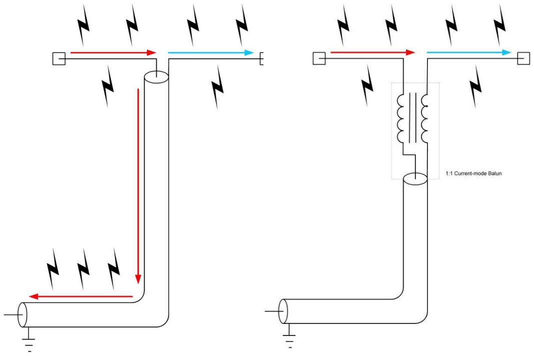
Why use attenuators sometimes?

- In some situations, we insert a pad (attenuator) at the input port of the antenna to lower VSWR. Why?
  - Useful signal is attenuated "one-way"
  - Reflection is attenuated twice
- Reduces standing waves on the cable – therefore reduces measurement uncertainties from mismatches

Standing wave: it takes two hands to clap



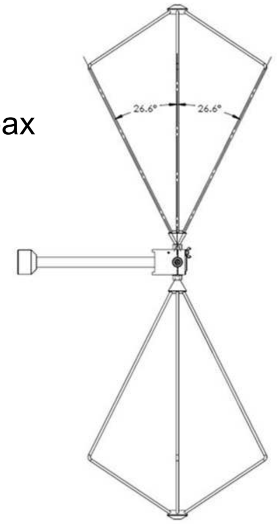
Transmission Baluns (



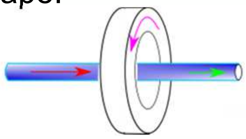
Source: Wikipedia

- ***Bal***anced-to-***Un***balanced transformer.
- Provides low impedance to differential current, and high impedance to common mode current.
- Baluns are used to isolate feeding cable from antenna responses
- ✗Unbalanced antennas have different responses depending on which side is up when vertically polarized. This causes large measurement uncertainties.

Baluns/Transformer



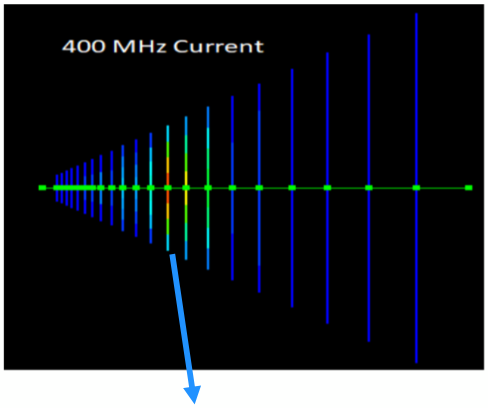
- Baluns are necessary for biconical antennas to suppress large common mode currents on the outer shield of the coax cable. Ferrite beads also help in this regard.
- Some baluns also provide a function as an impedance transformer.
- Typical MIL-STD 461 “Birdcage” biconical elements are close to a 200 Ω structure.
- One such example is the 200 ohm (4:1) Guanella Current Balun.
- Ferrite Beads – EMC engineers’ duct tape!



“Symmetry” or “Balance” Test

- Unbalanced antennas are very susceptible to coax feed cable placement - large measurement uncertainties!
- EMC antennas must show to be balanced, based on requirements in ANSI C63.5 or CISPR 16-1-4.
- This is done by an inversion test
- In the vertical polarization over a conducting ground, antenna receive response must not differ by more than 0.5 dB when oriented by 180 degrees apart (upside down vs. downside up)

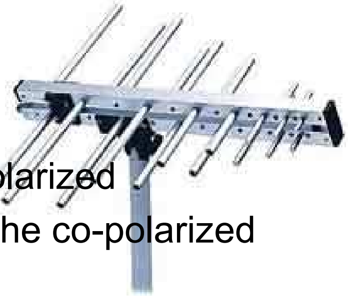
Phase Center



Active region moves with frequency

- Radiated wavefront has a curvature when in near field (in far field, the curvature is so large that it can be regarded as plane wave). The apparent center of the curvature is the phase center.
- For log periodic antennas, phase center moves with frequency. The measurement distance from antenna to device under test is ambiguous. It is often chosen at a fixed position as an approximation.
- Convention (defined by standards) is
  - For RE: mid-point of the boom
  - For RI: Front tip

Cross-Polarization Ratio



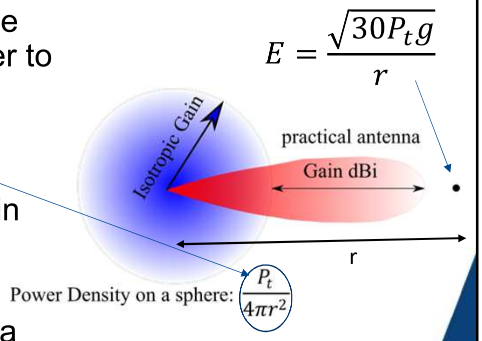
- EMC antennas are designed to be linearly polarized
- The ratio of the cross-polarized response to the co-polarized response is the cross-polarization ratio.
- Poor cross-pol causes large measurement uncertainties, as the cross-pol signal contaminates the desired reading.
- Both ANSI and CISPR standards stipulate that the cross-pol ratio must be better than 20 dB.
- Cross-pol is a greater concern for Log Periodic Dipole Arrays, because the dipole arrays are arranged in a staggered pattern.

Estimating E field from a Transmit Antenna, or EIRP

- Antenna gain is the same in either Tx or Tx mode by reciprocity. For a transmit antenna, it is easier to work with the gain (instead of AF)
- Power Density at a distance $= \frac{E^2}{\eta} = g\frac{P_t}{4\pi r^2}$
- Where η≈120π; P_t:forward power; g:realized gain

$$E = \frac{\sqrt{30P_t g}}{r}$$

- This equation is useful to estimate the E field at a distance r. Note that this assumes far field. Near field gain is always smaller, so this is optimistic.



Friis Transmission Equation (coupling between Tx and Rx)

Friis Transmission Equation:

$$\text{path loss} = \frac{P_R}{P_T} = \frac{g_t g_r \lambda^2}{(4\pi r)^2}$$

Convert to antenna factors:

$$\boxed{\text{Free space Site Attenuation} = S_{21} = \frac{V_R}{V_T} = \frac{2.4\pi}{\lambda AF_t AF_r}\frac{1}{r}}$$

- ☐Where f_M is frequency in MHz;
- ☐ V_R and V_T are receive and transmit voltage;
- ☐ r is the distance between the antennas

Antenna Factor Calibration

- In ***free-space***, we calibrate AF using the “three antenna method” (utilizing the Friis Transmission Equation)
- The three antennas are measured in pairs
  - Antenna 1 -> Antenna 2
  - Antenna 1 -> Antenna 3
  - Antenna 2 -> Antenna 3
- We then have three transmission equations, and three unknowns (AF_1, AF_2 and AF_3). The three antenna factors are therefore solved.
- This is the method adopted in the ARP/SAE 958 Standard

Standard Site Method (SSM)

- In practice, it is impractical to calibrate in free space, especially at low frequencies, where ground is always present and physical absorbers are not effective.
- We embrace the ground plane by calibrating antennas over a PEC (Perfect Electric Conductor) ground, i.e., a metallic conducting ground. Ground is accounted for using image theory.
- The AF obtained this way is still the free-space AF. The ground just provides a consistent environment where we can “mathematically remove” it in the calculation.

AF for Compliance Emissions Measurement

- EMC antennas (30 MHz – 1000 MHz) are calibrated using SSM over a PEC ground plane.
- Even though the antennas are calibrated on a ground plane, the result is the “free-space” AF (or close to it). Ground is there to provide a repeatable environment.
- Even if AF were perfect, when used for EMC measurements, the AF would still be an approximate transducer factor because we do not use antennas in free space (and in exact boresight).
  - Ground reflection
  - Non-boresight incident
  - Coupling
  - Phase center

Summary

- Reviewed Antenna Factor, and its relationship to gain
- Reviewed other common antenna terms used in EMC: mismatch, balun, cross-pol, phase center.
- Provided an overview of Friis transmission equation, and its applications in antenna calibration
- EMC antennas are typically calibrated over a PEC ground. Antenna Factor is a free-space factor even though it may be calibrated over a conducting ground.