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# Understanding the Unintended Antenna Behavior of a Product

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# Radiating System

- Source of RF energy
- Radiator
- Coupling



# Source Properties

- Current loop
- Potential difference
- Impedance



# Basic Antenna Structures

- Slot antennas
  - Seams
  - Unused connectors
- Monopole and dipole antennas
  - Interface cables
  - Other conductors
- Loop antennas
  - Cables
  - Other conductors



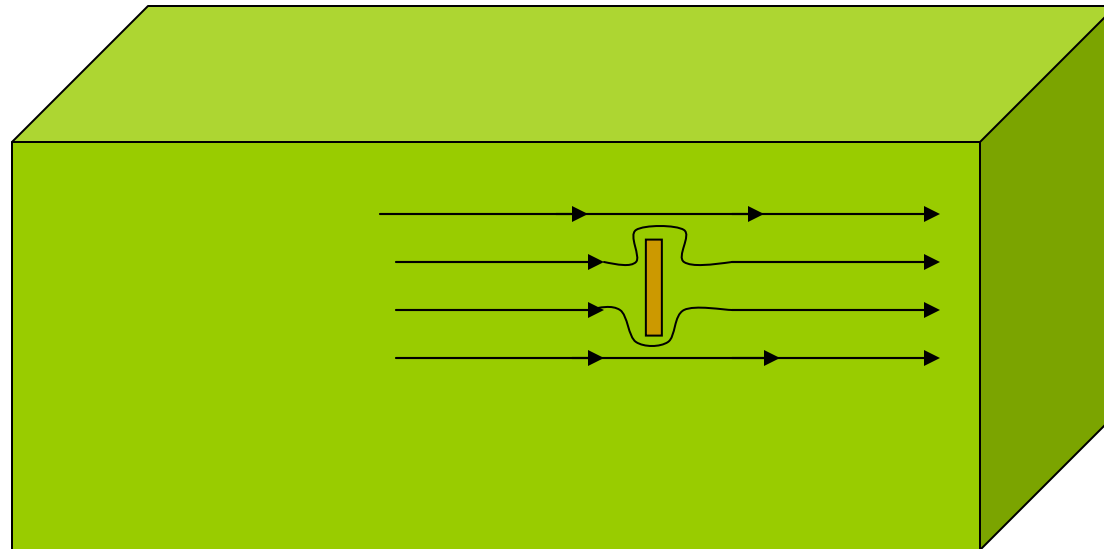
# Typical Unwanted Slot Antennas

- Gaps in an EMI shield
- Splits or void areas in a plane (power or return)



# Slot Antenna

- Diverted Current Sheet





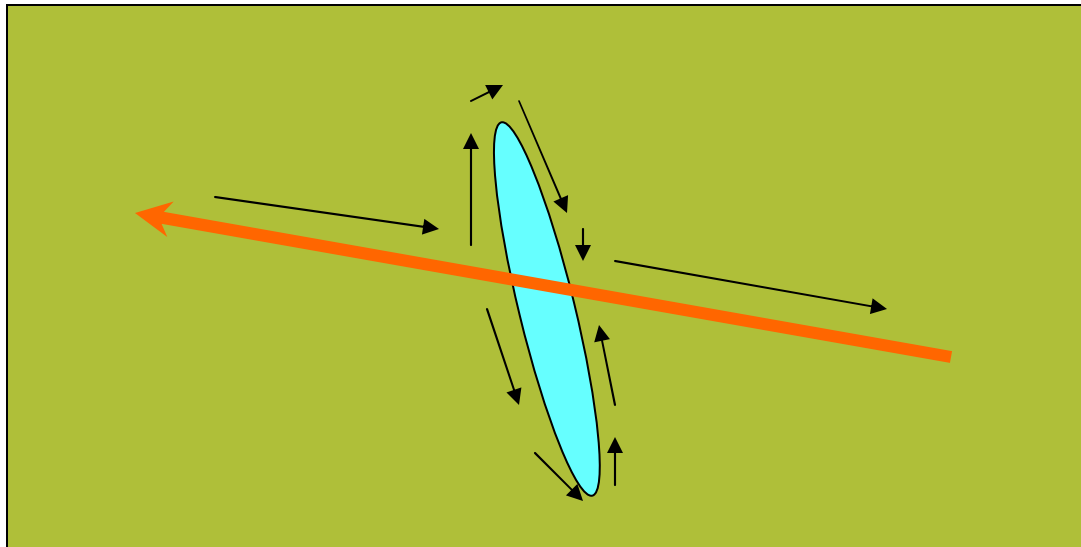
# Typical Unwanted Loop Antennas

- Etch route to decoupling capacitor
- Terminations with shared return
- Within a large VLSI device
- Poorly implemented return path



# Loop Antenna

- defined current path







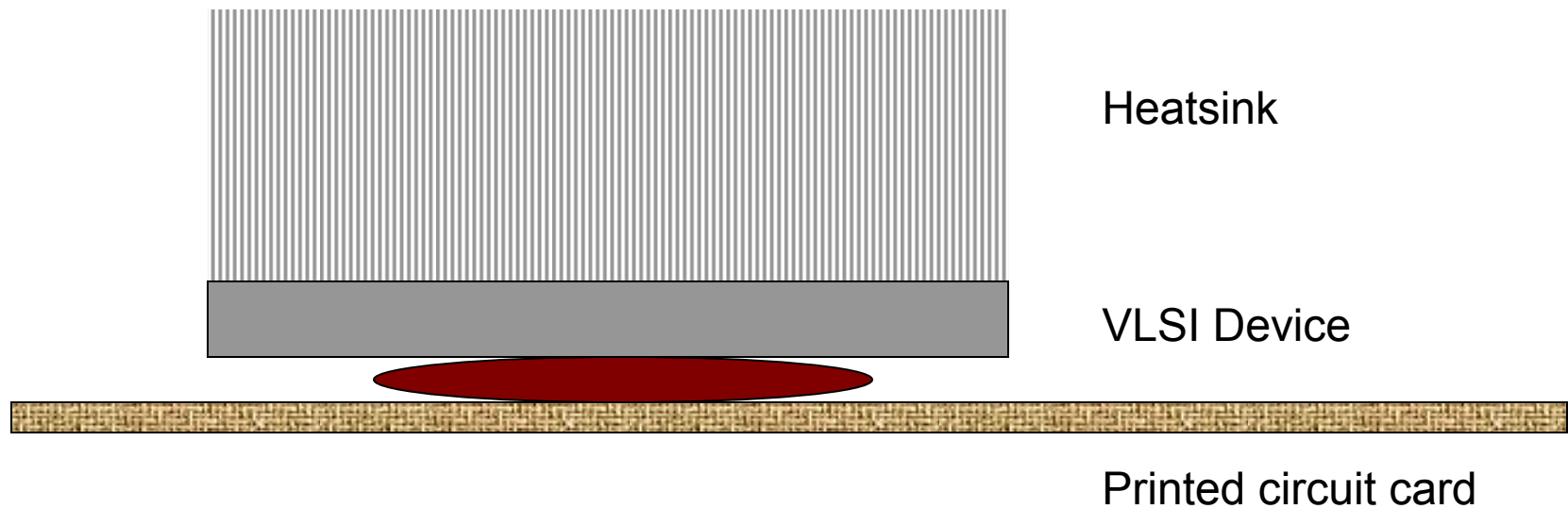
# Typical Unwanted Dipole Antennas

- Heat pipes or sinks
- Power wiring
- Interface wiring



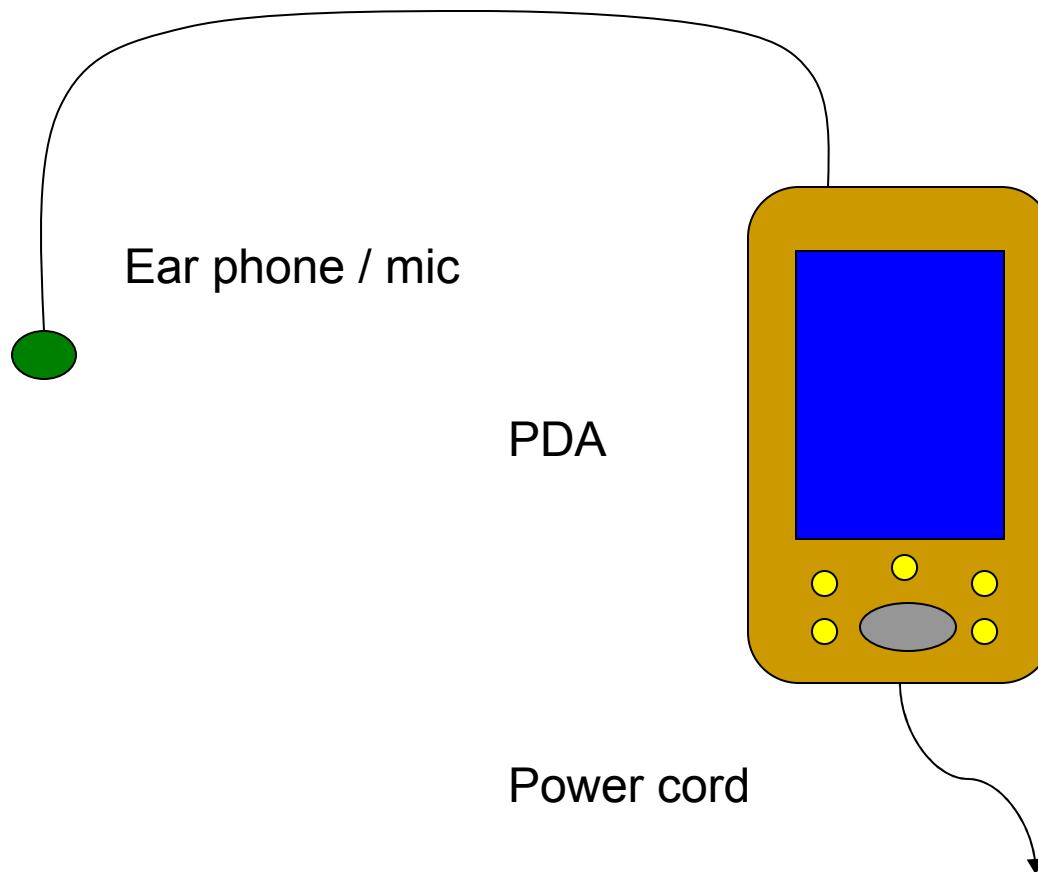
# Dipole Antenna

- RF potential exists  
between two conductors





# PDA Antenna Example





# Coupling Mechanisms

- Close and small
  - Directly coupled
  - Inductance
  - Capacitance
- Small and remote
  - Uncoupled
  - Point source
    - Current loop
    - Current element
- Large and very close
  - Tightly coupled
  - Distributed inductance
  - Distributed capacitance
  - Complex EM coupling
- Resistive
  - Common paths
  - Intentional and unintentional chassis to logic return connections



# Source Examples

- Current loops
  - Multi-point chassis to logic
  - Cable shield currents
- Voltage potentials
  - Between VLSI device and heat-sink
  - Between mother and daughter boards
- Common impedance



# Radiator Properties

- Terminal Impedance
  - Radiation resistance  
represents energy radiated
  - Terminal reactance  
the energy stored in the non radiating fields

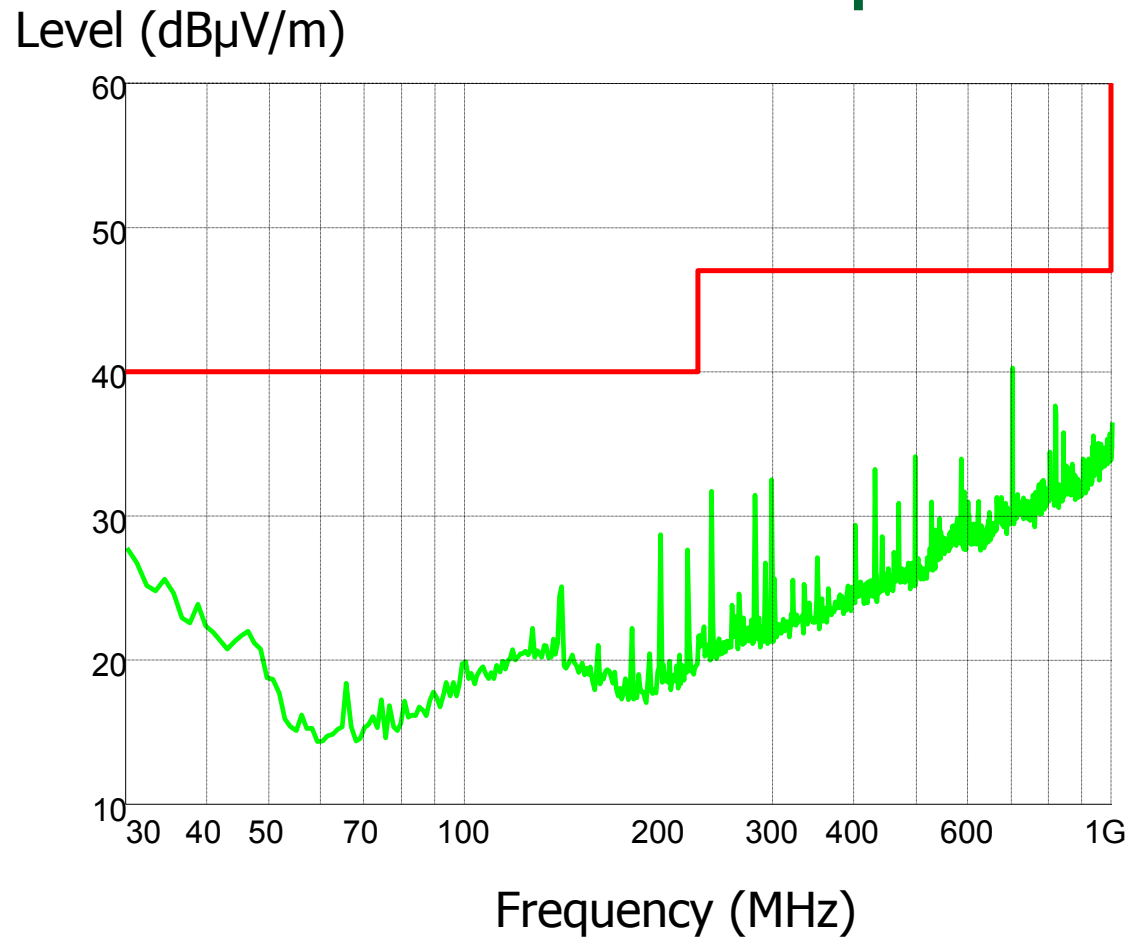


# External Conductor Example

- Rack mount sub systems from a variety of vendors were mounted in a rack
- All sub systems were compliant alone
- Total system emissions were marginal at high frequencies
- Total system emission profile was changed when the doors were closed



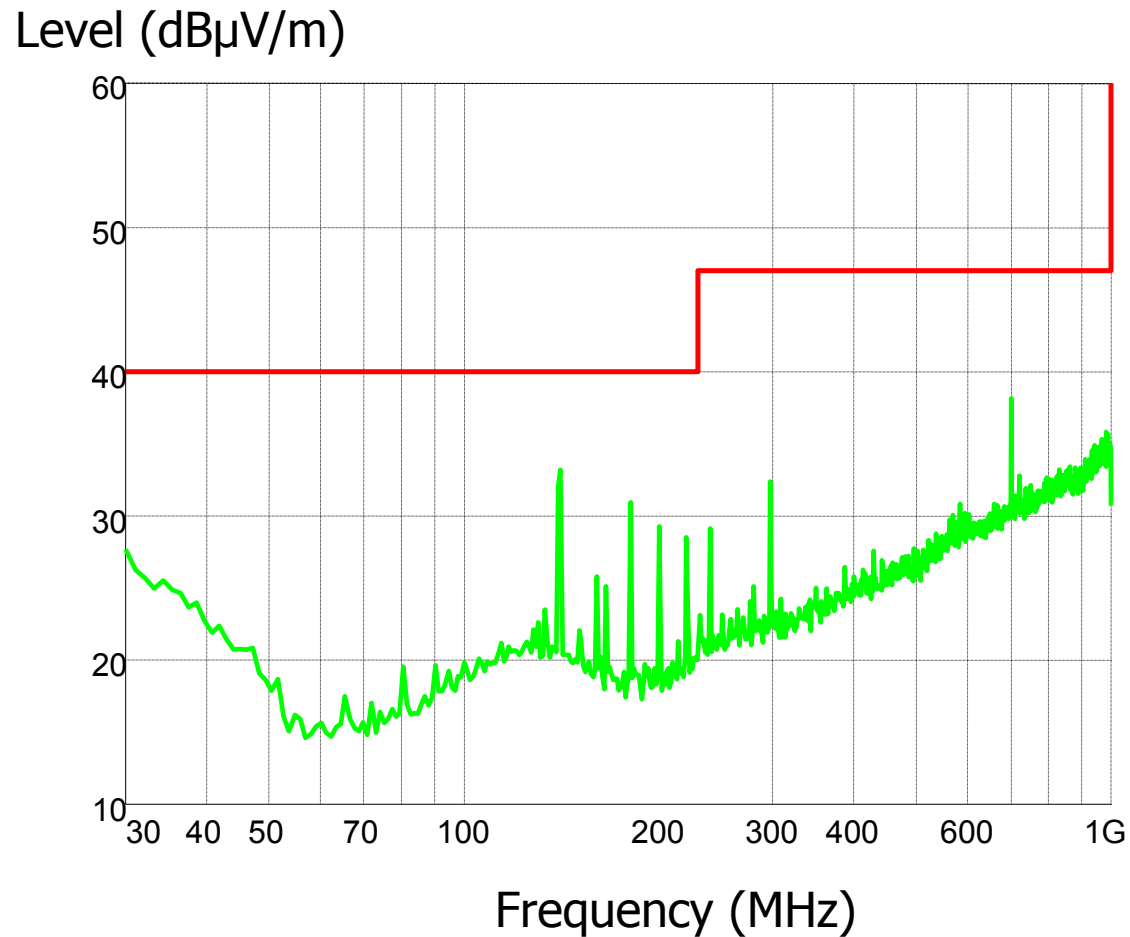
# Product Emissions with Doors Open





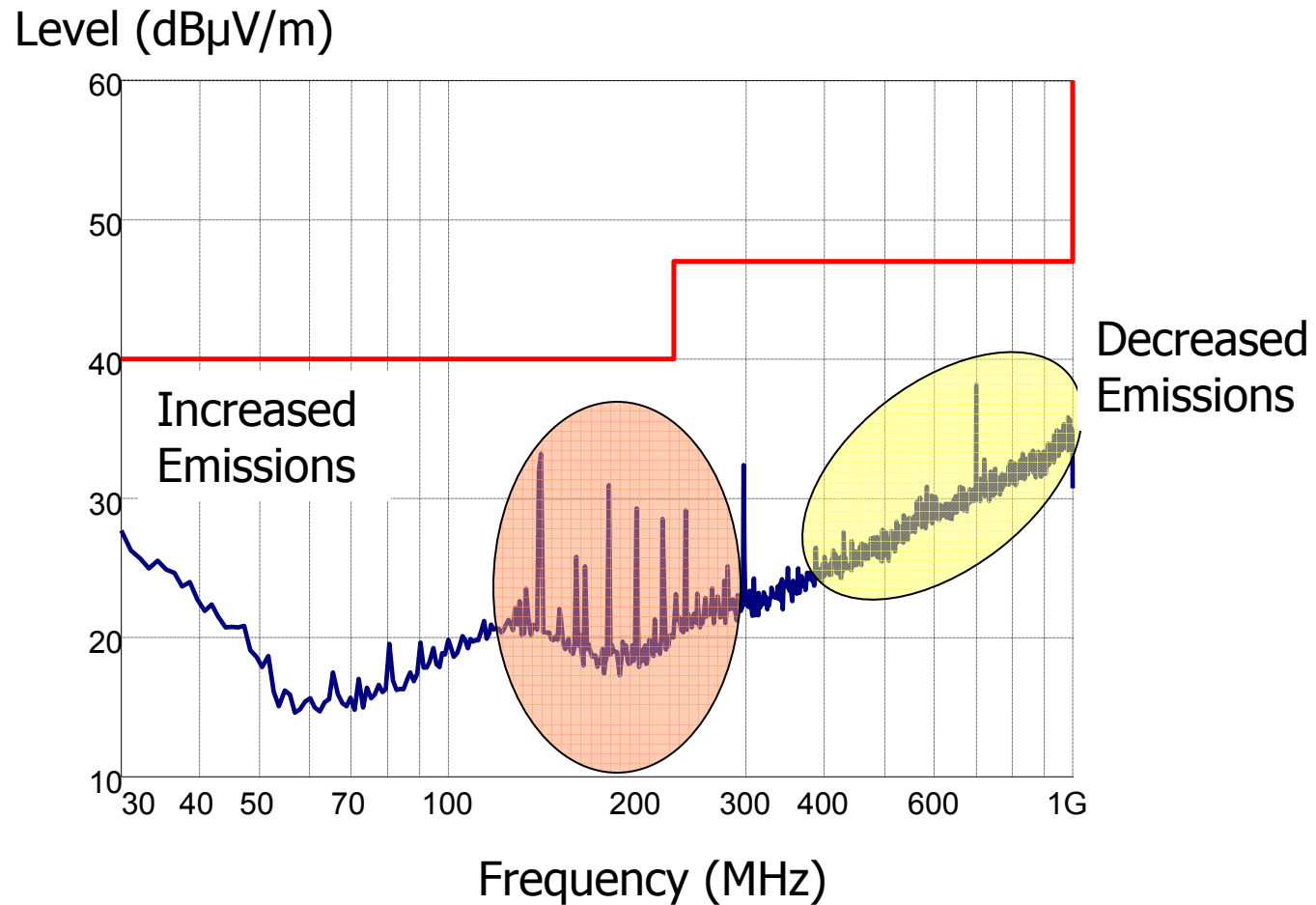


# Product Emissions with Doors Closed



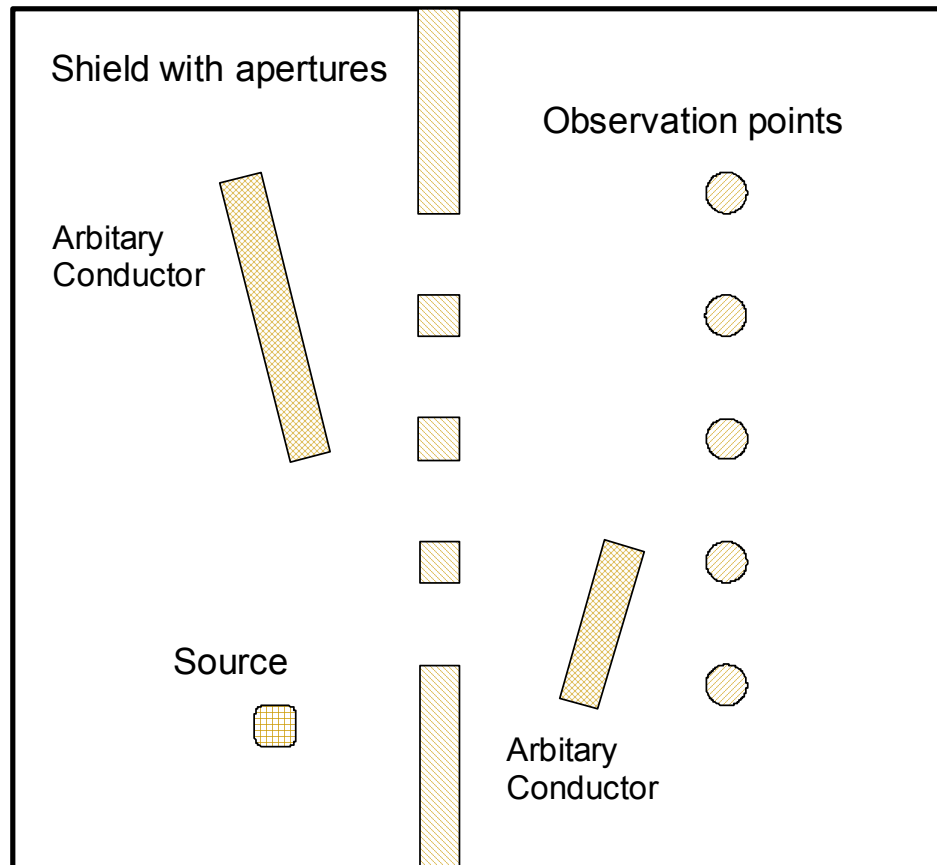


# Product Emissions with Doors Closed



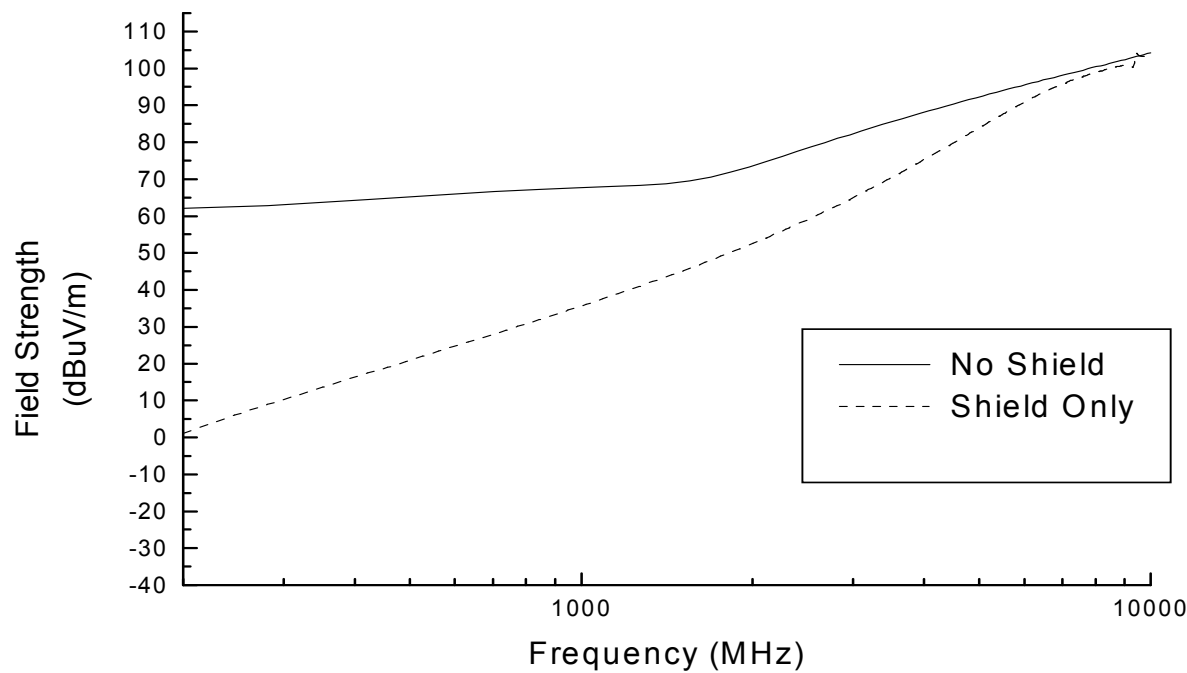


# Computational Model



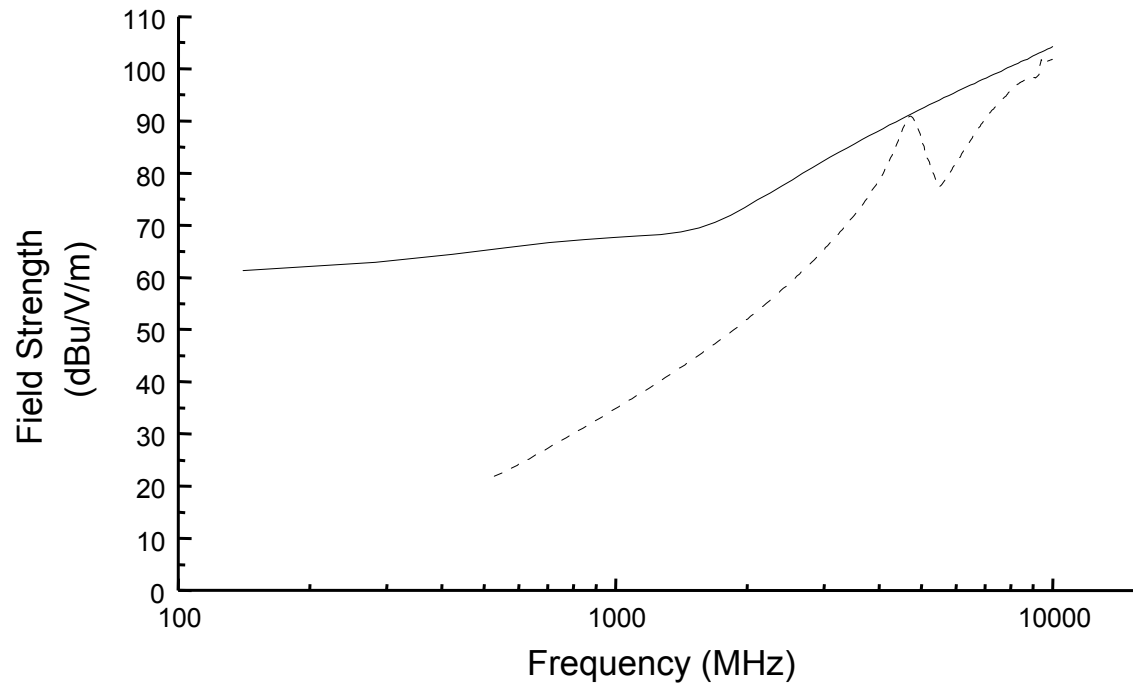


# Shield Performance With no Extra Conductors



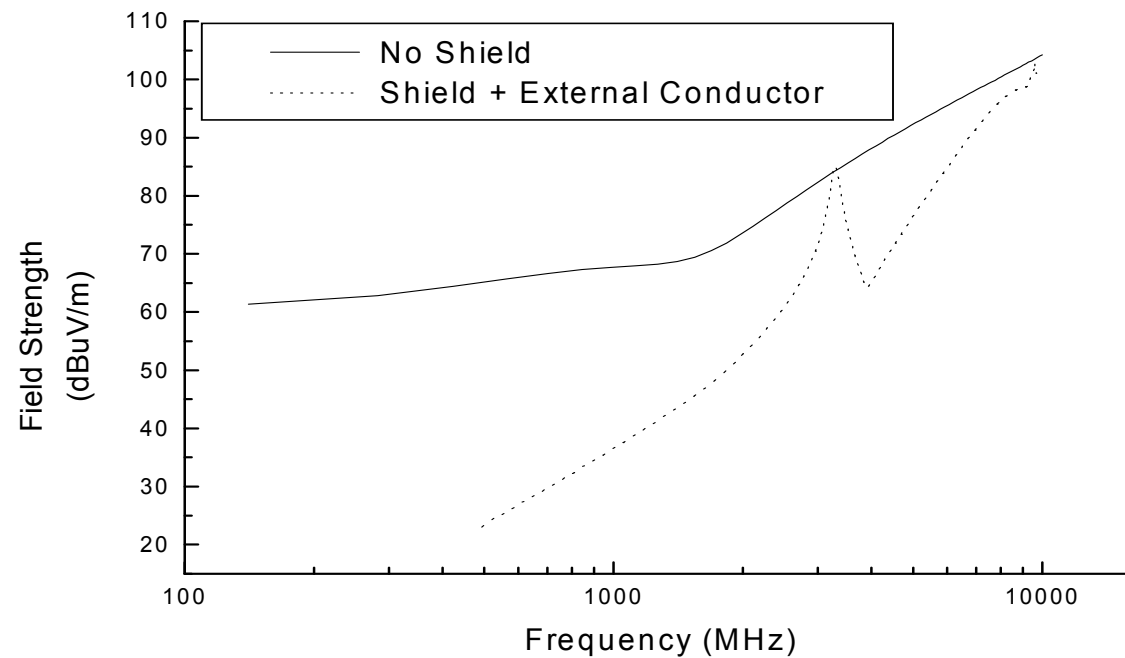


# Shield Performance with Internal Conductor



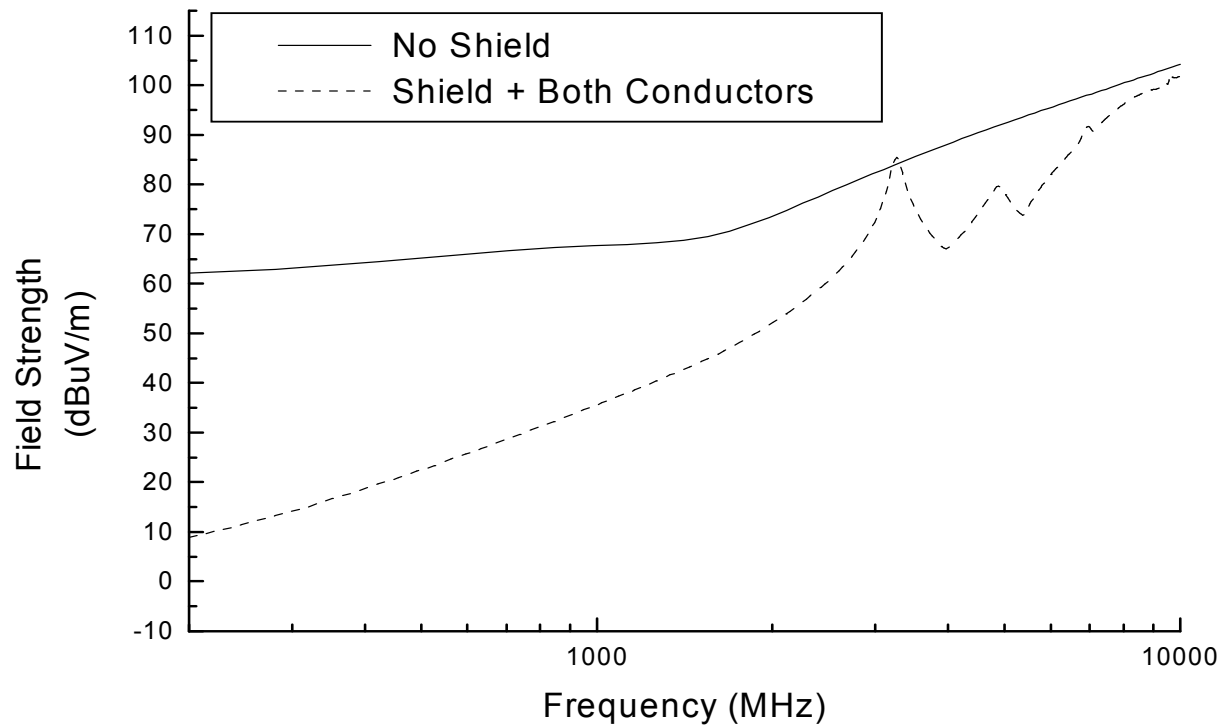


# Shield Performance with an External Conductor





# Shield Performance with Both Conductors





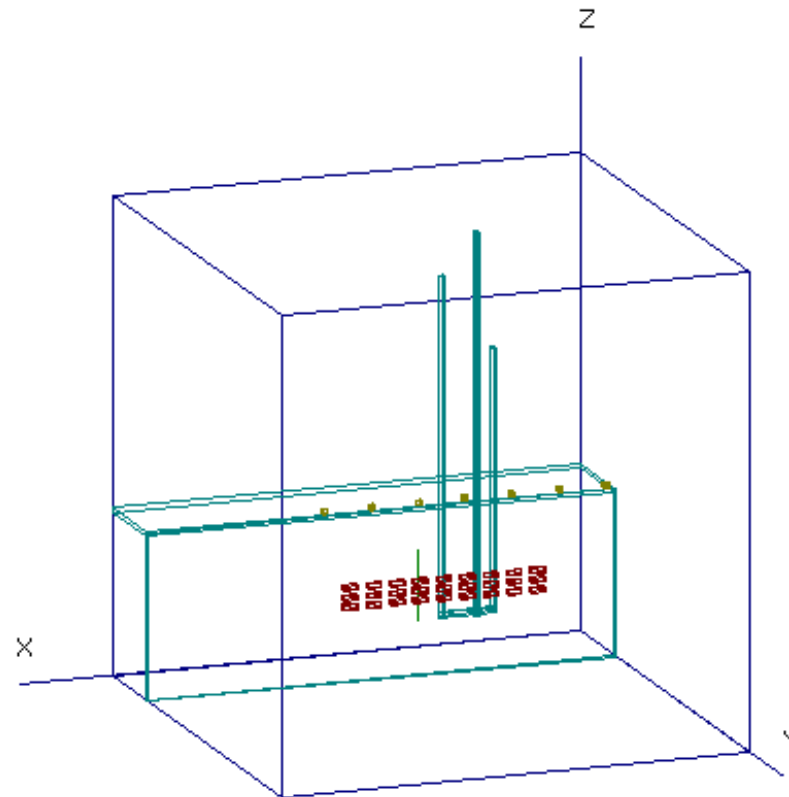
# Adding Details

- Refined source model
  - includes direct coupling between source and shield or external conductor
- Imperfections
  - induce some cross polarization
- More complex external structures





# Multi-Wire FDTD Model



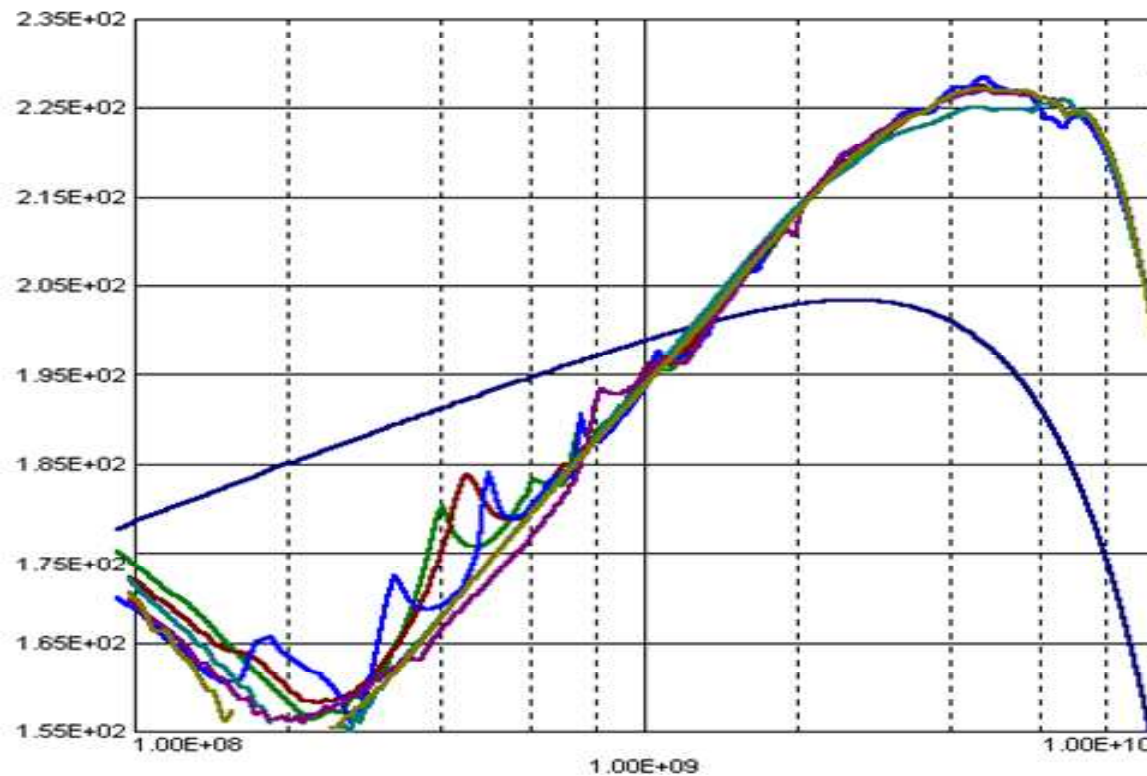


# Animated Field Plots

- Time domain view of electric fields propagating through an aperture
- Electric fields propagating in the presence of external conductors
  - Slots in infinite plane
  - Slots in a real enclosure
  - Grounded external wire
  - Isolated external wire



# Field Strength with External Wires





# Product Realities

- Antennas happen!
- Result from unintentional discontinuities in a current path and RF potentials between conductors
- Cannot be completely avoided
- Design requires a balance of minimizing:
  - ❑ RF energy source
  - ❑ Coupling
  - ❑ Antenna size and geometry



# Measurement Antenna Example

- 30MHz half wave dipole
- Terminal impedance
  - Ideal
  - As used on site
    - 4m horizontally polarized
    - 1m vertically polarized
  - With feed cable present
- Field distribution

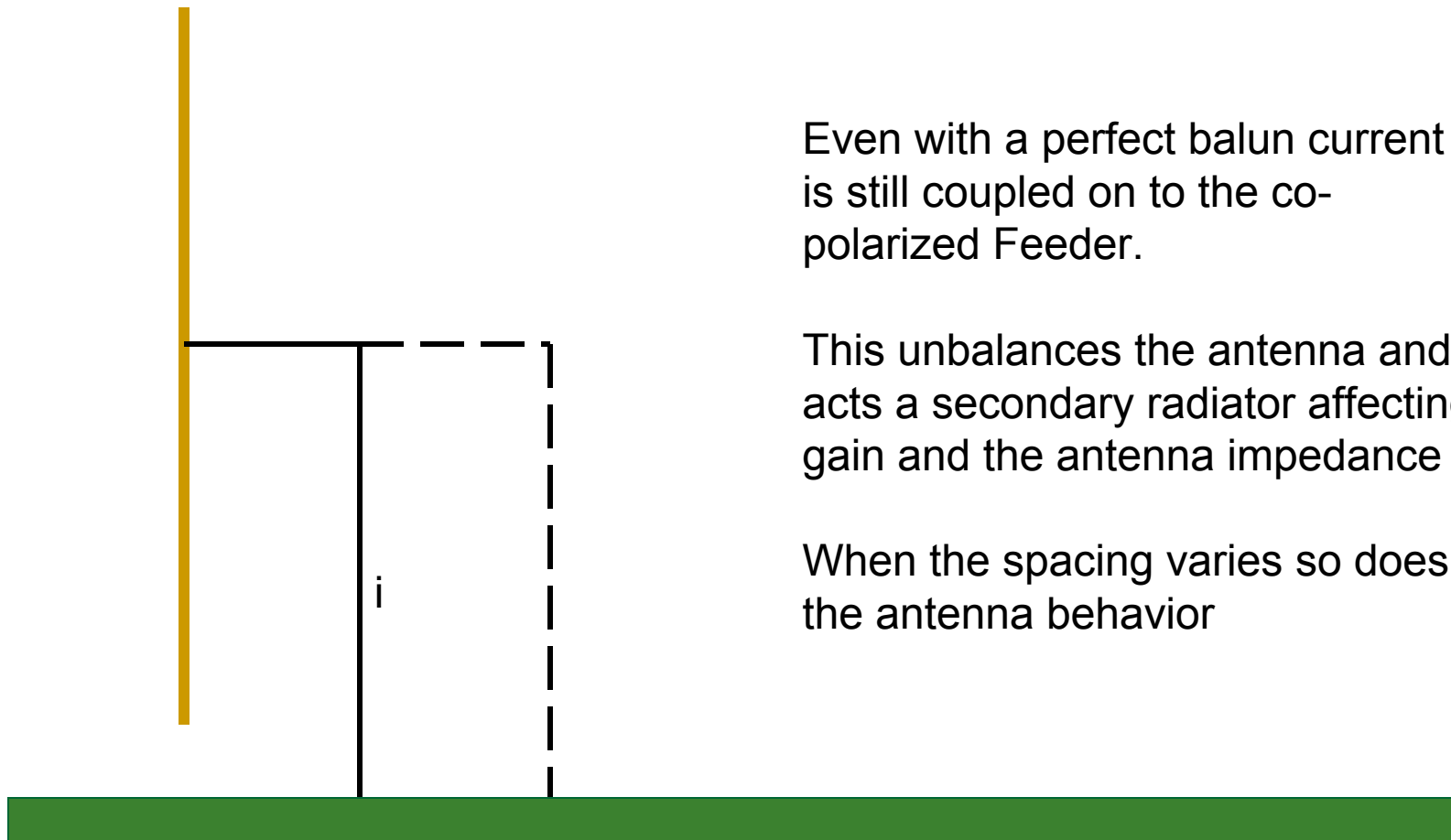


# 30 MHz Dipole Impedance for Different Environments

Condition	Resistive Value	Reactive Value	Mismatch Loss
	(ohm)	(ohm)	(dB)
Free Space	71.0	+j 0.26	0.00
Horizontal	87.4	-j 13.00	0.95
Vertical	93.8	+j 2.10	1.29



# Dipole With Feed Cable



Even with a perfect balun current is still coupled on to the co-polarized Feeder.

This unbalances the antenna and acts a secondary radiator affecting gain and the antenna impedance

When the spacing varies so does the antenna behavior



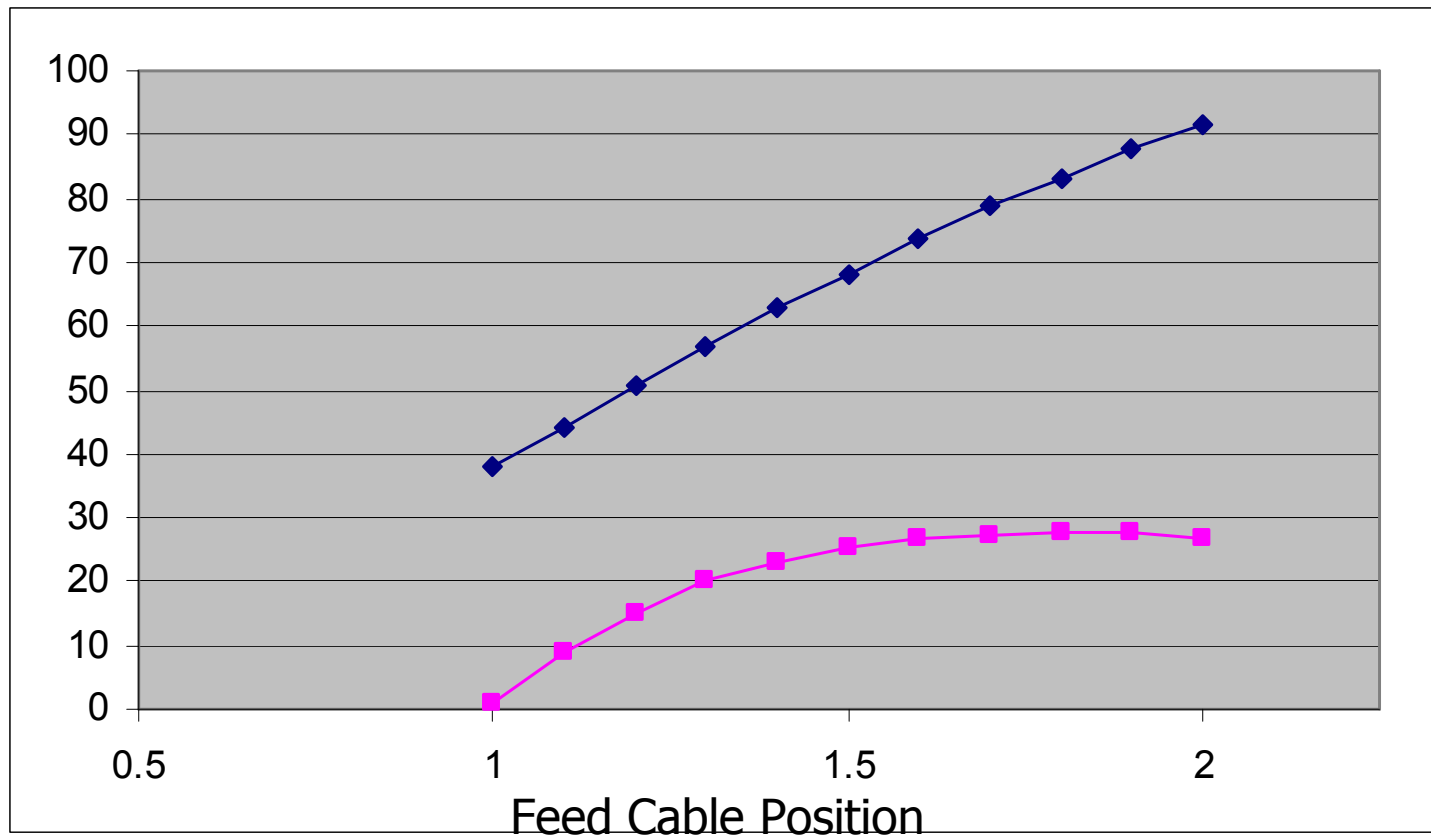
# 30 MHz Vertical Dipole Impedance for different feed locations

Feed Location (m)	Resistance (ohm)	Reactance (ohm)	Mismatch Loss (dB)
Antenna Alone	93.8	+j 2.10	1.29
1.0	37.8	+j 1.16	2.31
1.1	44.3	+j 8.80	1.78
1.2	50.6	+j 14.9	1.28
1.3	56.7	+j 14.9	0.82
1.4	62.7	+j 23.0	0.40
1.5	68.3	+j 25.4	0.02
1.6	73.7	+j 26.9	0.31
1.7	78.7	+j 27.0	0.60
1.8	83.3	+j 27.9	0.86
1.9	87.6	+j 27.5	1.09
2.0	91.4	+j 26.6	1.28



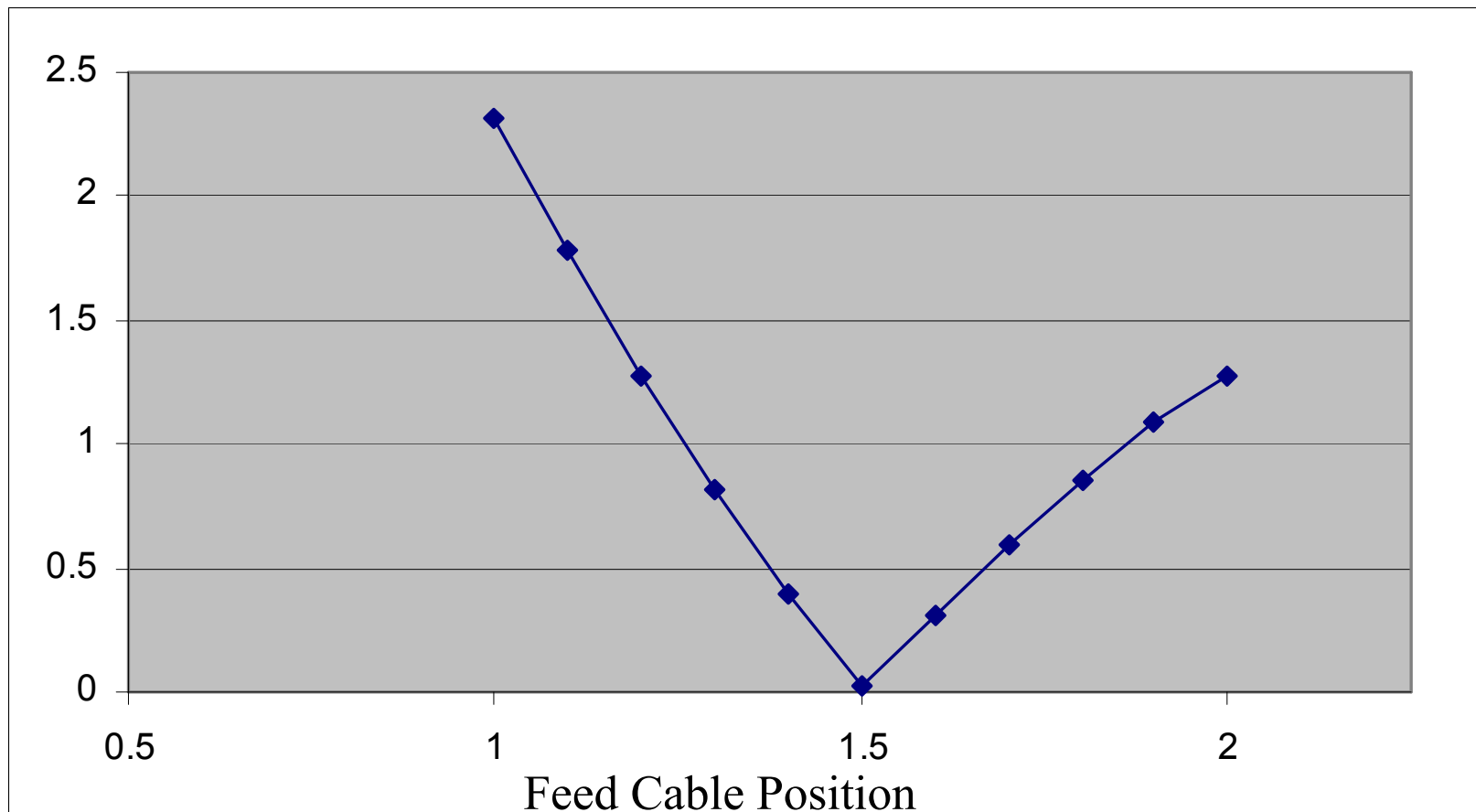


# 30MHz Dipole Impedance





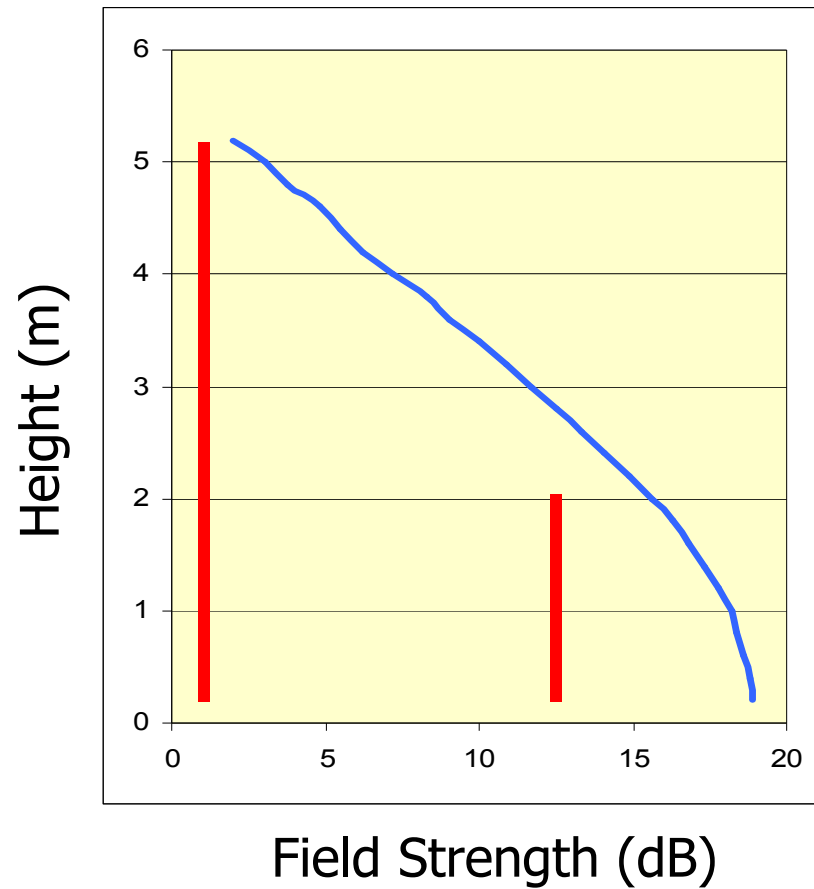
# Mismatch Loss





# Field Variation

## 30MHz Vertically Polarized Dipole





# Product Antenna Summary

- It is important to recognize and separate the antenna effects from the coupling effects
- It is important to identify the true source
- Confusion between the source the coupling mechanisms and the radiator can cause an engineer to chase phantoms during EMI failure analysis