

## Transfer Functions in EMC Shielding Design

- ◆ Transfer Functions Definition
- ◆ Overview of Antenna Theory
- ◆ Shielding Effectiveness Definition  
& Test Anomalies

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## Transfer Functions Definition

- ◆ **Intelligent Use of Ohms Law**
  - i.e., voltage creates current and current creates voltage.
- ◆ **From Duality Theorem:**
  - Voltage is dual of current
  - Capacitance is dual of inductance
- ◆ **Example 1: Using Duality Theorem**
  - Current in a wire creates a voltage in adjacent wire
  - Voltage spectrum in a wire creates current flow in adjacent wire
- ◆ **Example 2:**
  - Voltage on PC card trace generates current in shield of wire cable due to capacitive coupling.
  - Current in shield of cable generates voltage in wires of cable through inductive coupling.

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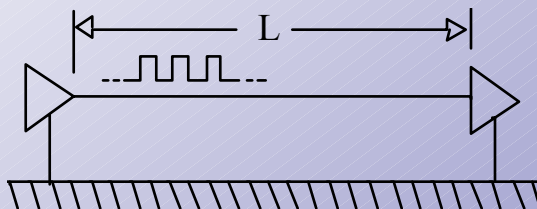
## Overview of Antenna Theory

- ◆ Generation of Displacement Current and the Subsequent EM Wave.
- ◆ Penetration of a Wave into and through Shielding Barriers.

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## Electromagnetic Force Field

- ◆ A radiated electromagnetic (EM) force field is generated by the action of driving a current through a wire. The figure below represents a sending/receiver circuit on a PC card.

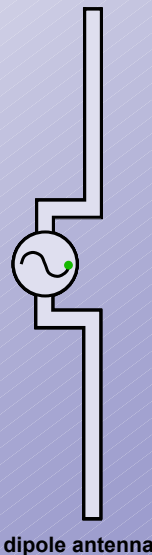


- The wire (or PC card trace) acts as a transmitting antenna as an emitter of EM interference and as a receptor with regard to EM susceptibility.
- A common method of reducing (or eliminating) the possibility of the PC trace being an emitter or receptor of EMI is by the use of a shielding barrier and gaskets at discontinuities of a chassis enclosure.

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## A Dipole Antenna

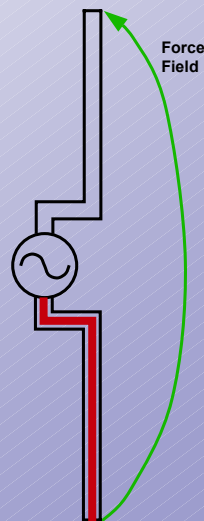
- ◆ The radiated EM wave generated by a PC card trace is similar to that generated by an electric dipole antenna.
  - The dipole antenna is connected to an alternating AC voltage source which causes current to flow from one side of the antenna to the other.
  - When the cycle is completed, the current and electron transfer reverses.



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## Electromagnetic Wave

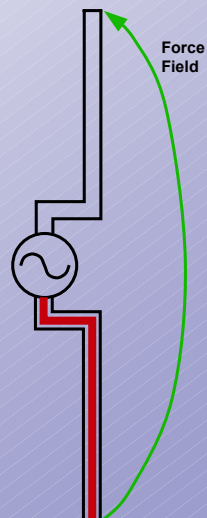
- ◆ In this illustration, the electrons are predominantly in only one leg of the antenna. This imbalance creates a force field - i.e., an electromagnetic (EM) wave.
  - The EM wave resulting from the displacement current contains power measured in Watts/meter squared and consists of an electric E field in volts/meter and magnetic H field in amps/meter.



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## Electromagnetic Wave

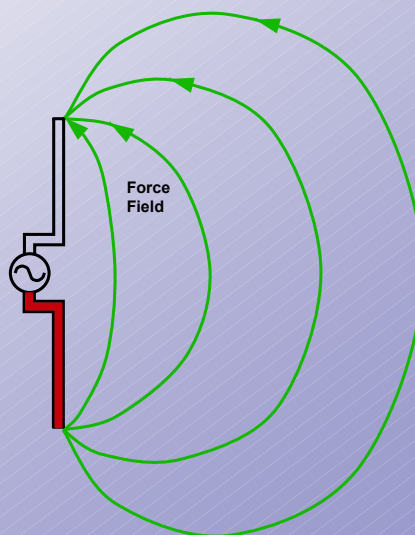
- ◆ The electric field potential (in volts/m) can be estimated by dividing the difference in voltage potential of the legs of the antenna by the distance in meters between the ends.
- ◆ A displacement current (in amps/m) is present along with the E field and is a function of the capacitive reactance between the legs of the antenna.
- ◆ This displacement current creates an inductive (i.e., magnetic) H field in amps/m which is at right angles to the E field. The H field is equal in value to the displacement current which is parallel to the E field.



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## Electromagnetic Wave

- ◆ The electromagnetic force field (EM wave) moves or radiates away from the antenna.
  - This is similar to a wave created by dropping a stone into water.
  - The power in the field decreases as the square of the distance from the antenna.



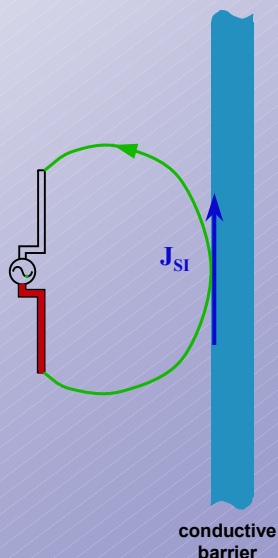
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## Conductive Barrier

- ◆ When the field is impinged on a conductive barrier, the current in the field is induced into the barrier as shown.
  - The current is measured by the value of the H field.
- ◆ The value of  $J_{SI}$  (the "Surface Current Density" induced into the barrier on the incident side) is the same as the value of the H field of the impinged wave at the barrier.

$$J_{SI} = H_I$$

$J_{SI}$  is measured in amps/m



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## Penetration of Conductive Barrier

- ◆ The current on the incident side of the barrier ( $J_{SI}$ ) is attenuated by skin effect as the field penetrates the barrier.

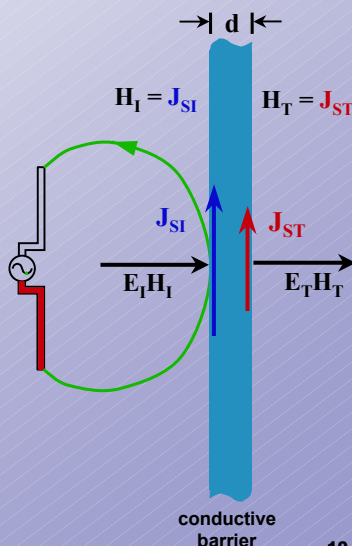
$$J_{ST} = J_{SI} e^{-d/\delta} \quad \begin{array}{l} d = \text{barrier thickness} \\ \delta = \text{skin depth} \end{array}$$

- ◆ The value of the E and H fields as the wave exits the barrier is equal to the fields on the transmitted side of the barrier.

$$\begin{array}{l} H_T = J_{ST} \\ E_T = J_{ST} Z_B \end{array}$$

- ◆ The H field lags the E field by  $45^\circ$  inside the barrier, therefore the Power as the wave exits the barrier is:

$$P_T = E_T H_T \cos 45^\circ$$



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## EM Wave Summary Notes...

- ◆ **A radiated electromagnetic (EM) force field is generated by the action of driving a current through a wire.**
  - The displacement current created by the capacitive coupling between the wire and the ground plane generates an Electromagnetic field (EM Wave).
- ◆ **This force field is similar to a field generated by an electric dipole antenna.**
  - The impedance (E/H) of the field is almost identical.
- ◆ **Power of the EM wave decreases as the square of the distance from the radiation source.**
- ◆ **When the wave is impinged on a shielding barrier, current is induced into the barrier (in amps/m).**

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## EM Wave Notes...

- ◆ **The value of the induced current (surface current density in A/m) is equal to the displacement current in the wave as measured by the H field.**
- ◆ **The value of the E field on the incident (impinged) side of the barrier is equal to the current times the impedance of the barrier (in volts/m).**
- ◆ **Both the E field and H field are attenuated equally as the current penetrates into the barrier.**
  - The attenuation factor is skin effect (i.e.,  $e^{-d/\delta}$  where d is any depth into the barrier.)
  - The relationship of the E field to the H field remains constant as the wave penetrates the barrier.

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## EM Wave Notes...

- ◆ The value of the E and H fields as the wave leaves the barrier is the same as the value of the fields at the transmitted side of the barrier.

$$H_T = J_{ST} = J_{SI} e^{-d/\delta} \quad E_T = J_{ST} Z_B$$

- ◆ The current (H field) lags the voltage (E field) inside the barrier by 45°. Therefore, the power of the field as it leaves the barrier is equal to:

$$E_T H_T \cos 45^\circ$$

- ◆ The power of the wave at any distance from the barrier is reduced as the square of the distance from the original source of energy.
  - Equations consistent with the basic laws of physics can be used to approximate the values of the E and H fields at any distance of interest.

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## Shielding Effectiveness Anomalies

- ◆ Definition
- ◆ Anomalies associated with Shielding Effectiveness of Shielding Barriers.
- ◆ Anomalies associated with Shielding Effectiveness Testing of EMI Gasketed Joints.

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## Definition of Shielding Effectiveness

◆ **From the IEEE Dictionary:**

- “For a given external source, the ratio of electric or magnetic field strength at a point before and after placement of the shield in question.”

◆ **Comments:**

- The definition implies that the shielding effectiveness of the E and H fields are the same which is not true.
- Shielding Effectiveness test results are universally used as a value of worth.
- The definition is flawed as well as test methods employed to grade shielding components.

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## Shielding Effectiveness of Barrier

Let  $E_1 = 377 \text{ V/m}$  &  $H_1 = 1 \text{ A/m}$

$Z_B = 1 \Omega$  &  $d/\delta = .001$

( $e^{-d/\delta} = .999$ )

$\therefore J_{ST} \approx J_{SI}$  &  $H_T \approx H_1$

$E_T = J_{ST} Z_B = 1 \text{ V/m}$

SE (E field) =  $E_1/E_T = 377$

$20 \log 377 = 52 \text{ dB}$

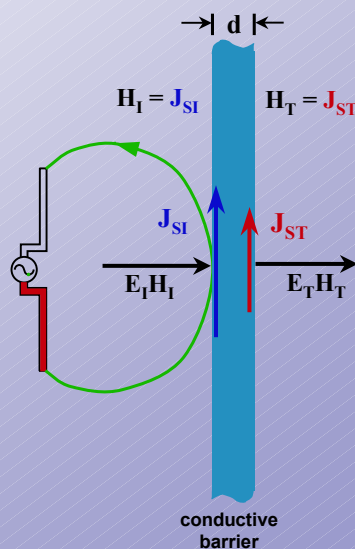
SE (H field) =  $H_1/H_T = 1$

$20 \log 1 = 0 \text{ dB}$

SE (power) =  $(E_1 \times H_1)/(E_T \times H_T)$

SE (power) =  $(377 \times 1)/(1 \times 1) \cos 45^\circ = 533$

$10 \log 533 = 27 \text{ dB}$



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## Testing of EMI Gaskets

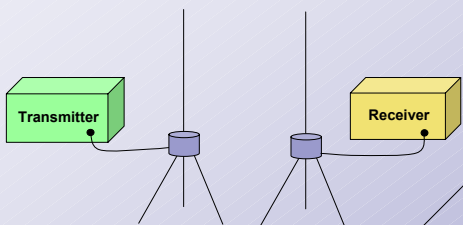
### Test Methods Used:

1. Testing using the Shielding Effectiveness Definition
2. Testing per MIL-G-83528
3. Transfer Impedance Testing

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## Shielding Effectiveness Testing of EMI Gaskets Using Definition of Shielding Effectiveness

### ◆ Initial E Field Reading



$$SE = E_I/E_A$$

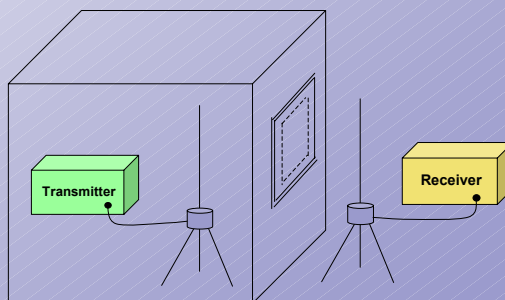
$$SE \text{ (dB)} = E_I \text{ (dB)} - E_A \text{ (dB)}$$

$E_I$  = Initial E field measurement

$E_A$  = E field measurement after placing transmitting antenna inside shielded enclosure.

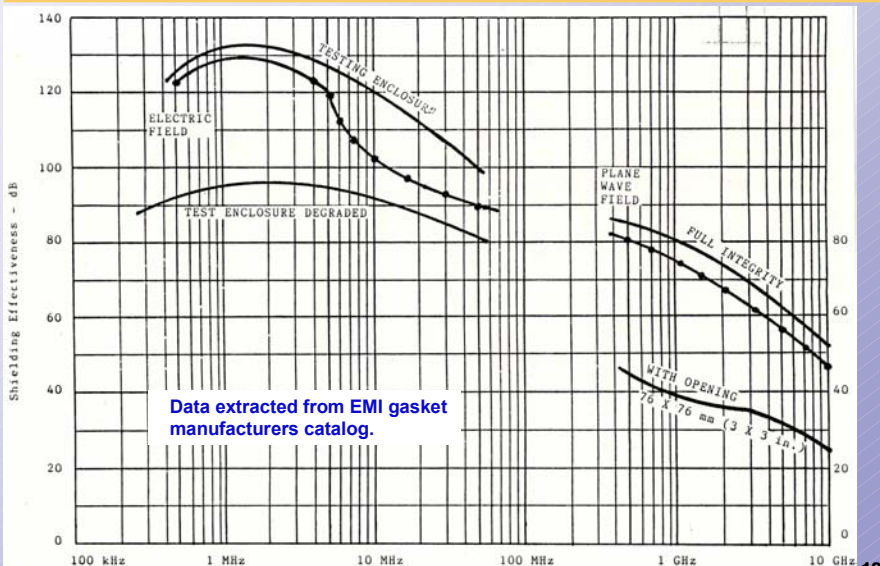
### ◆ After Reading:

- Consists of placing a gasketed cover on a shielded enclosure and measuring the value of the E field that penetrates the cover.



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## Shielding Effectiveness: Electric & Plane Wave Fields



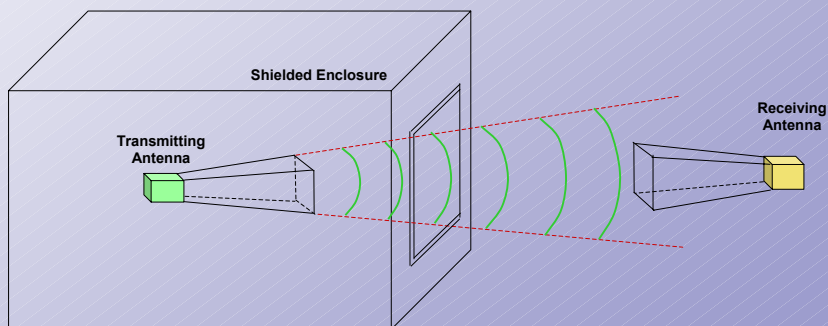
## MIL-G-83528 Test Method

- ◆ The Shielding Effectiveness Test described in MIL-G-83528 is a modified MIL-STD-285 Test.
- ◆ MIL-STD-285 stipulates that the wave generated by the Transmitting Antenna be directed at discontinuities or joint in the enclosure and the receiving antenna be positioned to receive the maximum field strength emanating from the joint.
- ◆ MIL-G-83528 stipulates that the EM wave be directed at the center of a large 28"x28" inch plate and the receiving antenna be located directly behind the plate.

## Shielding Effectiveness Testing of EMI Gaskets Using MIL-G-83528 Test Method

### ◆ Notes

- Measuring the field strength for MIL-G-83528 prior to installing gasketed cover.
- The field strength from the radiating antenna is aimed at a hole in the wall of a shielded enclosure and measured by the receiving antenna.



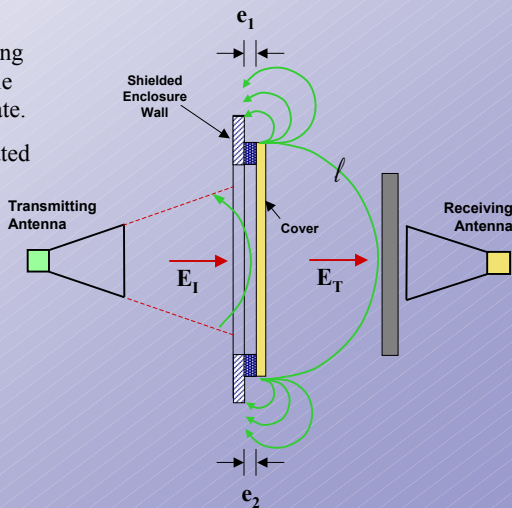
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## Shielding Effectiveness Testing of EMI Gaskets Using MIL-G-83528

### ◆ Notes

- The wave from the transmitting antenna ( $E_1$ ) strikes the middle of a large thick aluminum plate.
- The receiving antenna is located directly behind the plate.

$$E_T \approx \frac{e_1 - e_2}{l}$$

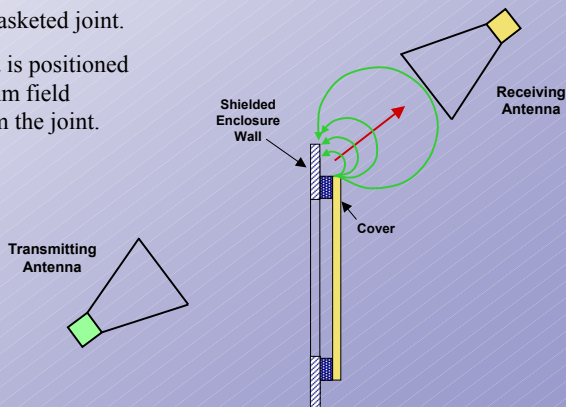


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## Shielding Effectiveness Testing of EMI Gaskets Using MIL-STD-285 at Microwave Frequencies

### ◆ Notes

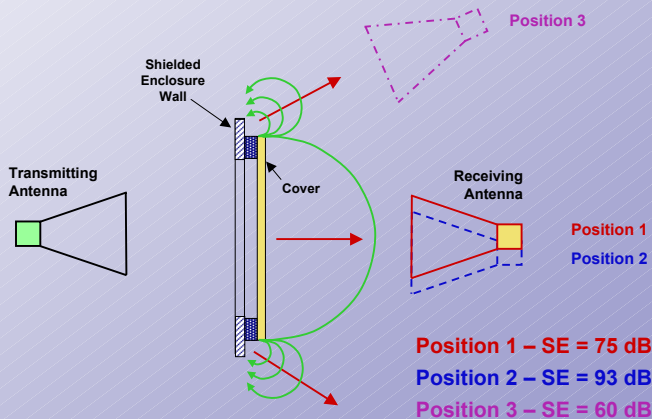
- The Transmitting antenna is positioned to maximize the EM field strength at the EMI Gasketed joint.
- The receiving antenna is positioned to receive the maximum field strength radiating from the joint.



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## Shielding Effectiveness: Position of Antenna

### ◆ Shielding Effectiveness Test Results of Newspaper at 2 GHz Using MIL-G-83528 Test Configuration



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## Transfer Impedance Testing of EMI Gasket

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- ◆ Transfer Impedance Testing measures the impedance of a gasketed joint and normalizes the impedance in terms of a meter length of gasket.