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Probes for Diagnosing EMC Problems

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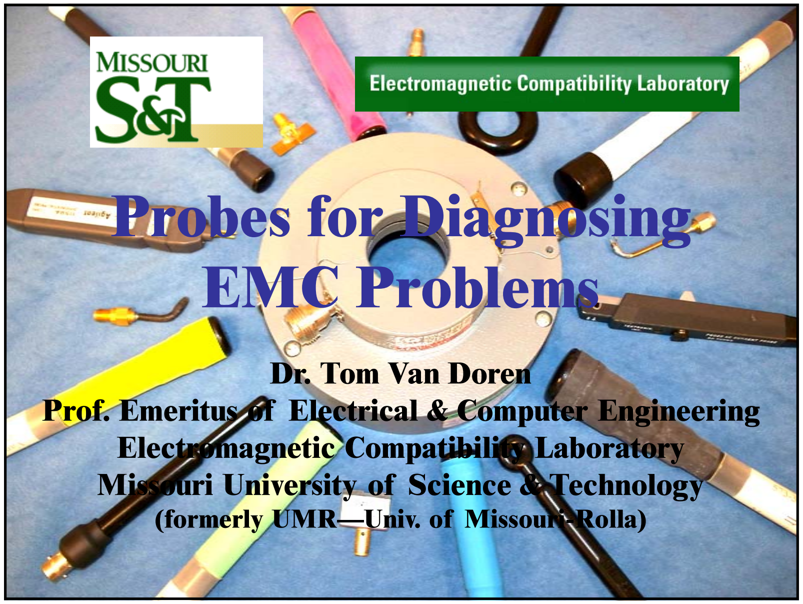

PRESENTATION OUTLINE

- Energy Coupling Mechanisms
- Key Probe Characteristics
- Voltage Probes
- Clamp-on Current Probes
- Magnetic-Field Probes
- Electric-Field Probes

MISSOURI S&T — Electromagnetic Compatibility Laboratory

ELECTRICAL INTERFERENCE REQUIRES:

INTERFERENCE SOURCE → ENERGY COUPLING MECHANISM → SUSCEPTIBLE SYSTEM

Coupling Mechanism	Quantity Measured	Measuring Process
Conducted	Voltage Difference (V)	Resistive Divider + Amplifier
	Current (I)	Resistive Shunt (I = V/R)
		Magnetic Coupling (XFMR)
Near Field	Magnetic Field (H)	Magnetic Coupling $V = MdI/dt \propto dH/dt$
	Electric Field (E)	Displacement Current $I = CdV/dt \propto dE/dt$
Far Field	EM Wave	"Antenna" $V_{OUT} = AF \times E$

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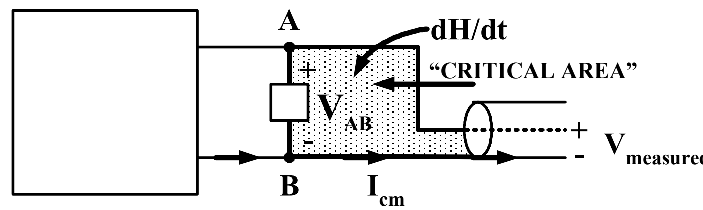
SOME KEY PROBE CHARACTERISTICS FOR DIAGNOSTIC MEASUREMENTS

Bandwidth
Sensitivity
Impedance Loading
Field Perturbation
Spatial Resolution
Impedance Balance
Repeatable Positioning
Ruggedness
Cost

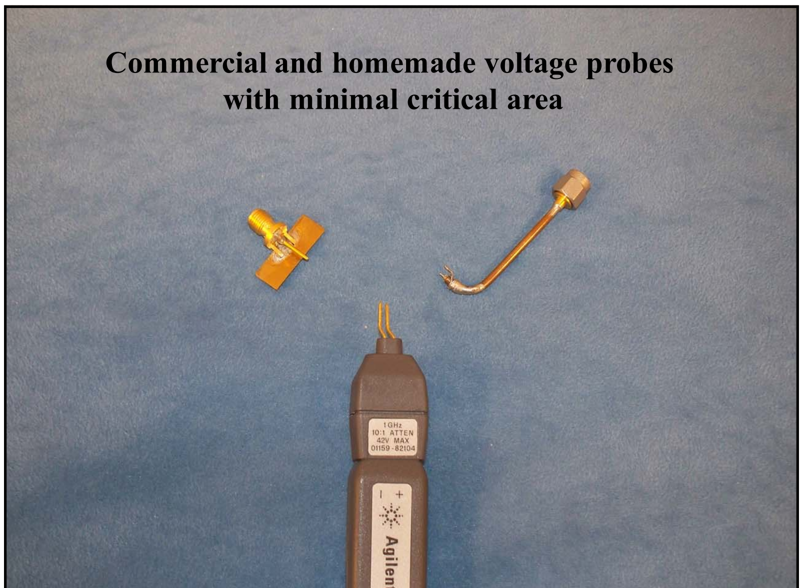
VOLTAGE PROBES MAJOR SOURCES OF MEASUREMENT ERROR



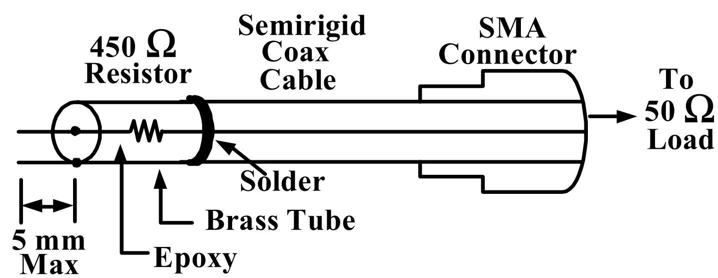
$$|V_{measured}| = V_{AB} \pm \omega_1 M I_{CM} \pm \omega_2 \mu \iint H \cdot ds$$

Must minimize the "CRITICAL AREA".

Might reduce I_{CM} with ferrite beads around coaxial cable.

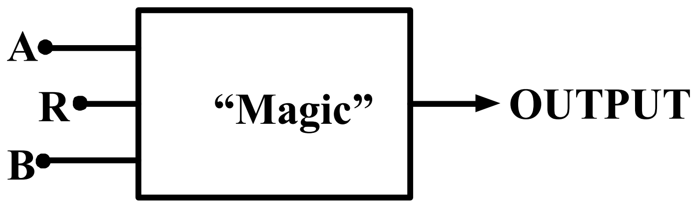


A SIMPLE, PASSIVE, UNBALANCED X10 VOLTAGE PROBE DESIGN



Inexpensive to buy or build
Only 500 Ω input impedance
Flat frequency response to several GHz
Minimal sensitivity to ESD

ACTIVE, BALANCED, HIGH IMPEDANCE DIFFERENTIAL VOLTAGE PROBE



R = "Reference Node" (= Ground ???)

Some differential probe systems can measure:
V_{AB}, V_{AR}, V_{BR}, & $(V_{AR} + V_{BR})/2$

GHz bandwidth, Expensive, ESD sensitive

MEASURING VOLTAGE DIFFERENCES ACROSS SEAMS AND ARPETURES

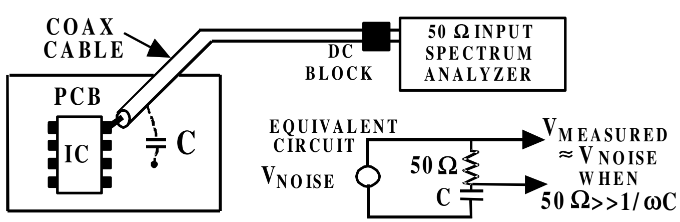
Estimate of E-Field at distance R:

$$E \approx \frac{10\,V}{L} = \frac{10\,V}{\pi R}$$

L = semicircular arc
Assumes R << λ

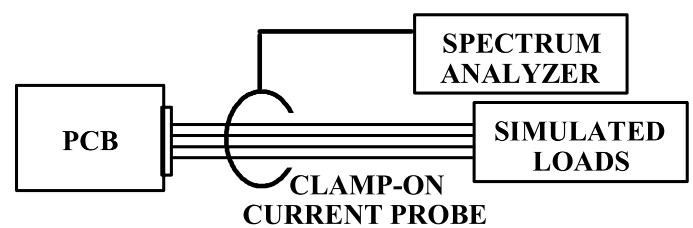
A relative measurement of the voltage differences across a variety of seams might identify the location of dominant energy leakage.

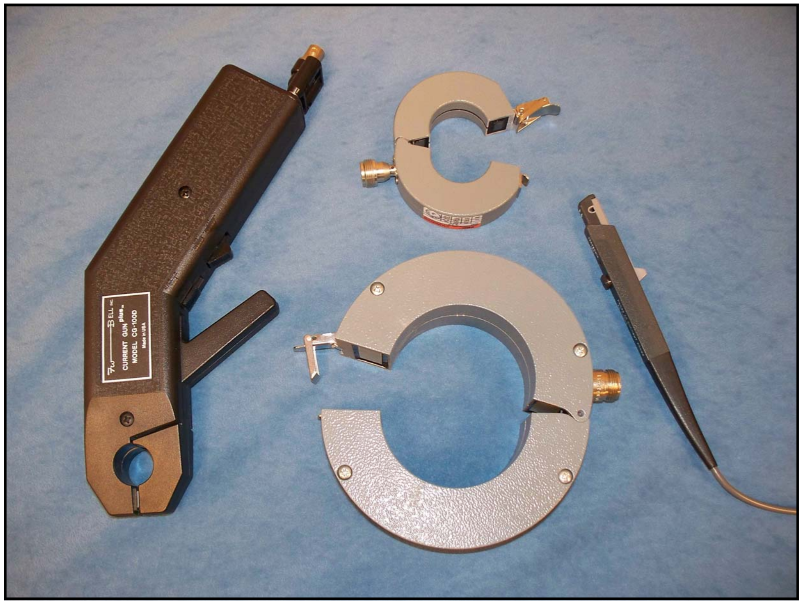
MEASURE APPROXIMATE RF VOLTAGE DIFFERENCE USING ONE CONDUCTIVE CONTACT AND ONE CAPACITIVE CONTACT



Find circuit nodes with unexpected RF activity

MEASURING I_{CM} ON CABLES USING A CLAMP-ON CURRENT PROBE





I_{CM} > 5 μA CAN EXCEED RADIATION LIMIT

E (V/m) at distance r (m) from a λ/2 dipole:

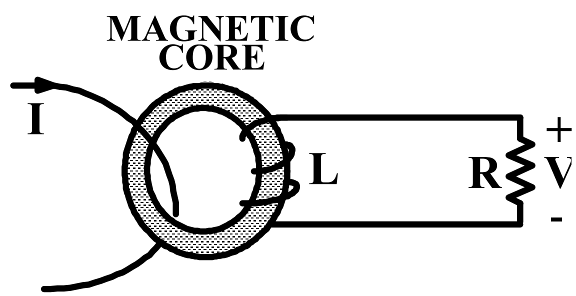
$$E = \frac{60I}{r}\text{, I = current (A) at center of dipole}$$

FCC class B radiated emission limit requires:

E < 40 dBμV/m = 100 μV/m, 30-88 MHz, r = 3 m

$$I < \frac{rE}{60} = \frac{(3\,m)(100\,\mu V/m)}{60\ \Omega} = 5\mu A$$

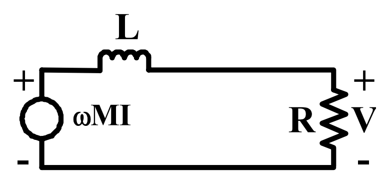
CLAMP-ON CURRENT PROBE



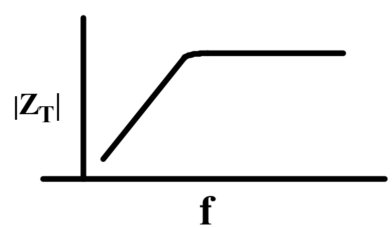
$$|I| = |V/Z_T|$$

I = the “net” or CM Current on the cable

CLAMP-ON CURRENT PROBE SIMPLIFIED EQUIVALENT CIRCUIT OF OUTPUT



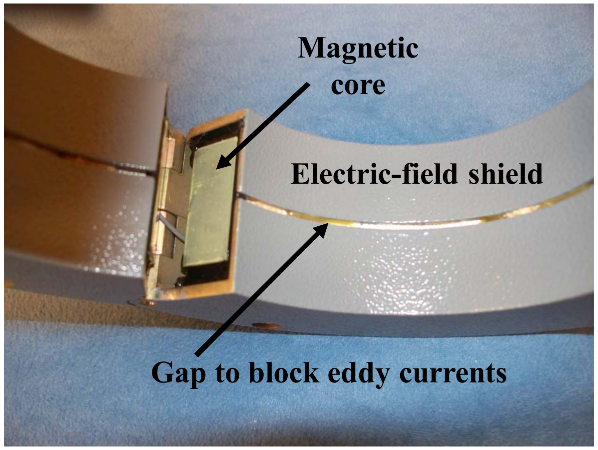
$$|V| = \frac{\omega MRI}{\sqrt{R^2 + (\omega L)^2}} = I|Z_T|$$



For ωL << R, $|Z_T| = \omega M$

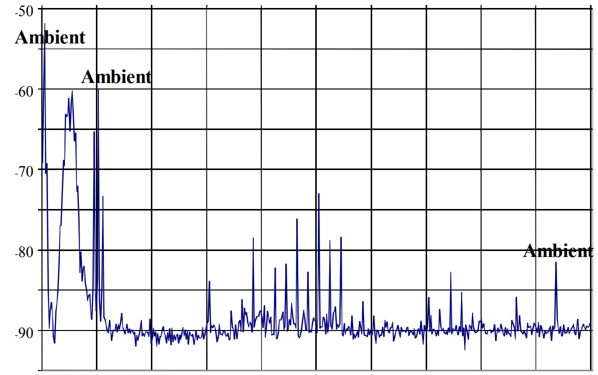
For ωL >> R, $|Z_T| = MR/L$

CLAMP-ON CURRENT PROBES REQUIRE ELECTRIC-FIELD SHIELDING



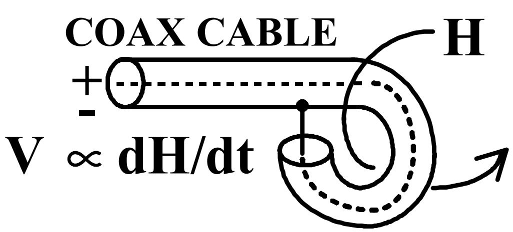
Typical Cable Common-Mode Current

(measured in terms of the power received at spectrum analyzer, dBm)



Frequency 0-1000 MHz

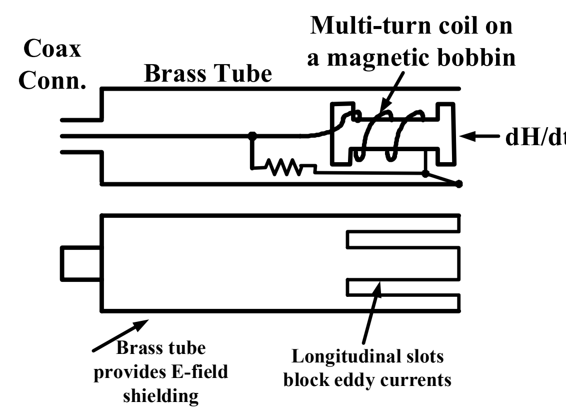
MAGNETIC-FIELD PROBES FOR MHz TO GHz FREQUENCIES



Electric-field shielding is provided by the coax outer conductor.

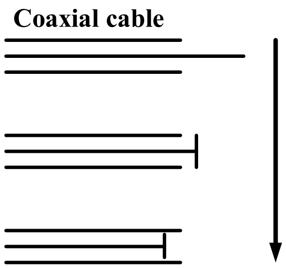
Usually, the loop diameter is reduced for higher frequencies to improve spatial resolution.

MAGNETIC-FIELD PROBE DESIGN FOR A PEAK RESPONSE IN THE 1 kHz TO 10 MHz RANGE



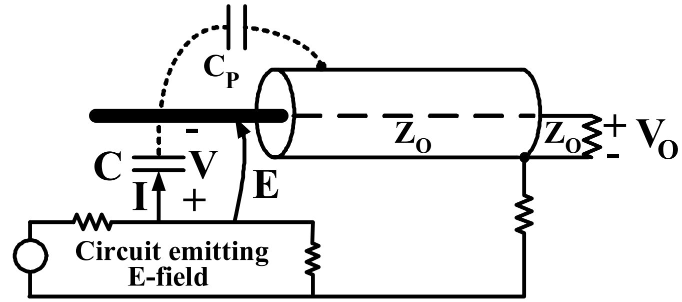
Center frequency and bandwidth are determined by number of turns, wire size, magnetic core material, etc.

VARIOUS ELECTRIC-FIELD PROBE DESIGNS



Reduced sensitivity but increased spatial resolution and directivity

ELECTRIC-FIELD PROBE MEASURES DISPLACEMENT CURRENT



$$V \propto E; \quad |I| = |\omega C V| \propto E$$

$$|V_O| = \left|\frac{\omega C Z_O V}{1 + j\omega C_P Z_O}\right| \propto E$$