A NEW COMMON-MODE VOLTAGE PROBE FOR PREDICTING EMI FROM UNSHIELDED DIFFERENTIAL-PAIR CABLES

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TOPICS:

INTRODUCTION

COMMON MODE

- **SOURCES OF COMMON MODE EMI**
- **OATS vs. CURRENT CLAMP AND ABSORPTION CLAMP**

MEASURING CM VOLTAGE INSTEAD OF CM CURRENT

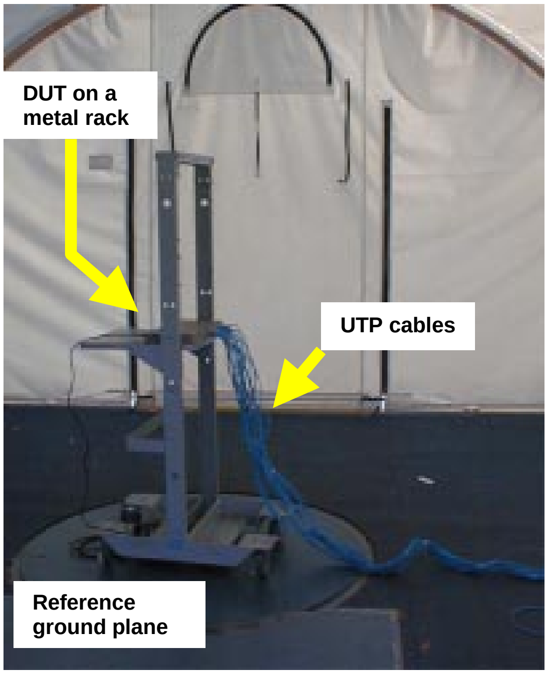
- **CM MODEL OF A DUT UTILIZING DIFERENTIAL PAIRS**
- **CM IMPEDANCE OF CABLES**
- **DESCRIPTION OF THE CM VOLTAGE PROBE**

APPLICATIONS

- **TROUBLESHOOTING**
- **PREDICTION**

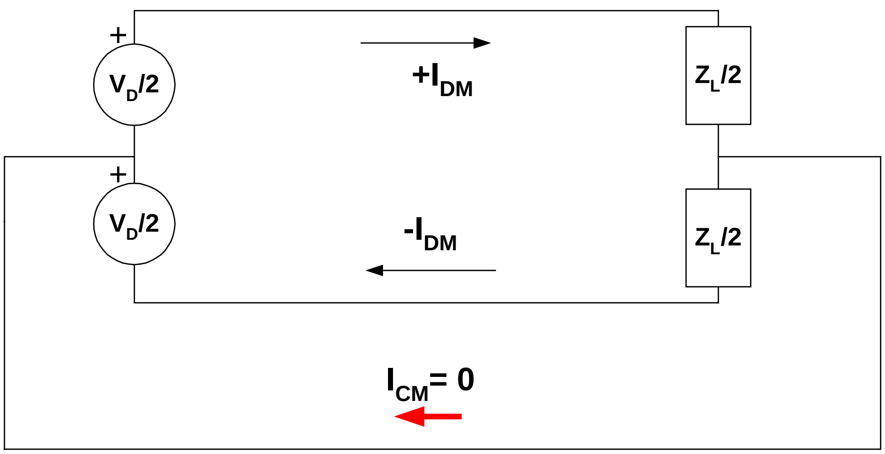
CONCLUSION

A TYPICAL EMI TEST SETUP



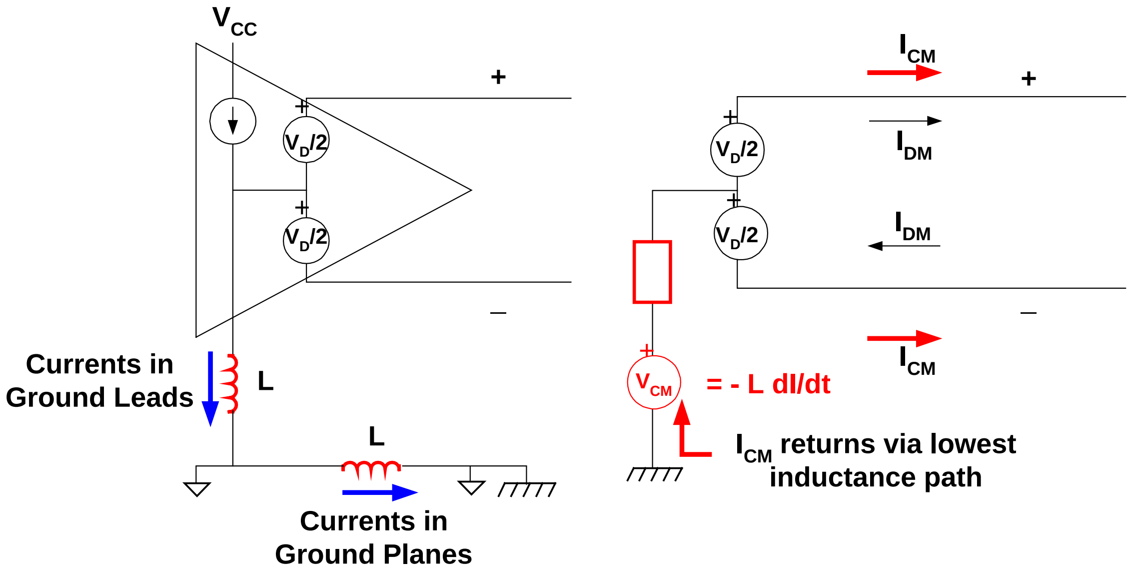
IDEAL CASE

When $+I_{DM}$ is physically close to $-I_{DM}$, flux cancellation resuls in low EMI from differential-mode (DM) currents. There is no common-mode (CM) current.



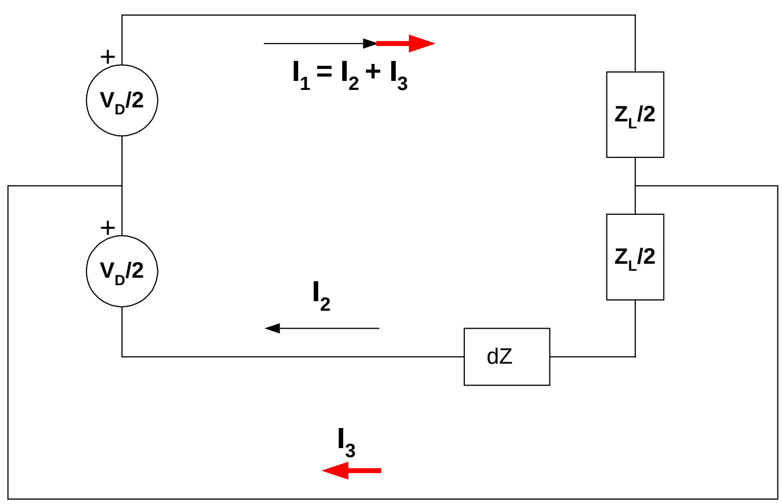
IN REALITY $I_{CM} \neq 0$

GROUND BOUNCE



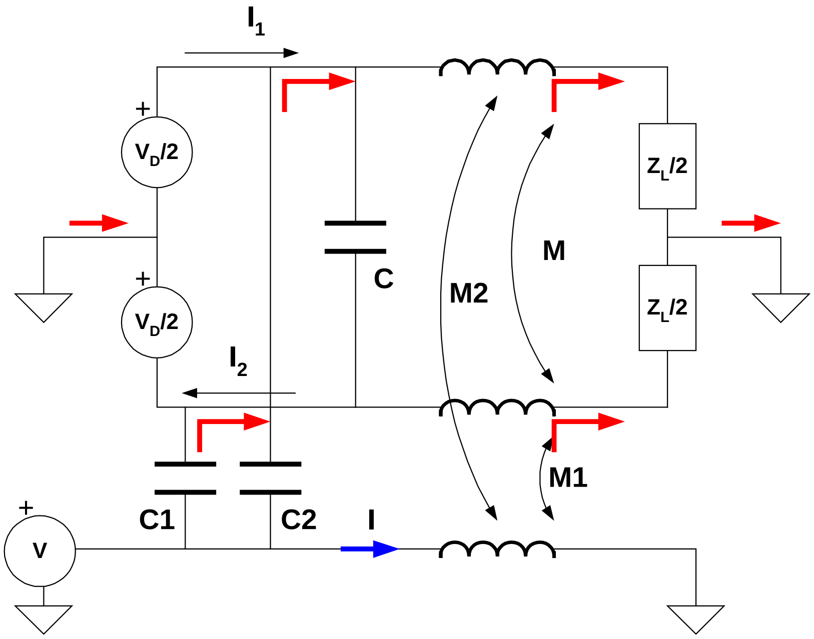
CAUSED BY CURRENTS IN GROUND IMPEDANCE

IMBALANCE DUE TO ASYMMETRICAL IMPEDANCE



CM CURRENT RETURN PATH IS OUTSIDE OF THE DM LOOP

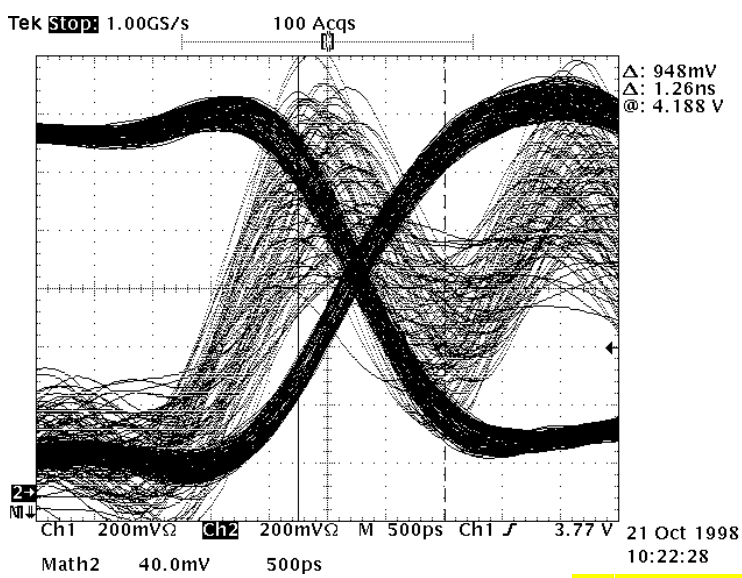
COUPLING / CROSSTALK



M1, M2, C1, C2 → CM & DM

I_1 close to I_2 and far from I → CM only

ASYMMETRICAL DIFFERENTIAL SIGNALS

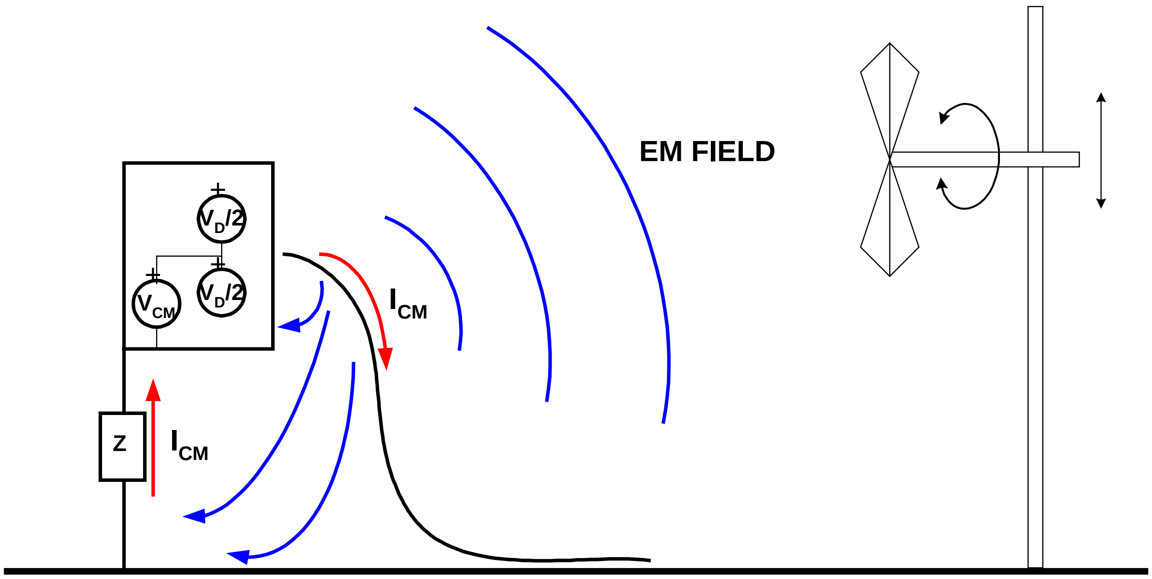


DIFFERENTIAL 25 MHZ, 1.2 V ECL

(200 mV/DIV SIGNAL 40 mV/DIV NOISE)

Tr= 1.5 ns Tf= 1.2 ns
240 mV CM VOLTAGE

EMI DUE TO CM CURRENTS ON CABLES



MAX. EMI COMES FROM THE FIRST COUPLE OF WAVELENGTHS ON THE CABLE

COMPARISON OF OATS, ABSORPTION CLAMP, AND CURRENT CLAMP

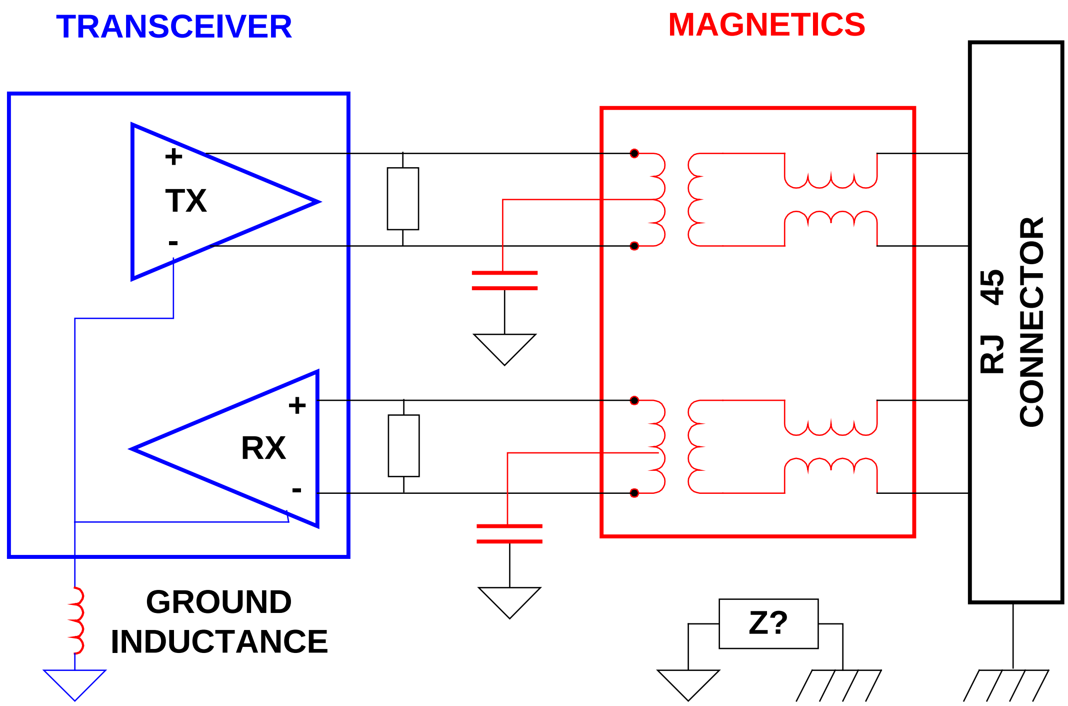
	OATS	ABS. CLAMP	CURRENT CLAMP
Standard	Widely	Limited	Not standard
Measure	Real emission	EMI from cables	EMI from cables
Time	Consuming	Faster	Fast
Noise	Ambients	Amb./Less sensitive	Amb./Less sensitive
Reproducibility	±4 dB + setup	Good	Good for debugging

WE NEED AN EASIER-TO-USE EVALUATION TOOL

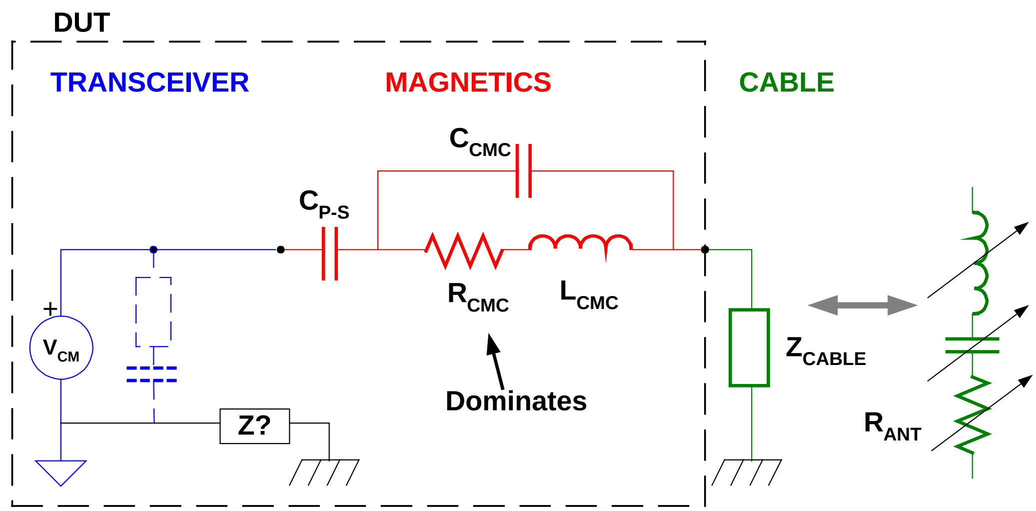
ABSOLUTE ACCURACY IS NOT THE PRIME FACTOR

DESIGN GOAL: SPEED AND REPRODUCIBILITY

LAN PORT



CM MODEL OF A LAN PORT WITH CABLE



CABLE CAN BE MODELED BY
TUNABLE IMPEDANCE

THEORY

MOVING CABLES FOR MAX EMI TUNES CABLE NEAR TO RESONANCE

IN RESONANCE, CABLE IMPEDANCE IS SIMILAR TO IMPEDANCE OF MONOPOLES OR DIPOLES

IMPEDANCE OF MONOPOLES AND DIPOLES

$\lambda/4$	**MONOPOLE**	$\Rightarrow$	**Rant =**	**36 Ω**
$\lambda/2$	**DIPOLE**	$\Rightarrow$	**Rant =**	**73 Ω**
λ	**DIPOLE**	$\Rightarrow$	**Rant =**	**199 Ω**

EXPECTED RANGE OF CABLE-IMPEDANCES IN RESONANCE

30 Ω - 200 Ω (real)

LITERATURE DATA *

CABLE IMPEDANCE IN RESONANCE IS ALMOST REAL

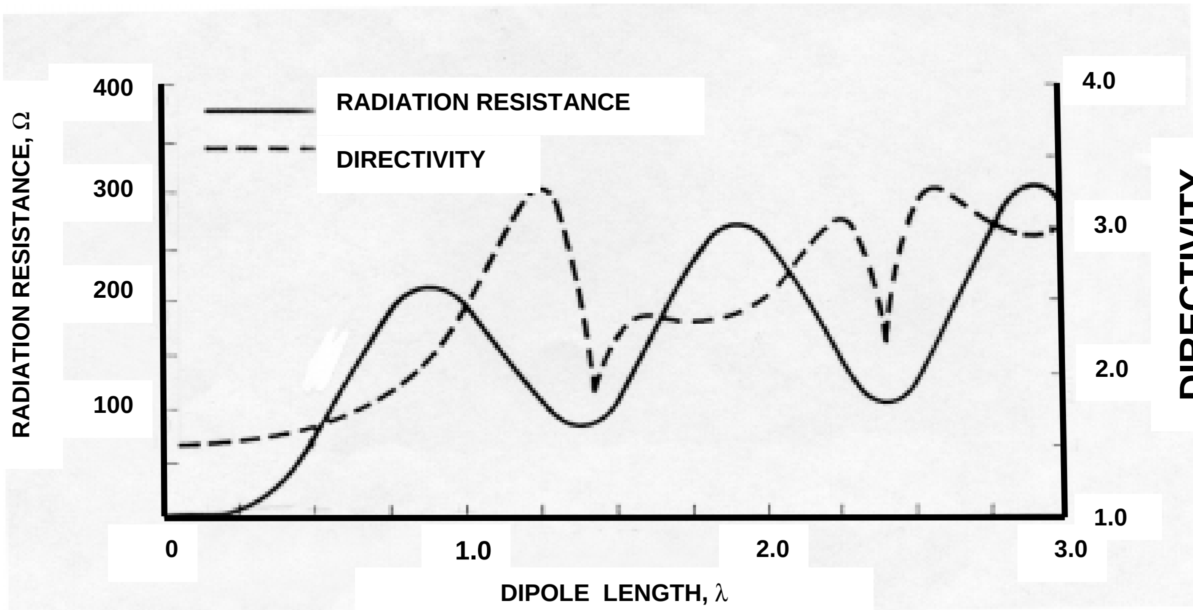
$$\arg (Z_{CM}) \leq 20^\circ$$

Z_{CM}= 150 Ω
STATISTICALLY IN RESONANCE

If the cable is not tuned for max. transfer of CM energy (max EMI), Z_{CM} is unpredictable, varying from below 1 Ω to more than a kΩ (>60 dB)

** PHILIPS Lab Report EIE 9200492004, July 1992*

DIPOLE RADIATION RESISTANCE



WITH FIXED LENGTH OF WIRE, Rant INCREASES WITH FREQUENCY, AND CONVERGES TO 300 Ω FOR DIPOLE AND 150 Ω FOR MONOPOLE WHEN L > 3 λ

"Antenna Theory, Analysis and Design", C.A. Balanis, Harper&Row, New Yor USA 1982

DESIGN CONSIDERATIONS

1. **Cable maximization tunes the cable to resonance/match with the output impedance of the port they are connected to. The I_{CM} level is defined by the CM voltage, output CM impedance, and cable CM impedance.**

2. **Output CM impedance of a DUT is mostly resistive due to the lossy CM choke, 100 Ω - 1 kΩ typical.**

3. **CM voltage of a differential pair referenced to the chassis ground.**

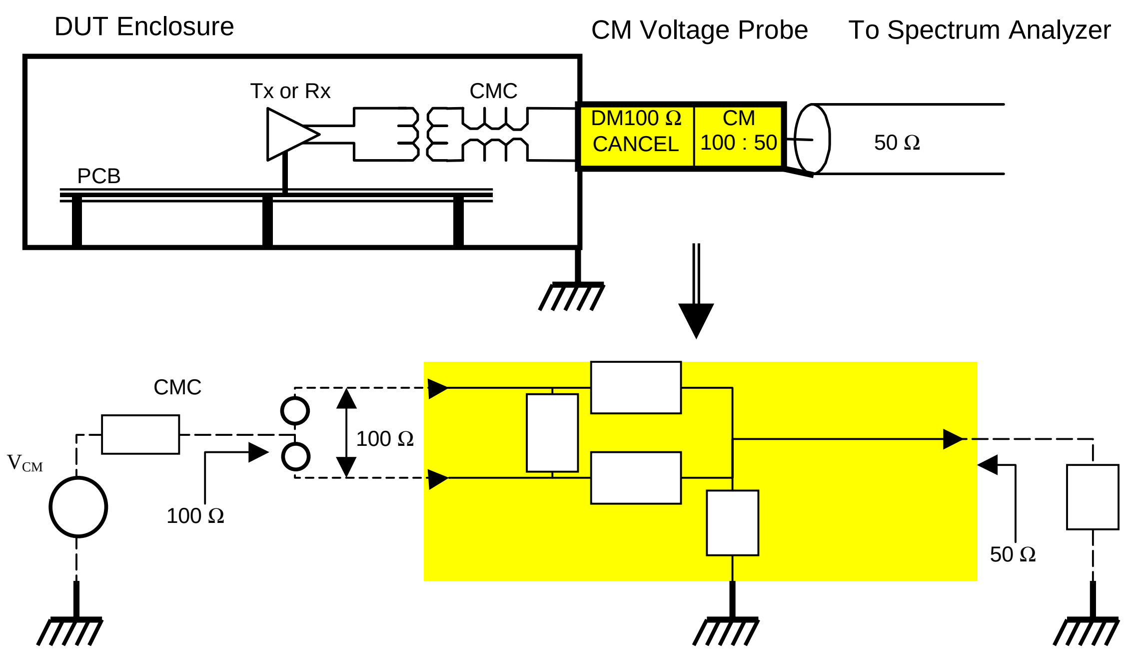
4. **A resistor can be used in place of the reactive (tunable) cable-impedance.**

The exact R-value will not likely occur in practice, but it provides a way of systematic and well reproducible evaluation in near worst-case conditions. The occurrence of the worst-case condition is random, but CAN always happen.

REQUIREMENTS FOR THE CM VOLTAGE PROBE

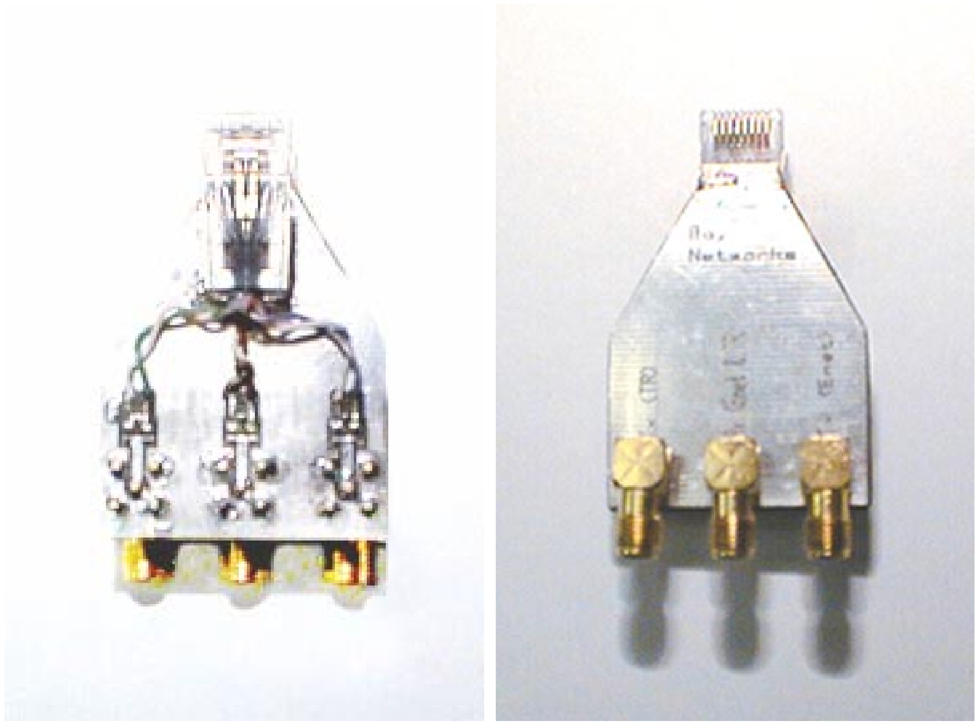
- **Separate measurement on Tx and Rx**
- **100 Ω differential impedance in Tx and in Rx**
- **Cancellation of differential signals**
- **Provides output for CM voltage measurement**
- **100 Ω CM impedance from each pair to chassis GND**
- **50 Ω output impedance (to spectrum analyzer)**

THE TEST APPARATUS USING THE CM VOLTAGE PROBE



Patent pending

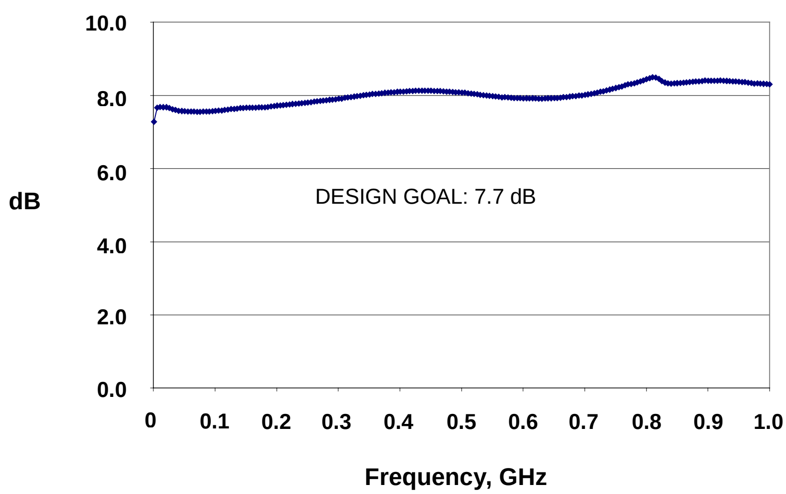
THE PROBE WITHOUT SHIELD



PARALLEL TX AND RX OUTPUTS
FOR ETHERNET AND TOKEN RING ARE PROVIDED

Patent pending

CM INSERTION LOSS OF THE PROBE

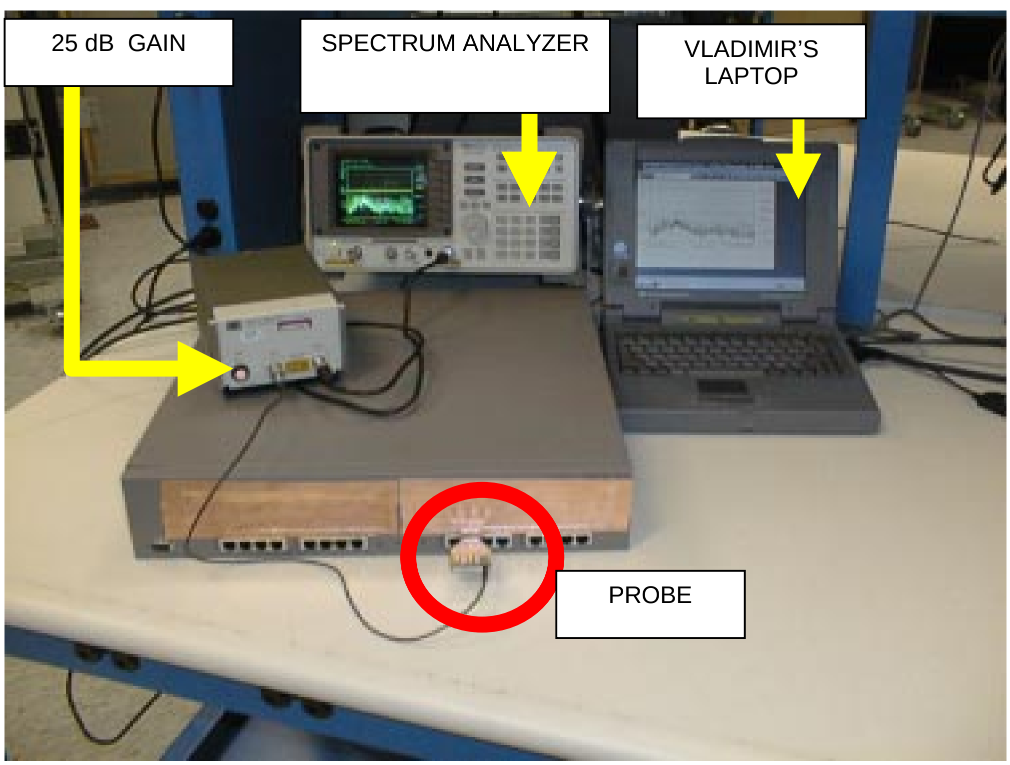


TROUBLESHOOTING

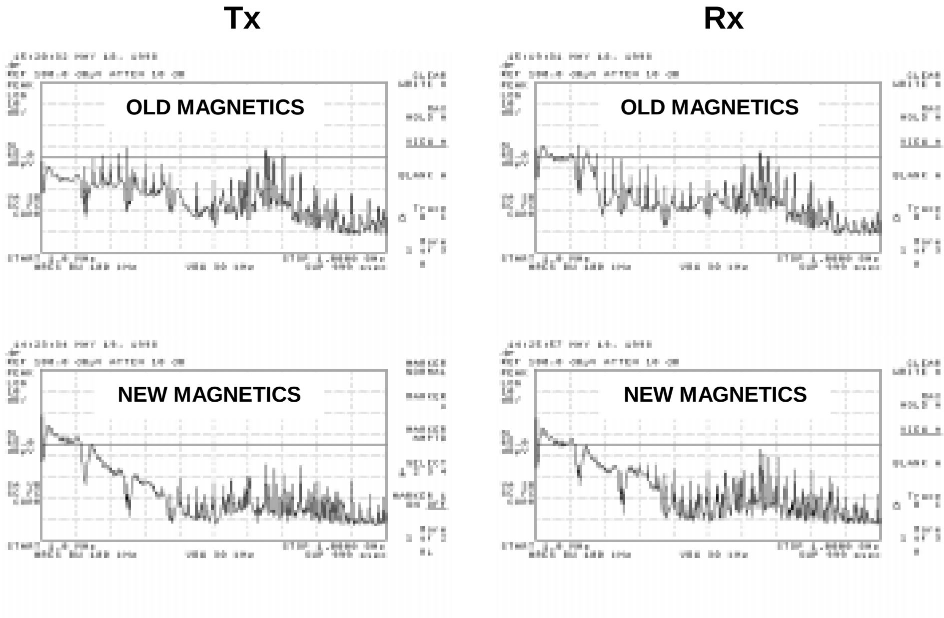
- Straightforward CM Voltage measurement on bench.
- Directly related to EMI.
- No maximization of cables.
- Reproducible within less than a dB.
- No problem with ambients.
- Separate measurements on Tx and Rx.
- Effects of modifications can be evaluated in seconds.
- Evaluation in broad frequency range (no surprises).
- Simplifies component selection and evaluation.

ADVANTAGE: EASY TO USE AND REPRODUCIBLE

BENCH TEST SETUP



EXAMPLE OF
CM VOLTAGE SPECTRUM @ RJ45



PREDICTING EMI BASED ON CM VOLTAGE MEASUREMENT

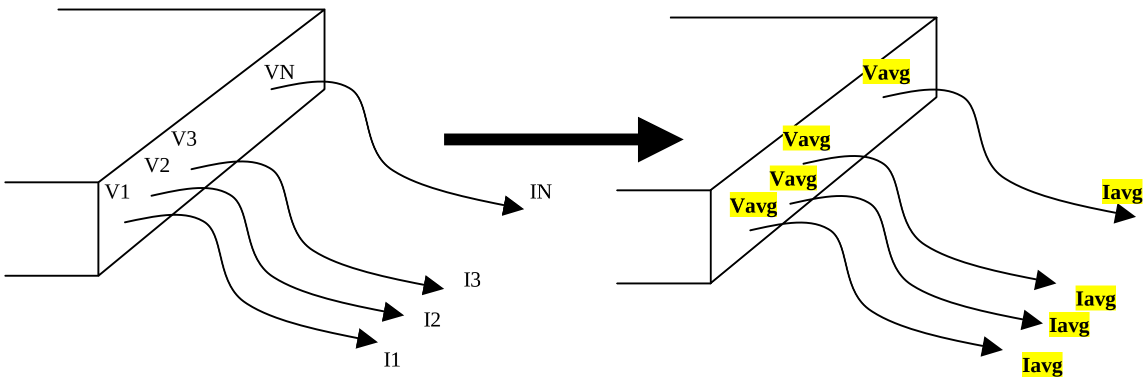
- **Significant differences in CM voltage levels may exist between Tx and RX, and between ports of a DUT.**

- **Worst-case for EMI is when CM currents are in phase.**

- **Assuming worst-case, we may linearly add up all CM currents that the DUT would produce. Adding the currents is equivalent to adding up all CM voltages.**

  (The worst-case approach also assumes that the cable impedance is same for each cable.)

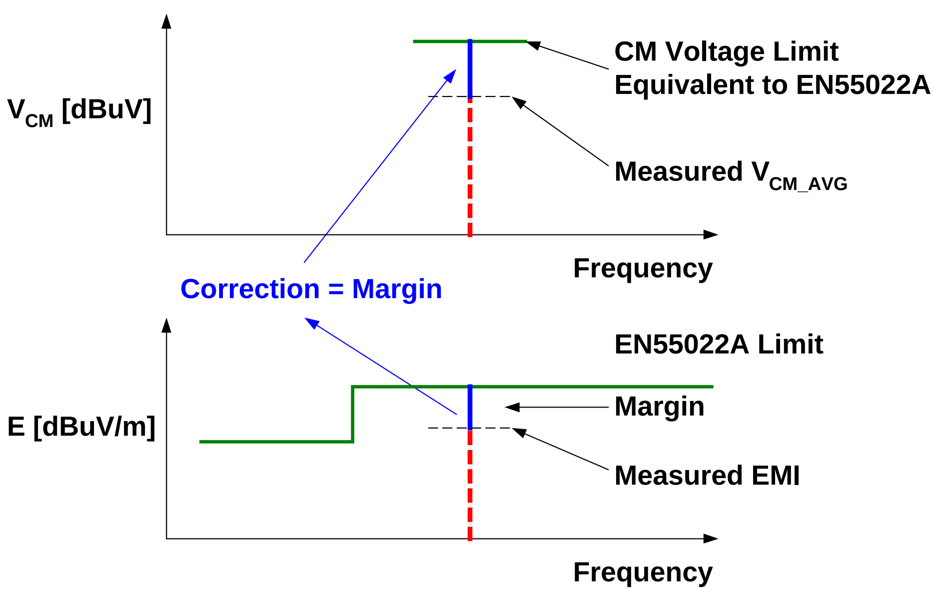
USING AVERAGE CM VOLTAGE INSTEAD OF SUM OF CM CURRENTS



Itota l= I1 + I2 + ….+ IN =
= (V1 + V2 + …+ VN) / Z

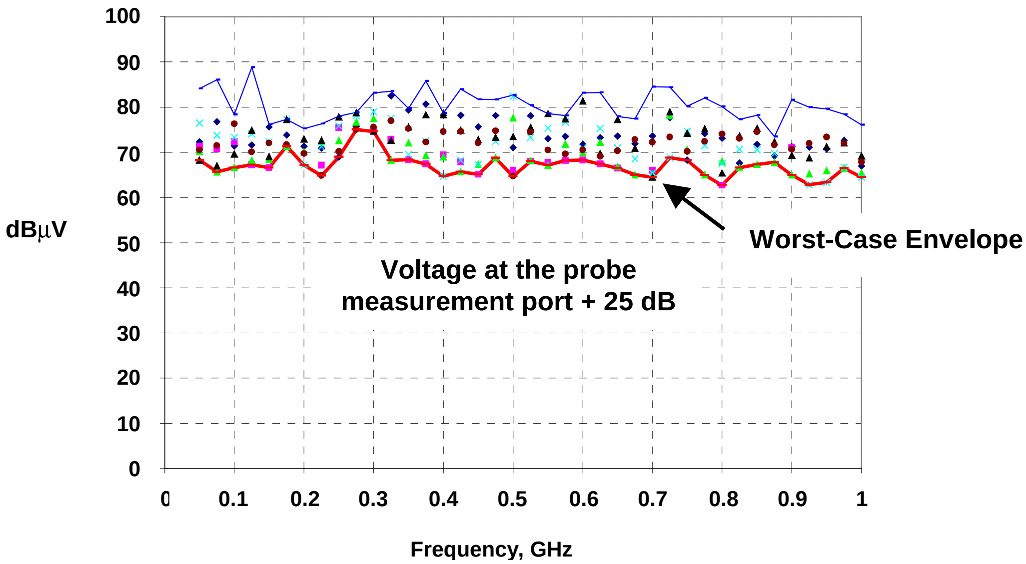
Iavg = Itotal / N =
= (V1 + V2 + …+ VN) / (NZ)
= Vavg/Z

V_{CM} EQUIVALENT TO EN55022A LIMIT



MEASURED V_{CM_AVG} IS CORRECTED BY MEASURED MARGIN TO EN55022A

V_{CM} LIMIT FOR PREDICTION OF EMI



Correlation of V_{CM_AVG} to the EN 55022 A Limit
Obtained by Correlating V_{CM_AVG} and EMI of Eight DUTs @ 10-m OATS

CONCLUSION

– A simple bench-method tool has been developed for efficient troubleshooting and prediction of EMI from unshielded differential-pair cables.

- CM voltage probe provides impedance match for:
differential pairs, CM output impedance of DUT, impedance of a measuring device.

- The probe puts a CM impedance to the differential pairs that is similar to cable-impedance in resonance.

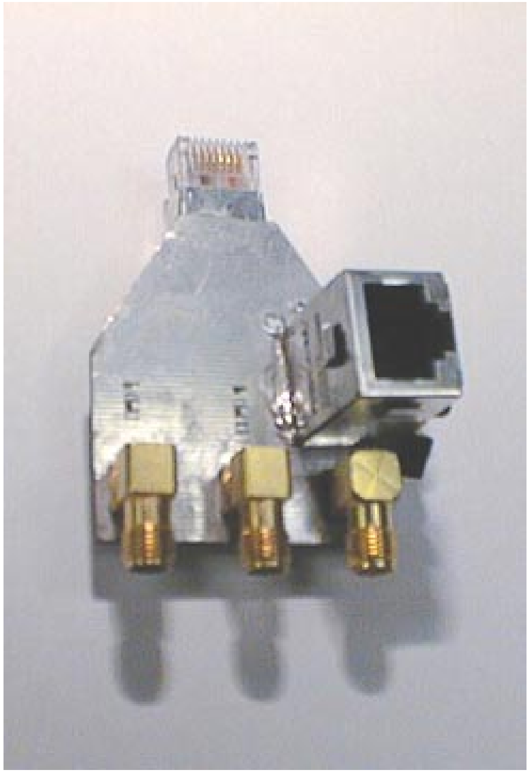
- The probe is not sensitive to ambients.

- The method does not require cable maximization.

- Using worst case, which is max. EMI, a correlation between EN55022A and CM voltage has been established.

A limitation of the probe is case when EMI is related to actual data traffic through the differential cable. However, in most cases (but not always), EMI is related to clock and similar signals (PLL, LO), and hence not dependant on data on the cables.

Modified probe that permits data traffic AND simultaneous measurement of CM voltage on DUT ports.



Patent pending