MANAGING ELECTROMAGNETIC INTERFERENCE in LARGE INSTRUMENTATION ENVIRONMENTS

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International Beam Instrumentation Conference 2014
September 14-18, 2014

A Few Things to be Covered in this Presentation

- **This presentation focuses on practical aspects of EMI management**
  - Very Little Theory – well not much anyway – real-life examples
  - ***It's all about the current – pretty much!***
- **EMC vs EMI**
  - Differences
  - Standards
- **What is EMI**
- **The instrumentation environment**
  - Purpose Built
  - Legacy
- **Ground – what is it and why**
- **EMI Points of Entry – real-life examples**
- **EMI mitigation – real-life examples**
- **Summary**

EMC vs EMI

- **EMC: "Electromagnetic Compatibility"**
- **EMI: "Electromagnetic Interference"**
- **These terms are often improperly applied somewhat interchangeably**
  - EMC is a design goal to be achieved
  - EMI is a corrupting influence to be reduced
- **The goal of EMC is to reduce (not necessarily eliminate) EMI**
- **EMC is most effectively addressed in the design phase of a facility**
- **Managing EMI is very often required well after facility construction**
  - Working in legacy systems: LANSCE, SLAC
  - Implementing new measurements, new experiments
  - Little or no opportunity to modify legacy facility infrastructure

EMC/EMI Standards and References

- **Numerous IEEE standards**
- **MIL-STD-461 [1]**
  - RE – Radiated Emissions
  - CE – Conducted Emissions
  - RS – Radiated Susceptibility
  - CS – Conducted Susceptibility
- **Standards are compliance references, not “How To” references**
  - Define allowed emissions, and survivability requirements
  - Do not provide guidance for designing systems to control emissions or to tolerate exposure to emissions
- **Very many “How To” references**
  - Typically very general, and often highly theoretical
  - Often difficult to interpret and apply to “your” environment and your task
  - Experience is the best teacher

EMC System Design Process Identifies Effective Methods to Reduce EMI Energy Transfer [2]

1. Identify and characterize EMI sources
2. Apply EMC methods to limit the disturbance at the source and/or to minimize EMI coupling to the environment
3. Identify and characterize EMI coupling mechanisms
4. Apply EMC methods (shielding and grounding) to minimize coupling through radiation or conduction paths
5. Identify and characterize diagnostic system receptors
6. Minimize receptor EMI susceptibility by shielding, grounding, isolation, filtering, balancing, orientation, separation, impedance, etc.

A Few Classic EMI Mitigation Approaches

At the Source	At the Receiver
Shielding	Shielding
Grounding	Grounding
Shielded Source Cables	Shielded Signal Cables
Shielded Signal Cables	Shielded Source Cables
Balanced Source Signals	Balanced Data Signals
Filtering	Filtering
	Separate Equipment Ground
	Cable Routing
	“Single-Point Ground”
	“Eliminate” Ground Loops
	Etc.

Understanding EMI

- **One person's signal is another person's EMI**
- **This presentation is somewhat different from other EMI discussions**
  - My definition of EMI is somewhat different than traditional - I consider *ANY* corrupting electrical signal as EMI
- **Focus on EMI both from "outside" sources as well as EMI we create ourselves**
- **Understanding why EMI happens is the first task in managing EMI**
- **When you are trying to mitigate some EMI signal, if chasing the wrong source or wrong point of entry, your efforts will be very frustrating, and your results perhaps less than desirable, even making it worse!**
- **There is no "cookbook" solution to mitigating EMI**
- **There is no "one size fits all" solution to mitigating EMI**
- **All EMI mitigation must be "engineered"**

DRAW A PICTURE !

DEFINITION

EMI is *any* electrical signal adversely affecting data quality whether from external or internal sources

Just What is EMI?

- **EMI is typically a catch-all term for any unwanted electrical signal**
  - AC Power MAINS noise – unknown sources – it is just there!
  - Noise generated by equipments in the facility
    - High-energy power supplies
    - Motors, contactors and other AC MAINS devices
    - HID lighting
    - Solid-state ballasts
  - Noise generated ***within*** instrumentation systems themselves
    - Switch-mode power supplies
    - Motor drive systems
    - Digital electronics
  - Environmental noise
    - Lightning
    - Earth currents – AC Power Distribution, Radio, TV, Wireless
- **First-Principle noise**

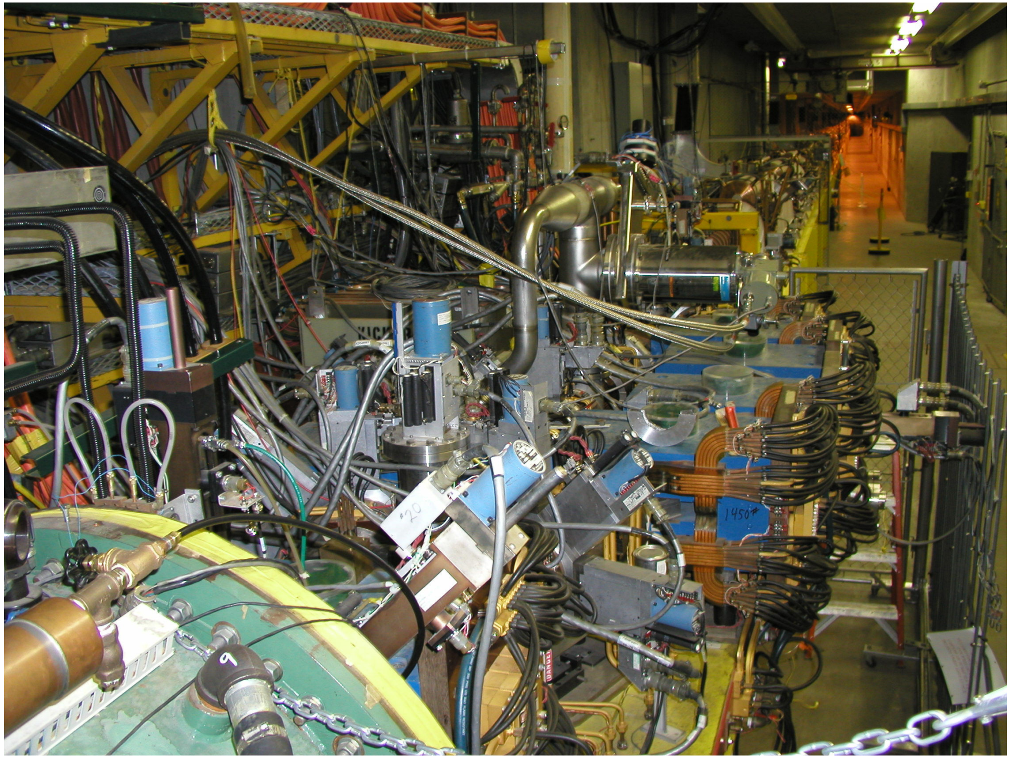
The Instrumentation Environment

- **New purpose-built systems (Greenfield Constructions)**
  - Built from the ground up
  - Typically the physics drives the overall infrastructure design
  - Some opportunity to optimize data acquisition
  - The instrumentation must function within the structure defined by the physics
  - The physics defines what sensors are to be implemented and where
  - The instrumentation engineering task is to competently collect the sensor signals
- **Legacy Systems**
  - Many tasks require working in systems which have been around for a ***long*** time
    - New missions are implemented
    - New experiments are designed and implemented
    - Little opportunity to modify the legacy environment
  - The new instrumentation systems must work in the legacy environment
  - The physics defines what sensors are to be implemented and where
  - The instrumentation engineering task is to competently collect the sensor signals

Working Within Legacy Systems

- **Legacy systems are already fully implemented**
  - No reasonable ability to alter facility infrastructure
    - Fixed shielding of emission sources
    - Fixed routing of high-energy cabling
    - Fixed site for instrumentation
    - Fixed, and long, routing of instrumentation cabling
- **Often actual noise sources are difficult to locate**
  - Multiple sources distributed over the complex
  - Sources very remote to the instrumentation systems and sensors
- **Little reasonable opportunity to "improve" emission source shielding**
- **EMI mitigation must typically be done in the instrumentation systems**
- **And, what works in a legacy environment will work when applied in a new facility design**

Typical Legacy Environments You May Encounter



Goal of EMI Mitigation

- **The goal of EMI management is to be "Good Enough," but not perfect**
- **First Principle Noise Limits**
  - Thermal noise: $V_T = \sqrt{4kTRBW_n}$ RMS
    - ~1 ηV for 50 Ohms at 300º K and 1 Hz BW, ~1 μV @ 1MHz BW
  - Shot noise: $I_n = \sqrt{2IqBW_n}$ RMS
    - ~20 pA for 1 mA and 1 Hz BW, 20 ηA @ 1 MHz BW ⇒ ~1 μV into 50 Ohms
  - Use only the bandwidth you need
- **Practical EMI mitigation must be "good enough" for each specific application**
  - If your data are digitized to 16 bits, e.g., a theoretical precision of one part in 65,546, there is no added value in reducing EMI to 1 ppm.

EMI Points of Entry

- **Radated susceptibility**
  - E-field coupling – Antennas: Long cables, unshielded conductors
  - H-Field coupling – Loops: Cables with more than one ground connection, capacitive coupling
- **Conducted susceptibility**
  - Currents – That's it, currents!
- **Radiated noise may be managed with shielding, conducted noise typically cannot**
- **In my experience, almost every case of EMI contamination has resulted from conducted points of entry, but not all**
- **Ground – but, just what is *GROUND*?**

To Ground or Not to Ground

- **The majority of grounding in a facility is not at the discretion of the instrumentation engineer**
  - Must work within the existing facility grounding structure
  - May ***NOT*** break safety ground connections for convenience - ***NEVER***
    - Breaking of a safety ground to reduce EMI in your instrumentation system is a good way the have the facility Electrical Authority Having Jurisdiction, e.g., the electrical safety officer, invite you to seek other employment!
- **Instrumentation systems must be designed to operate competently within the prescribed facility grounding structure**
- **However, instrumentation cabling is typically *permitted* be grounded or ungrounded**
  - The question which then arises is: To Ground or Not to Ground?
  - No grounding? One end grounded? Center grounded? Both ends grounded? Grounded every ¼ wavelength? Every ½ wavelength? Every $\lambda/50$?
  - And, grounded to what?

What to Ground

- **Just how much discretion do you have in *allowed* grounding?**
  - The instrumentation equipment is almost always grounded
    - Virtually all AC MAINS-powered equipment is required to be grounded for safety
    - Battery-powered equipment need not be grounded
      - Very inconvenient in terms of maintenance
      - Reliability always questionable – are you sure the batteries are charged, in all 500 of your instruments before a critical, and long, experiment run?
      - But, such battery-powered equipment must still “talk to” grounded equipment
    - High-isolation power supplies
  - Often the sensor itself defines the grounding structure at the point of measurement
  - Instrumentation cable paths are typically routed near grounded structures
    - Metal cable trays
    - Metal conduits
    - Along the concrete floor above, e.g., “near,” the facility grounding mesh
    - Capacitive coupling to ground – electric field risk and can result in ground loops
    - Loops formed between cable shield and nearby ground – magnetic field risk
      - The much maligned and feared “Ground Loop”

Typical Beam Current Sensor [3]

Bergoz FCT In-Flange Beam Current Monitors

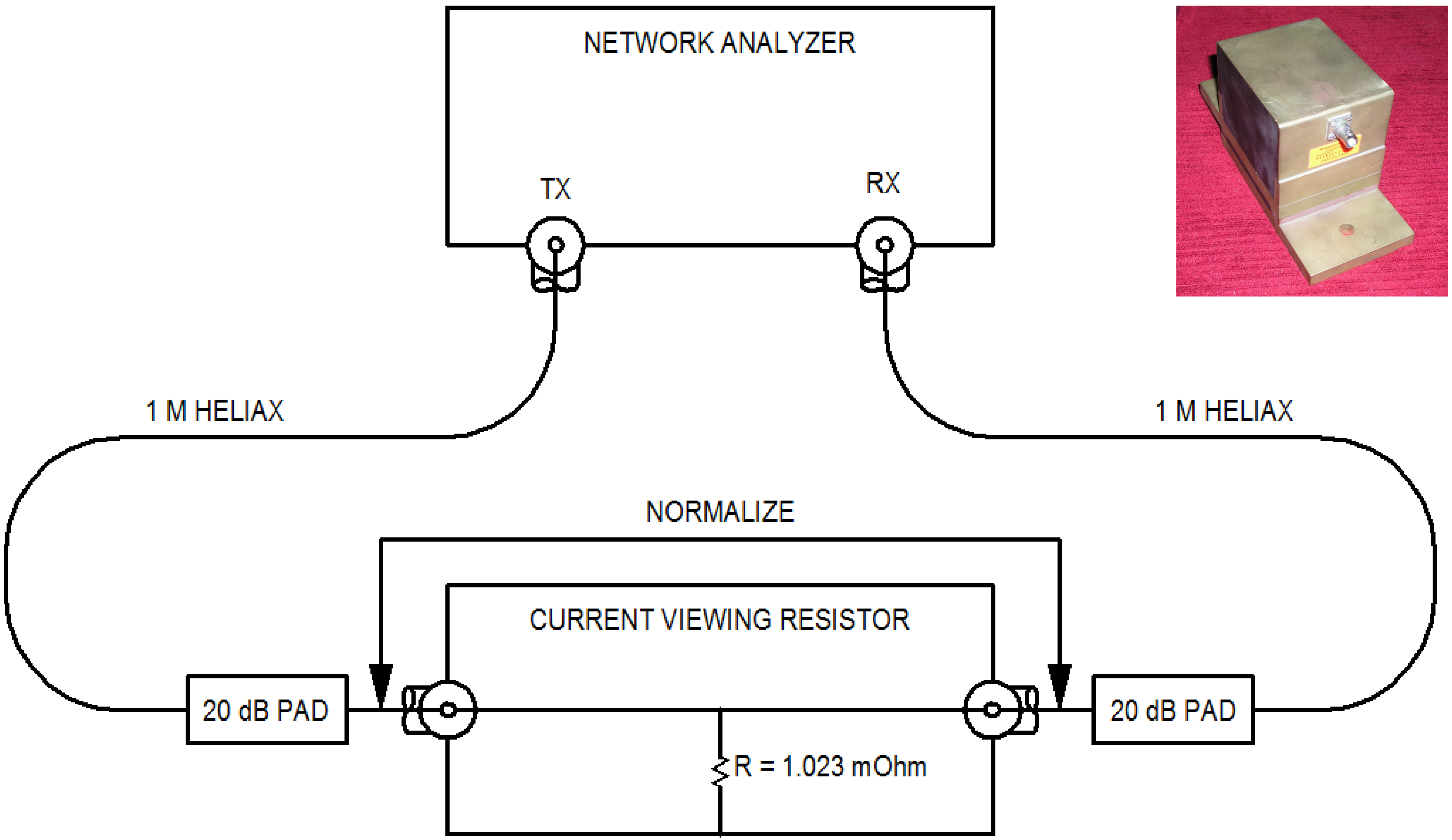
Current-Viewing Resistor Sensor [4]

T&M Research Products 250 µOhm W-Series CVR

Subtle but Important Sensor Configuration

Sensor signal is presented with respect to “ground”

CVR Frequency Response Configuration – Real-Life Example With a Nominal 1 mOhm CVR

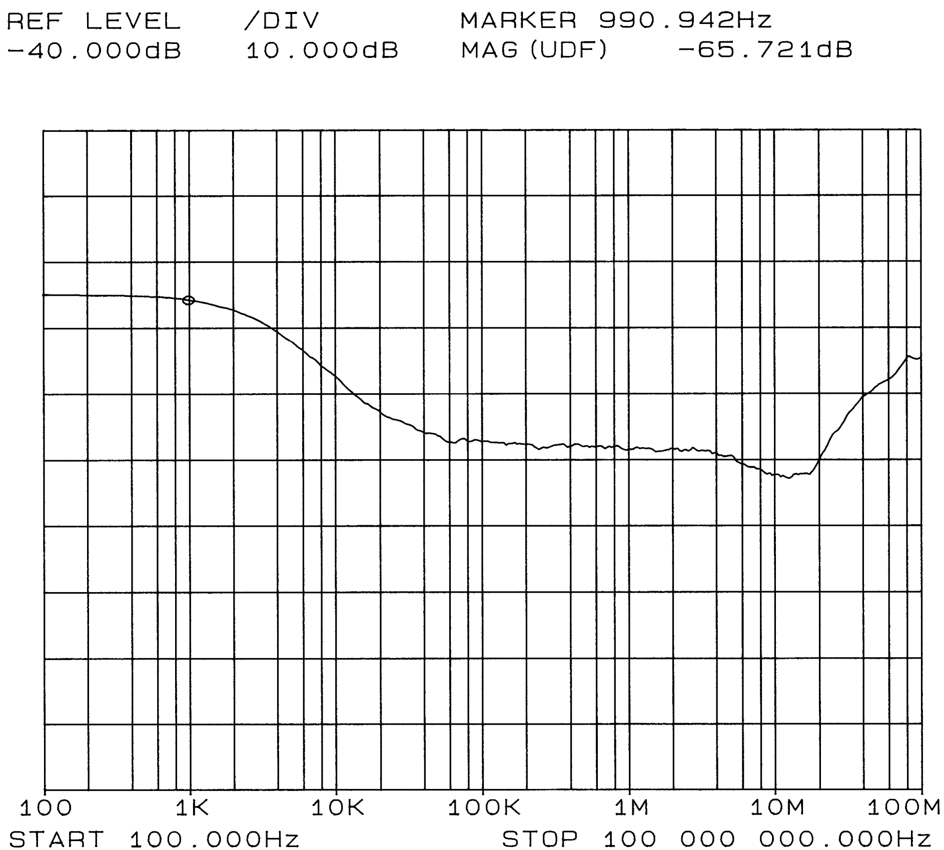


T&M SDN-001 1 mOhm CVR – Apparent Response

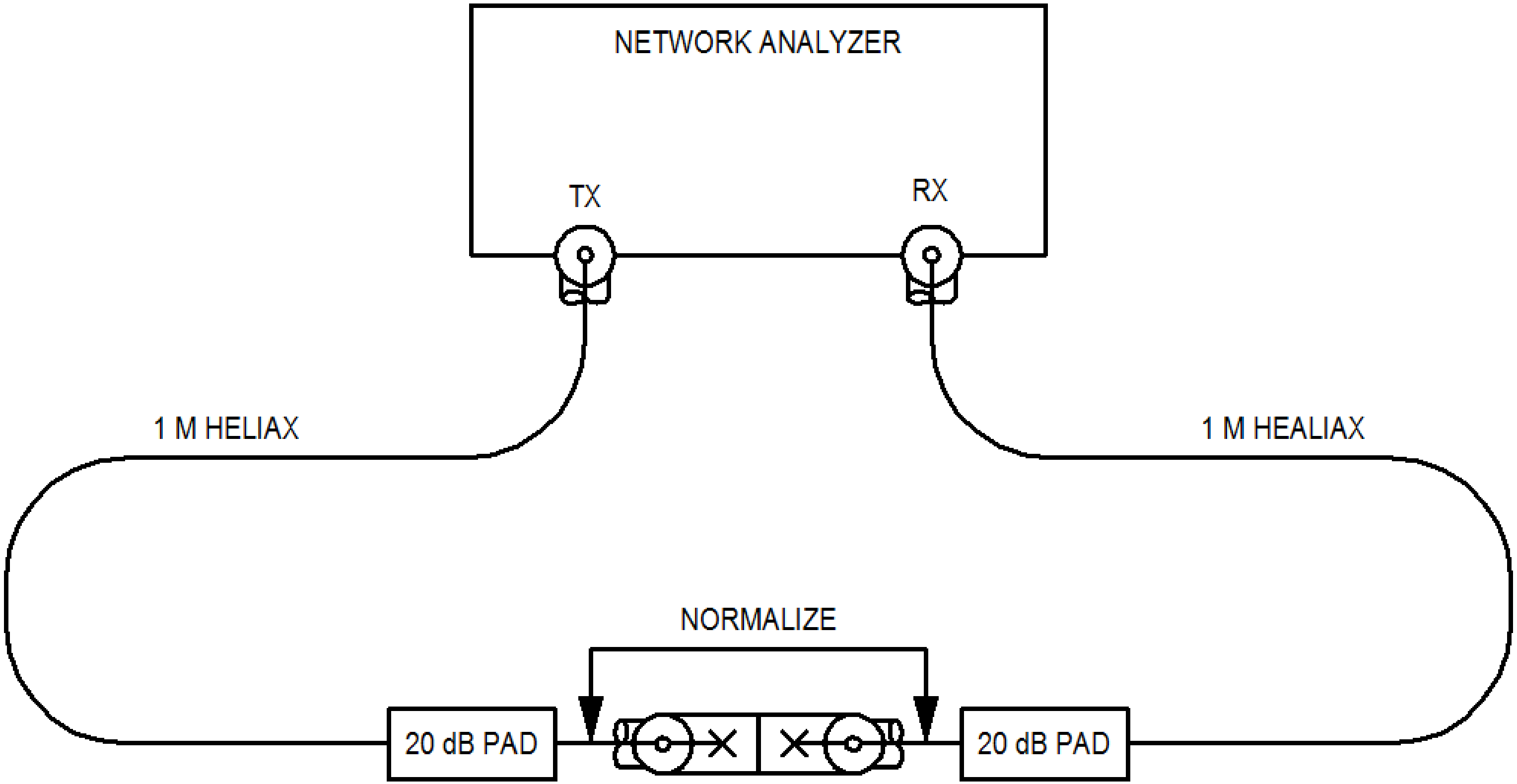
1.023 mOhm DC

-65.721 dB →12.9 mOhm

- 1Hz Resolution BW
- 30s Sweep
- 16 Trace Average
- 1m Heliax Feed Lines



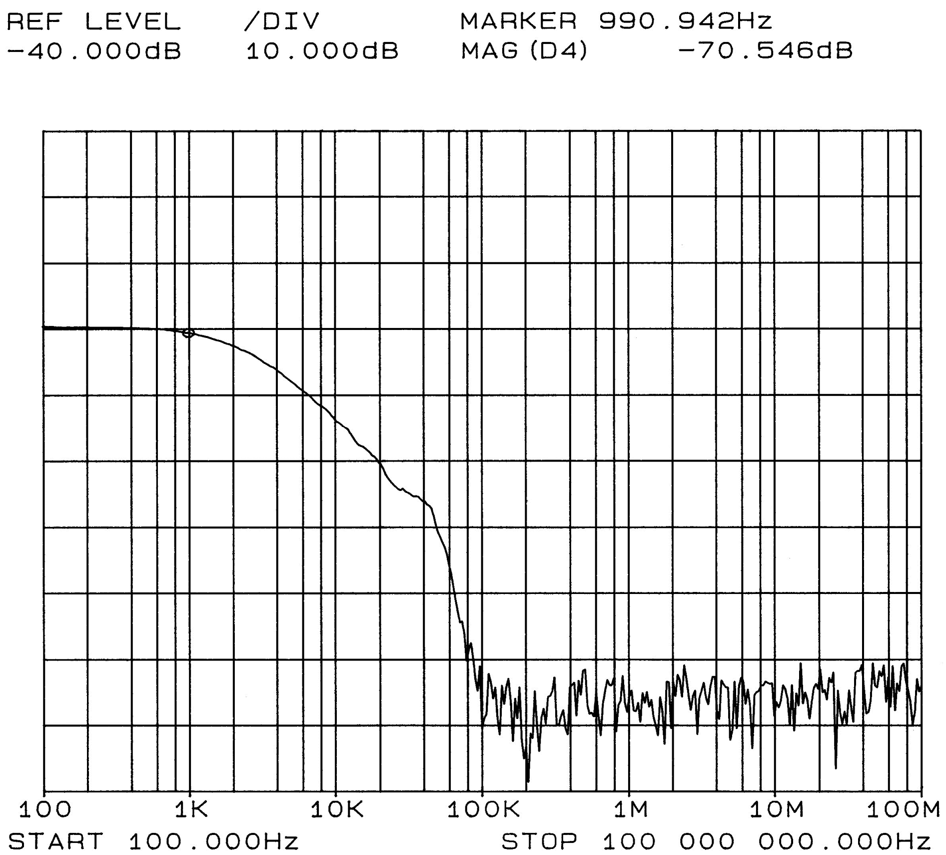
Capture of Shield-Current Artifact



Cable Shield-Current Artifact

-70.546 dB → 7.42 mOhm

- 1Hz Resolution BW
- 30s Sweep
- 16 Trace Average
- 1m Heliax Feed Lines

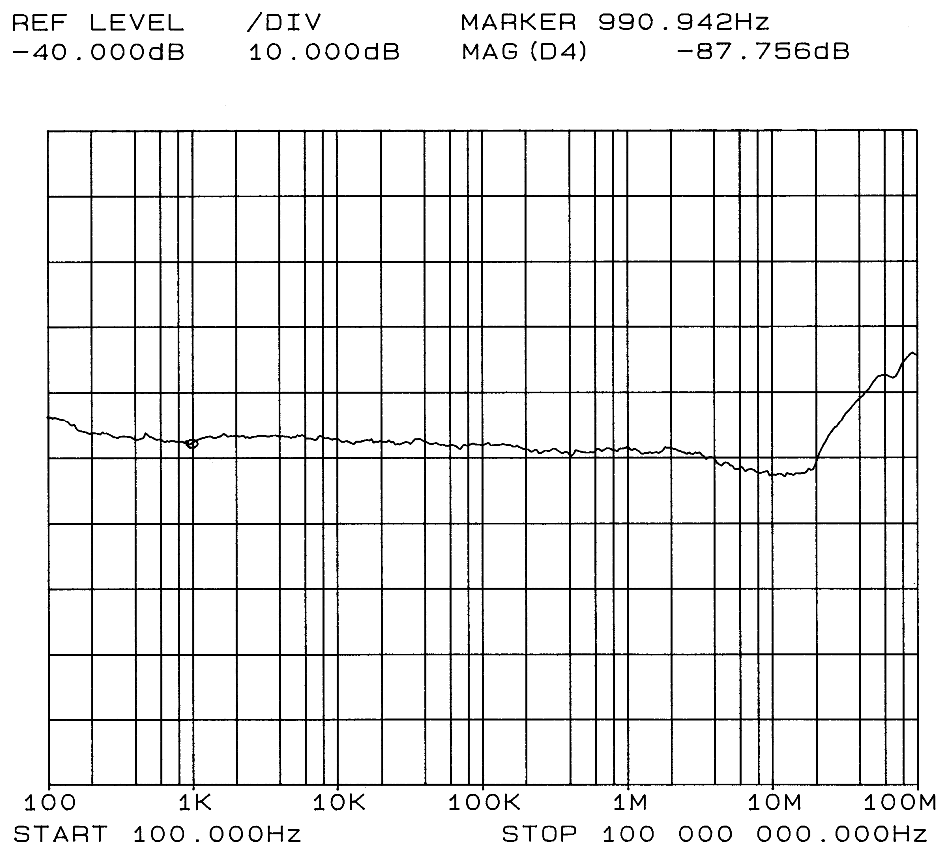


1 mOhm CVR With Common-Mode Isolator

1.023 mOhm DC

-87.765 dB →1.023 mOhm

- 1Hz Resolution BW
- 30s Sweep
- 16 Trace Average
- 1m Heliax Feed Lines



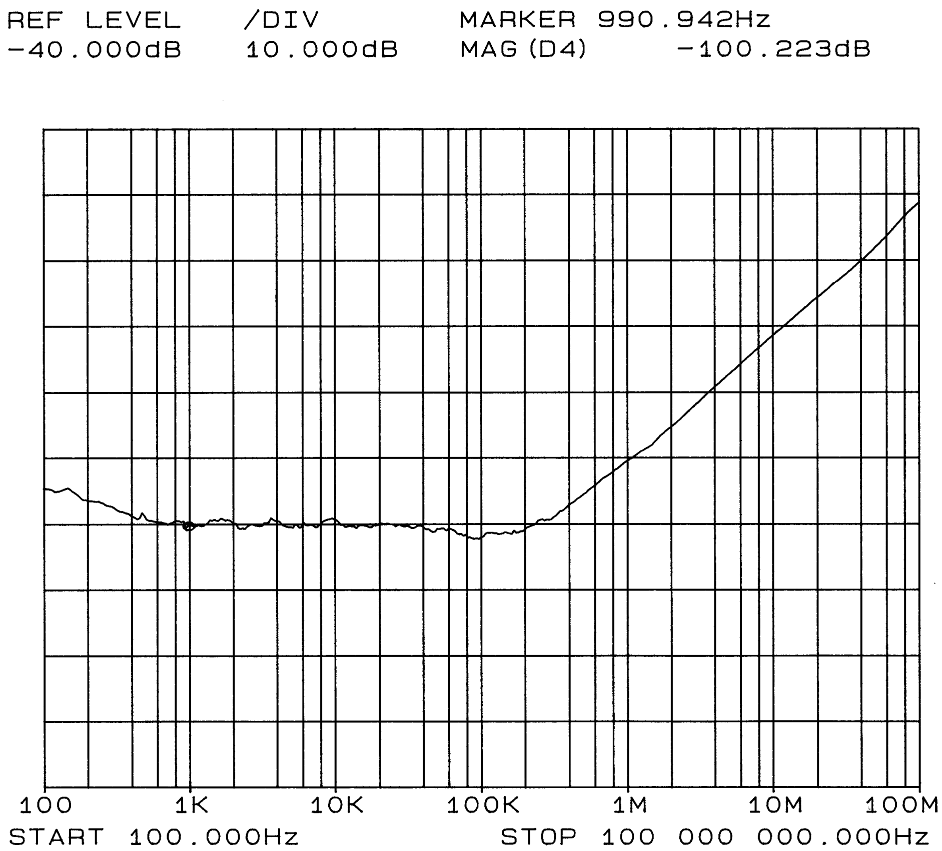
(The common-mode isolator (“CMI”) is reviewed in detail later)

250 µOhm CVR With Common-Mode Isolator

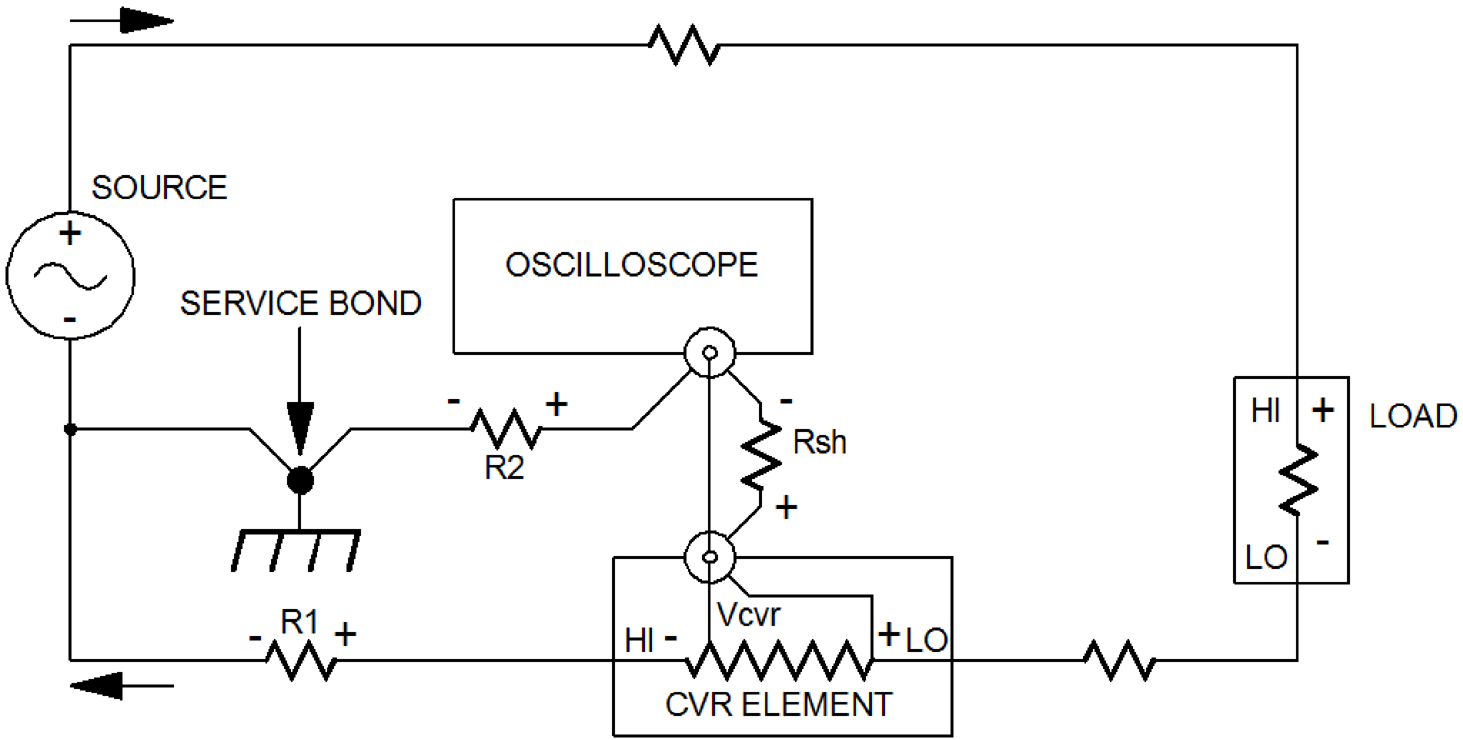
243.3 µOhm DC

-100.223 dB → 243.7 µOhm

- 1Hz Resolution BW
- 30s Sweep
- 16 Trace Average
- 1m Heliax Feed Lines



Low-Frequency EMI Errors – Another Real-Life Example
I Drew a *Picture* of the Configuration

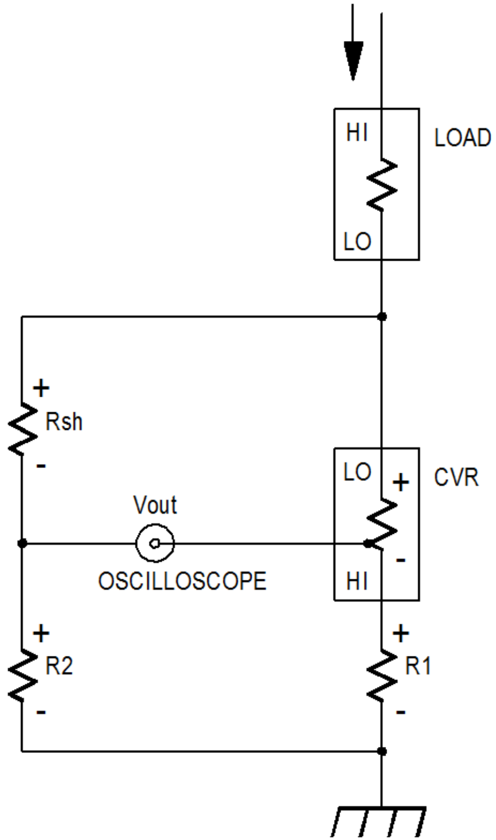


CVR Equivalent Circuit

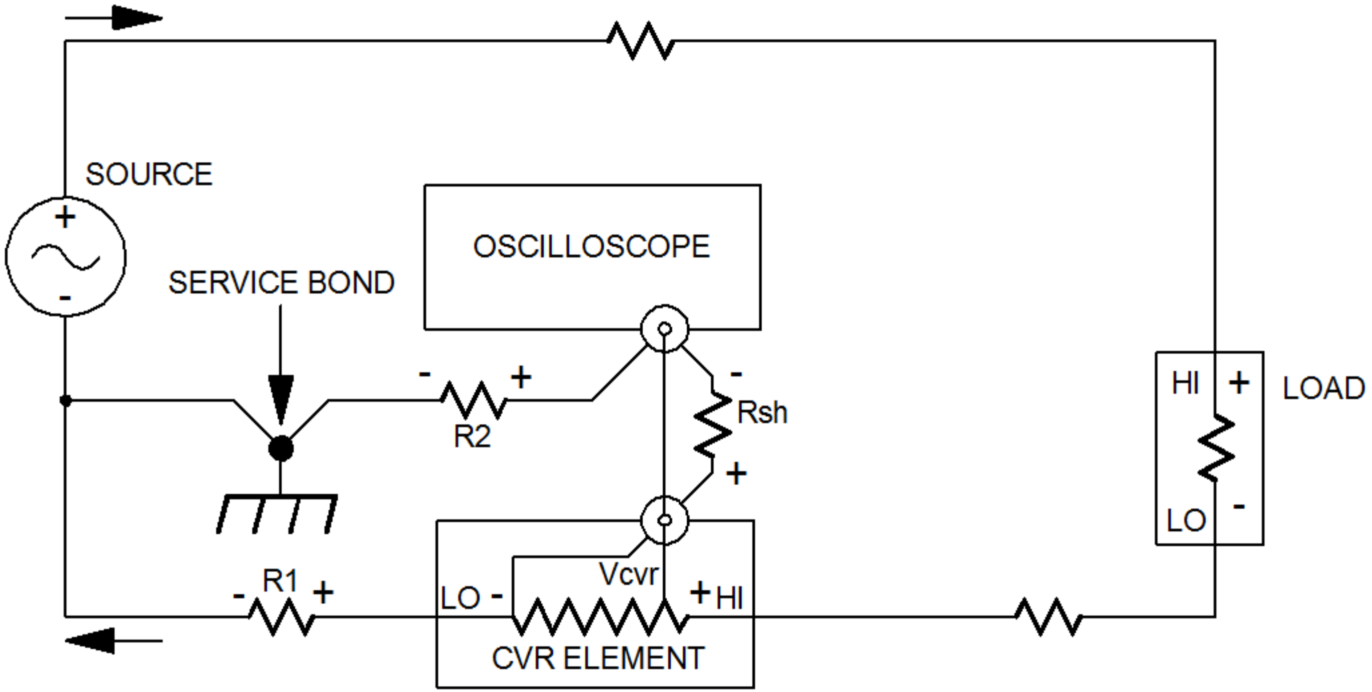
$$For\ {}^{R_S}/_{R_2} \cong {}^{R_{CVR}}/_{R_1} \Rightarrow V_{out} \cong 0$$

so, indicated $I_{load} \cong 0$

This is not a very good measurement of load current!



Low-Frequency EMI Error – Real-Life Example, Again

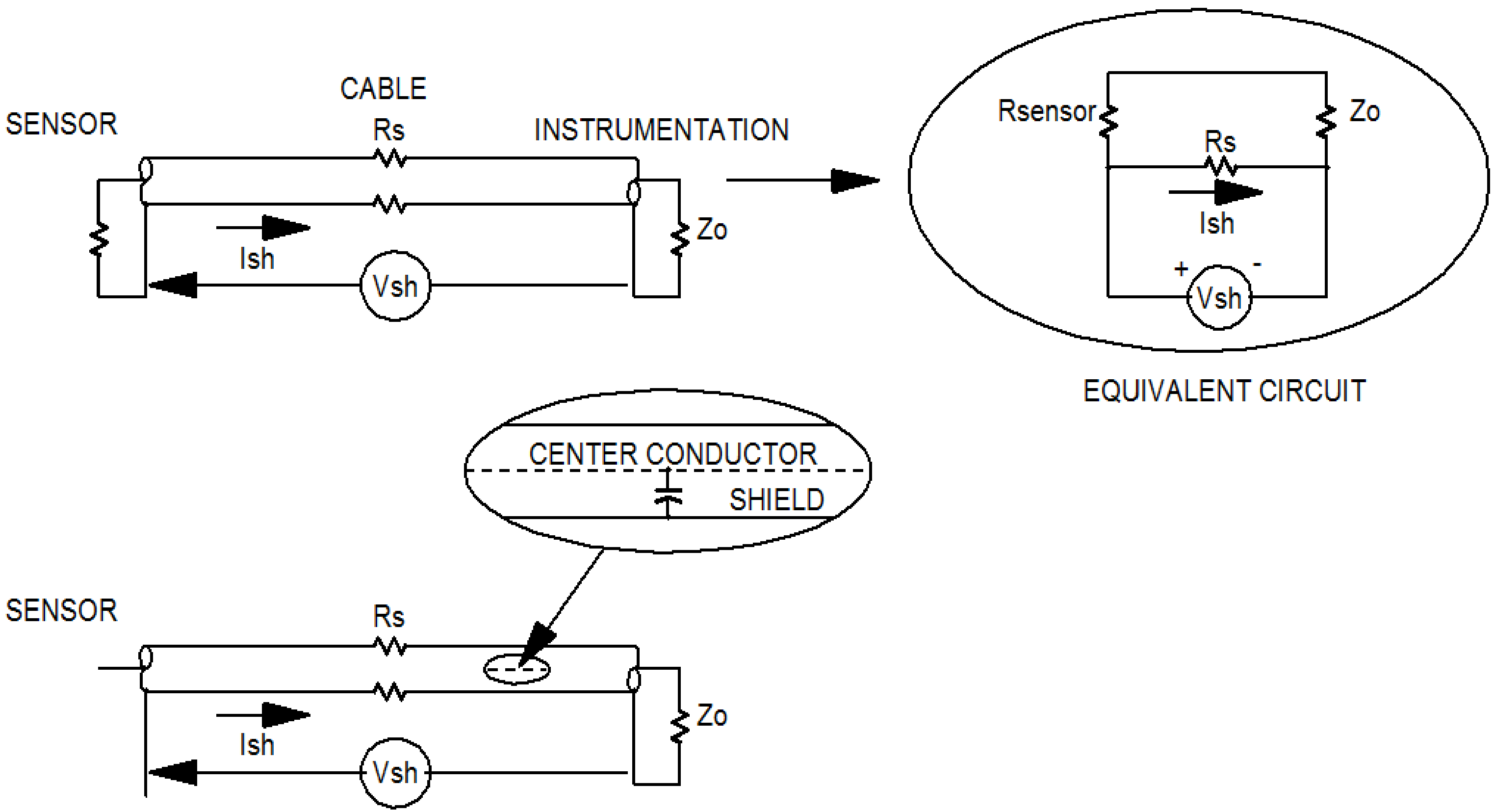


Example:

- CVR=100 μΩ, R1=~65 μΩ, R2=~100 mΩ, Rsh=~1 Ω, I=1000 A
- Expected CVR voltage=100 mV ⇒ 1000A
- Indicated CVR voltage=159 mV ⇒ 1590A

This is not a very good measurement of load current either!

It's All About the Current, Pretty Much



Cable Shielding Properties

- **Two common terms used more or less interchangeability**
  - Cable transfer impedance Rt
  - Cable Shielding effectiveness SE
- **These are not the same**
  - Cable transfer impedance is the ratio of the voltage induced on a cable signal conductor due to a current flowing on the "outside" of the cable shield
    - One cable end terminated, other open
    - expressed in Ohms/m
  - Shielding effectiveness "can" be expressed as the ratio of the current impressed on the "outside" of the cable shield to the current induced on a signal conductor due to the shield current
    - Both cable ends terminated
    - Typically expressed in dB
- **These two definitions based on shield current**
  - It is not important how the shield current is impressed
  - It is only important that it is impressed

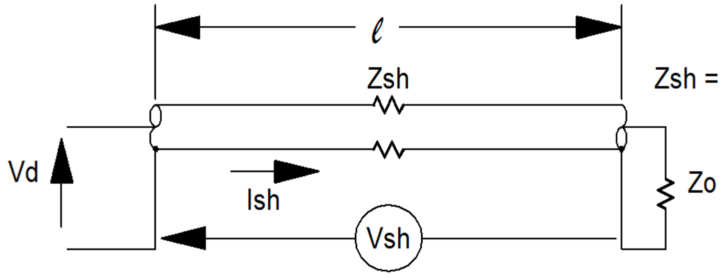
Shielding Effectiveness – Strict Definition

- **Ott [5] defines Shielding Effectiveness as:**
  - $\boldsymbol{SE_{electric\ field} \equiv 20log_{10}\left(\frac{E_0}{E_1}\right)}$
    - E_0 = Incident Electric Field Strength
    - E_1 = Electric Field strength emerging from shield
  - $\boldsymbol{SE_{\ magnetic\ feld} \equiv 20log_{10}\left(\frac{H_0}{H_1}\right)}$
    - H_0 = Incident Magnetic Field Strength
    - H_1 = Magnetic Field strength emerging from shield
- **Not particularly useful in solving EMI issues in legacy environments**
- **Numerous "creative" definitions of shielding effectiveness**
  - Strict field related SE definitions such as above often difficult to apply
  - SE definitions based on conducted emissions and susceptibility often more easily applied

Shielded Cable Transfer Impedance

- **Very simple definition:**
  - The ratio of some output voltage due to some excitation current
  - The excitation current is the current on the outside of the shield
  - The output voltage is the voltage induced on the shielded signal lines
- **Definition based on currents**
  - Based on conducted emissions and conducted susceptibility
  - Much easier to visualize than field-related definitions
  - Typically much simpler to apply than field-related definitions
- **Virtually every case of EMI contamination is the result of uncontrolled shield currents in the signal cables – It's the current, pretty much**

Cable Transfer Impedance vs Shielding Effectiveness



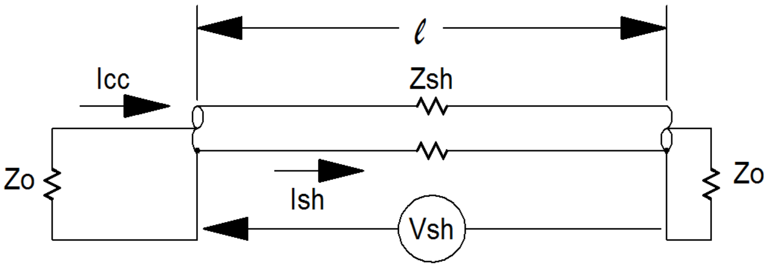
TRANSFER IMPEDANCE

$$SE = 20\log_{10}\left(\frac{2 \cdot Z_0}{Z_t \cdot \ell}\right)$$

$$Z_t \cdot \ell = \frac{V_d}{I_{sh}}$$

$$Z_t(\ell) = \left(\frac{V_d}{I_{sh} \cdot \ell}\right) \quad \text{[Ohms/m]}$$

$$2 \cdot Z_0 = \frac{I_{sh} \cdot Z_{sh} / I_{cc}}{V_d / I_{sh}}$$



SHIELDING EFFECTIVENESS

$$I_{sh} \cdot Z_{sh} = V_d$$

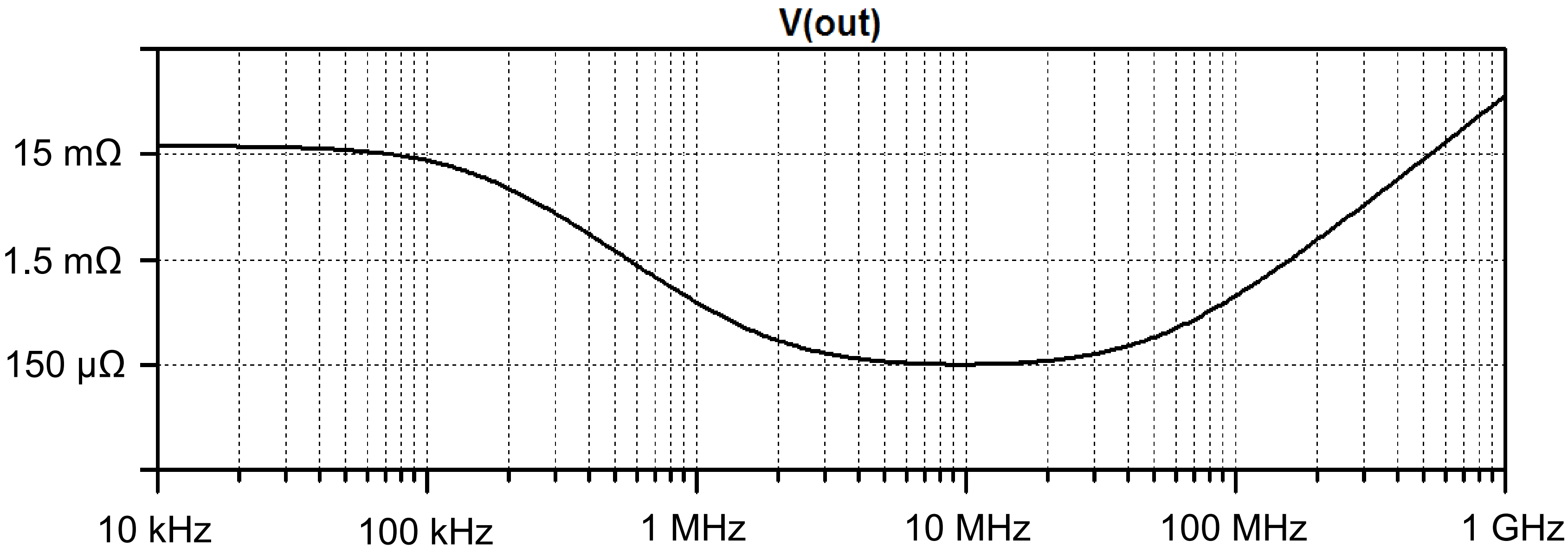
$$SE = 20\log_{10}\left(\frac{2 \cdot Z_0}{Z_t \cdot \ell}\right) = 20\log_{10}\left(\frac{I_{sh}}{I_{cc}}\right) \quad \text{[dB] [6,7]}$$

$$\boxed{SE = 20\log_{10}\left(\frac{I_{sh}}{I_{cc}}\right) \quad [8]}$$

Shield Reduction Factor K_r – Michel Mardiguian [5,6]

- **Define K_r:** $K_r \equiv \frac{V_d}{V_{sh}}$
- $V_d = Z_t \cdot \ell \cdot I_{sh}$
- $I_{sh} = {}^{V_{sh}}/_{Z_{sh}}$
- $Z_{sh} = (R_{sh} + j\omega L_{sh}) \cdot \ell$
- **Express Z_t in complex form:** $Z_t = R_t + j\omega L_t$
- **At DC** $Z_t = R_{sh} \Rightarrow R_t = R_{sh} \Rightarrow Z_t = R_{sh} + j\omega L_t$
- $K_r = \frac{(R_{sh}+j\omega L_t)\cdot\ell}{(R_{sh}+j\omega L_{sh})\cdot\ell}$
- $K_r = \frac{(R_{sh}+j\omega L_t)}{(R_{sh}+j\omega L_{sh})}$

Typical Cable Transfer Impedance



Simulated R_t of Nominal 2m Length of RG400

EMI Mitigation

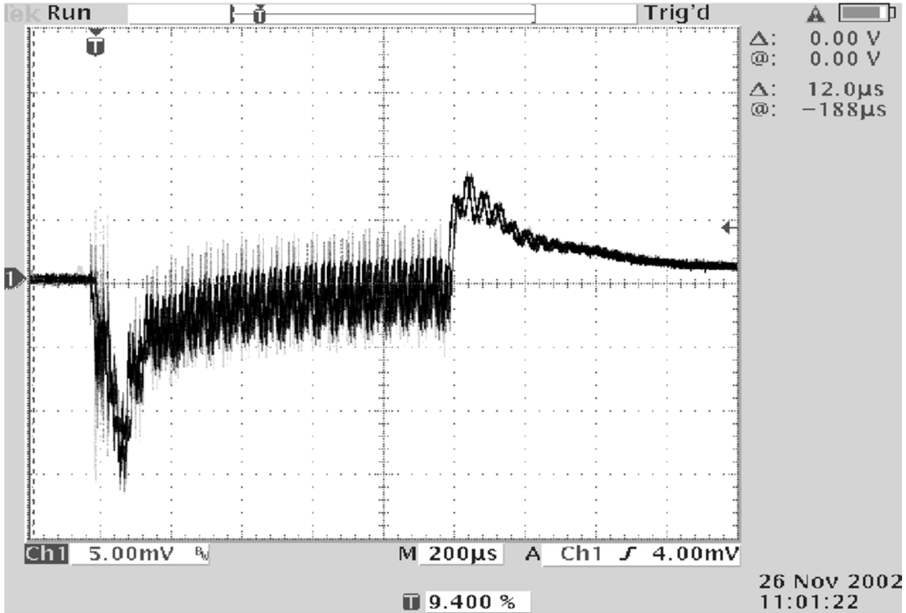
- **At the source – often difficult if not totally disallowed**
- **At the instrumentation**
  - Must be an engineered solution
    - Isolation – fiber-optic signal paths – power required at the sensor end
    - Filtering – useful for narrow-band and out-of-band signals
    - Shielding – useful for radiated susceptibility, not for conducted susceptibility
    - Balancing – useful if the common-mode signal is not too large
    - Orientation and Separation – not typically useful – instrumentation location and cable routing fixed
    - Shielding effectiveness, transfer Impedance – Somewhat useful
  - Minimize data cable shield currents
    - Isolation – transformer coupling
    - Grounding – maybe
    - Common-mode impedance

DRAW A PICTURE !

A Couple of Real-Life Examples

- **SNS – EMI corruption of facility timing and machine-protect systems**
  - Pulsed EMI signal
  - Very rich frequency spectrum
  - Facility systems could not be easily modified, e.g., shielded
- **LANSCE – EMI corruption of capture of low-level wire-scanner signals**
  - Very high AC MAINS correlated component
  - Very rich frequency spectrum
  - Wire-scanner system was a new design allowing design control of EMI

SNS HVCM EMI: Current on Outside of Triaxial Output Cable Shield [2]



Amperes of transient current flow on HVCM triaxial output cable shield at SNS. These include the 1.2 ms modulator pulse, the 20kHz/60 kHz chopping from the inverter and under-damped ~ 4MHz switch transients.

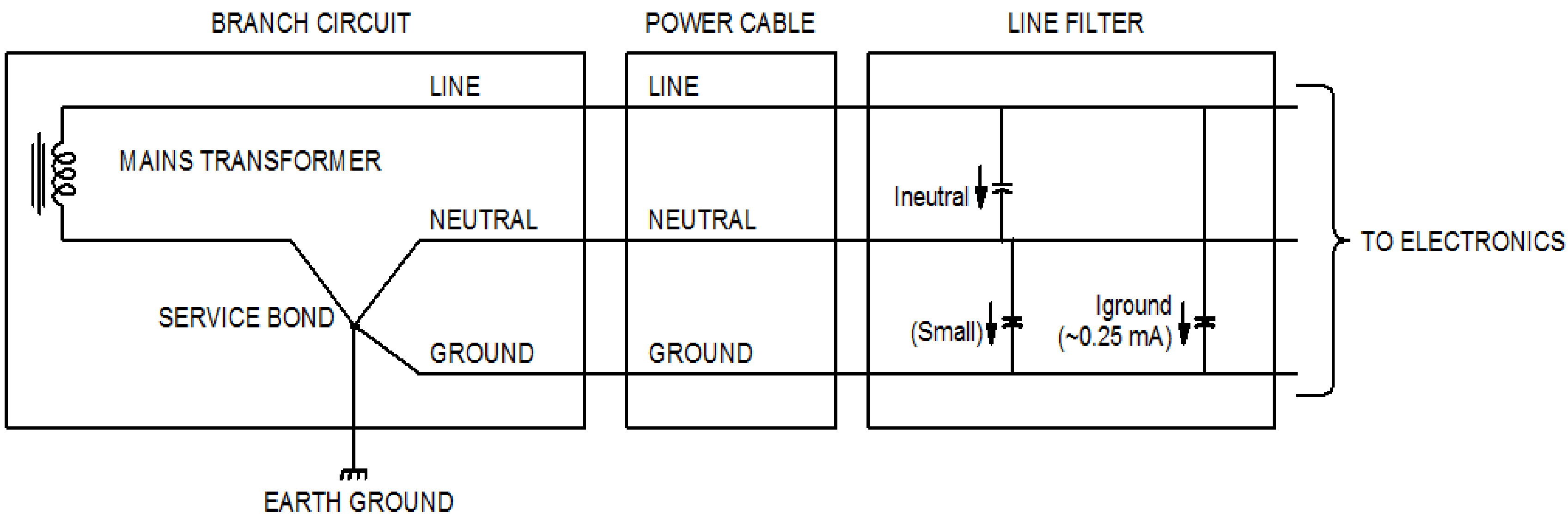
Root Cause and Mitigation

- **The source of the EMI observed is the result of:**
  - Triax not being fully in cutoff at 800 Hz, and having significant coupling to the grounded outer triax shield
  - Triax copper shields are only a few skin depths thick at the frequencies of the 20 KHz and 60kHz chopped components
  - Shield coverage is only ~ 85%, so strong high frequency components leak and become major components of the external field
- **The most significant EMI component of this source can be controlled by routing the output cable in grounded steel conduit (source is low Z)**
  - Provides layer of shielding which is many skin depths thick
  - Conduit grounded at both ends greatly reduces loop area
  - Acts as a common-mode choke for low frequencies <~60 kHz

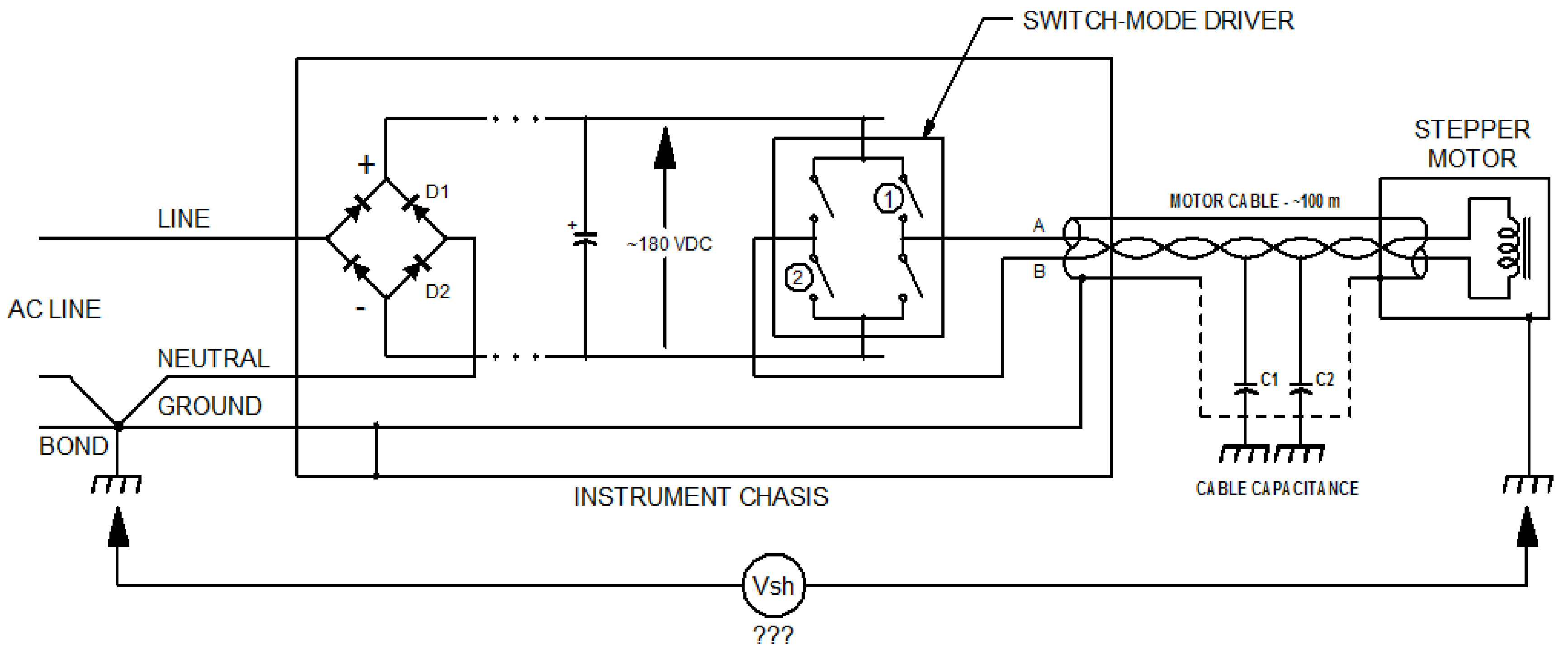
Wire-Scanner EMI

- **High AC MAINS correlated EMI**
- **High ~20kHz EMI artifact**
- **EMI directly related to actuator motor drive operation**
  - Stepper motor
  - PWM drive
  - AC MAINS powered motor driver
- **Motor driver installed in wire-scanner system chassis**
- **Separate shielded, twisted pair cables for all signals**
  - Motor drive
  - Wire sensor signals
  - Brake
- **Motor drive cable routed in different facility tray/conduit from signal cable**

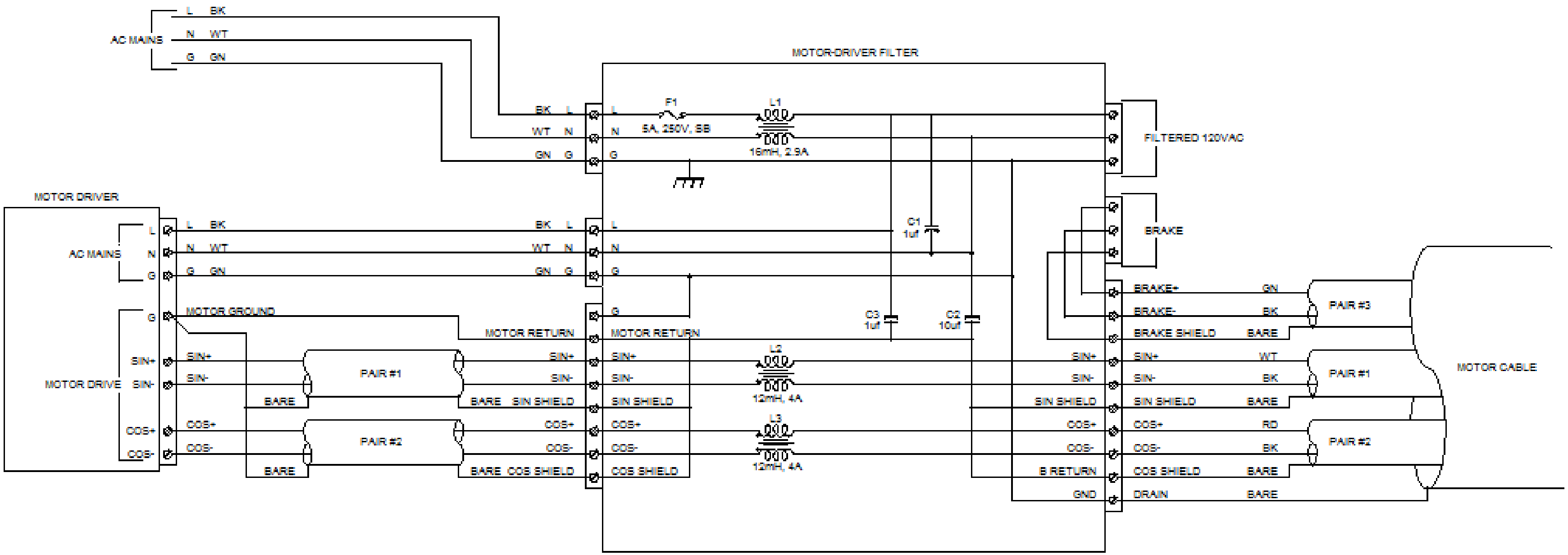
Wire-Scanner EMI – AC MAINS Filter



Wire Scanner Stepper-Motor Drive



Wire Scanner Motor-Drive Filter



LANSCE Wire-Scanner System Chassis Configuration

BiRa cRIO Chassis

Motor-Driver Filter Function

- **Capacitive filtering to the designated motor return (motor ground) of the motor-driver**
- **Common-mode isolators**
  - Provide high impedance to common-mode signals
  - Improves balanced in the twisted pair
  - Reduce common-mode currents
  - Reduce circulating currents
- **Common-Mode Isolators control circulating currents**
  - Force forward and return currents to be equal
  - Reduce escape of currents to unwanted conduction paths

Wire-Scanner EMI Mitigation Success

- **Motor driver filter implemented in an Aluminum enclosure**
  - Primarily intended as a safety consideration for AC MAINS-tied elements
  - Provides only minimal shielding
- **Motor driver filter implemented in the wire-scanner system chassis immediately at the motor driver**
- **Shielded twisted pair between motor driver and filter**
  - Cable shields returned to motor-driver motor return, not chassis ground
  - Motor return not externally tied to chassis ground
- **EMI mitigation successful**
  - EMI reduced to nominally the digitizer LSB
  - Amount of EMI mitigation just adequate
  - Not overkill – “just right”

General EMI Mitigation Approaches

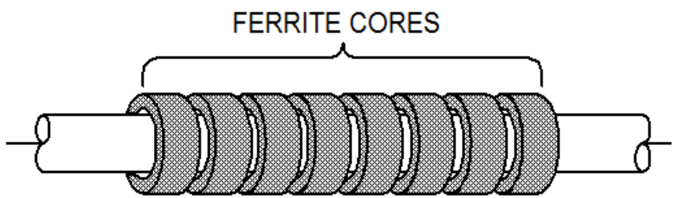
- **Isolation**
  - Transformer coupling
    - Low-frequency response pole
    - Loss of signal DC component
    - Subject to coupling from magnetic fields
  - Optical (fiber-optic) signal lines
    - Excellent isolation, sort of
    - The optical source must typically be powered
      - High-Isolation power supplies
      - Battery power – inconvenient, maintenance intensive
      - Connection to AC MAINS power system and facility ground – loss of isolation
    - Some signal-powered and light-powered fiber-optic systems available
      - Tend to be quite costly
      - Tend to be comparatively complex and tedious to operate and maintain

General EMI Mitigation Approaches

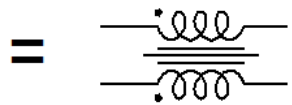
- **Twisted pair and shielded twisted pair cable**
  - Low cost
  - Can be very effective
    - Provides balanced differential signal path
    - Only useful if the common-mode signal is sufficiently small
  - Where to tie the shield
  - How to interface the differential pair to single-ended sensors and receivers
- **Basic coaxial cable**
  - Generally required for RF signals ranging from a few kHz to high RF
  - Shield currents must be controlled
    - High shielding effectiveness materials – typically not high enough
    - Solid shield (Heliax) provides lowest R_t – typically not low enough
- **Triax cable – just where does one ground what?**
- **Continuous steel conduit – grounded?**
- **Shielding – signal penetrations?**
- **Common-mode isolator**

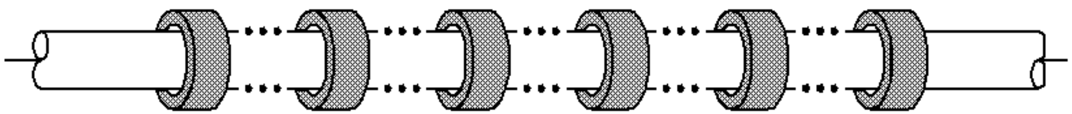
Simple Common-Mode Isolator Configurations

- As simple as ferrite cores on the signal cable
- I use this configuration in virtually all EMP testing to control shield currents on cables in the illuminated test environment



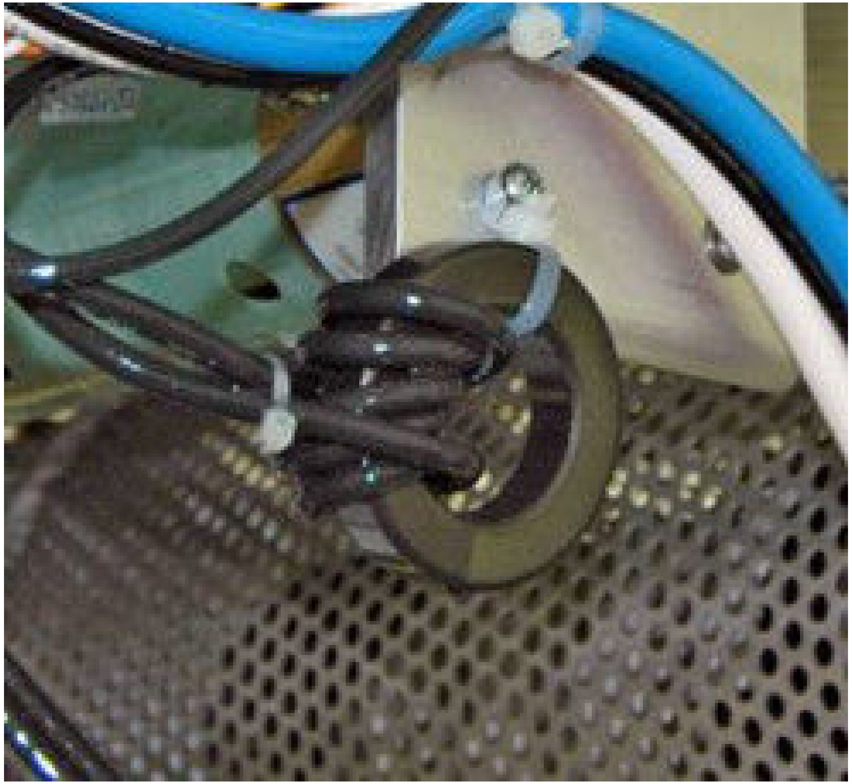
Compact





Distributed along entire cable length

Multi-Turn Common-Mode Isolator



Inductance Proportional to N^2
High Capacitive Coupling Input to Output

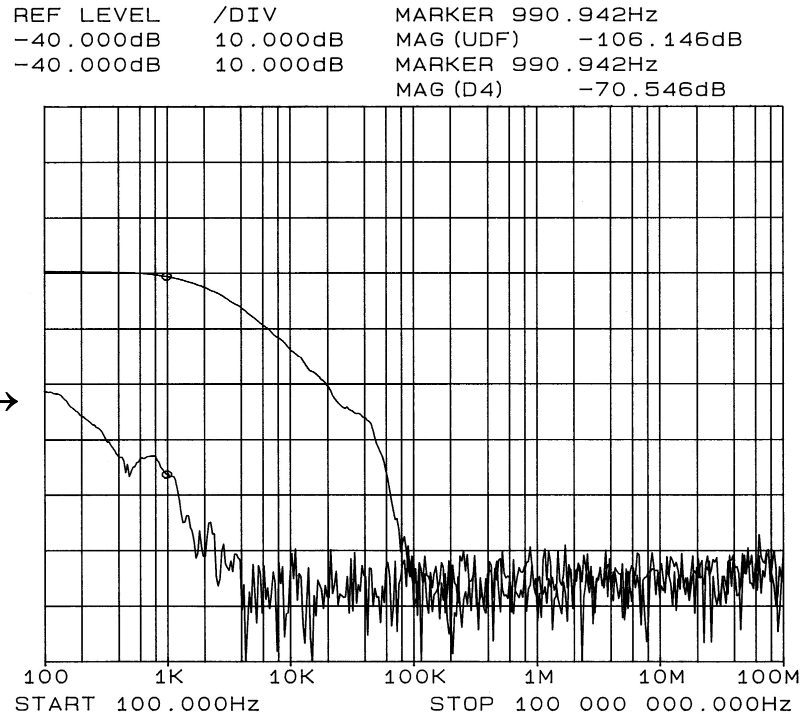
Common-Mode Isolator Operation

-70.546 dB → 7.42 mOhm

-106.146 dB → 123 μOhm

With Common-Mode Isolator →

- 1Hz Resolution BW
- 30s Sweep
- 16 Trace Average
- 1m Heliax Feed Lines



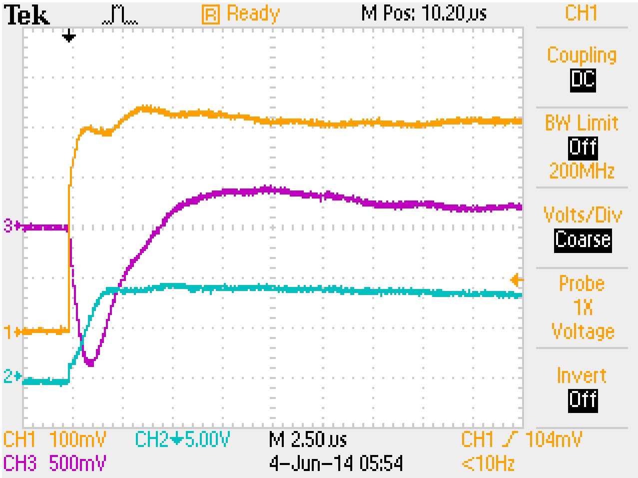
Common-Mode isolator provides ~50 dB reduction in EMI at 2 kHz, and >20 dB at 100 Hz

Example of Error Due to Common-Mode Currents

Oscilloscope measurement of the 243.3 µOhm CVR pulse response

Ch1: UUT Signal, 4.11 kA/V   Ch2: Pulser Voltage Signal (Uncalibrated Magnitude)   Ch3: Shield Current, 1 V/A

Incorrect Measurement



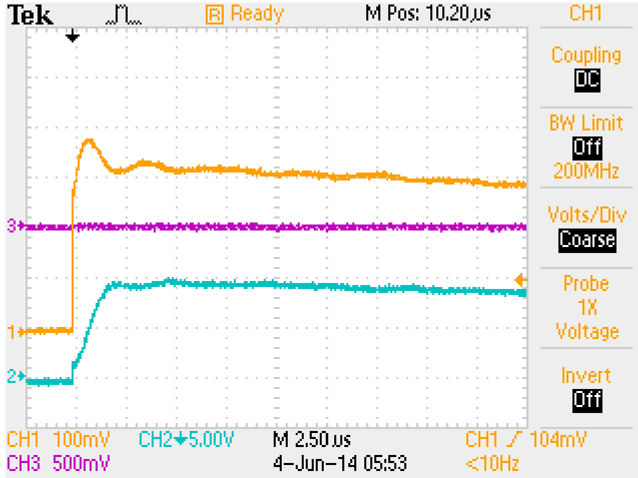
Without Common-Mode Isolation

~1.6 kA peak, little droop, no peaking

High Shield Current

I_{sh} ~1.3 A

Correct Measurement



With Common-Mode Isolation

~1.4 kA, nominal 200 A droop, peaking

Very Low Shield Current

I_{sh} < ~5 mA

How Does the Common-Mode Isolator Work?

- Does not alter the voltage across the shield
- Reduces shield current by increasing shield impedance
- Forces the voltage along the signal conductor to equal voltage along the shield
- Simply a 1:1 RF transformer
- Passes signals from true DC to GHz
- But, does not provide EMI mitigation all the way to DC
- Typically high-permeability ferrites are utilized to provide highest inductive reactance
- High-permeability materials also introduce resistive loss to damp shield resonances

Where to Use Common-Mode Isolators

- **Are equally effective on coax, triax, simple pairs, twisted pairs (UTP network cables), shielded twisted pair, multi-conductor cables, etc.**
- **Can be used on simple unshielded signal lines provided both signal and return conductors are included in the same isolator**
- **Equally useful in the cables of EMI sources and in instrumentation cables**
- **I utilized common-mode isolators in the wire-scanner motor EMI mitigation reviewed above to mitigate the noise *from* the EMI source**
- **About the least complicated, lowest cost EMI mitigation means**
  - Very easily implemented
  - Very useful to test mitigation approaches
- **Personally, I use common-mode isolators in almost every application**

A Quick Final Observation

Just Where did all that 180 Hz (or 150 Hz) noise come from?

3φ Harmonic Summing

Fundamental Phase Sum:

- $I^1{}_{SUM} \equiv I^1{}_A + I^1{}_B + I^1{}_C$
- $|I^1{}_A| = |I^1{}_B| = |I^1{}_C| \equiv |I^1{}_0|$
  - $I^1{}_A = |I^1{}_0| \angle 0$
  - $I^1{}_B = |I^1{}_0| \angle 120$
  - $I^1{}_C = |I^1{}_0| \angle 240$
- $I^1{}_{SUM} = 0$

Third Harmonic Phase Sum:

- $I^3{}_{SUM} \equiv I^3{}_A + I^3{}_B + I^3{}_C$
- $|I^3{}_A| = |I^3{}_B| = |I^3{}_C| \equiv |I^3{}_0|$
  - $I^3{}_A = |I^3{}_0| \angle 0$
  - $I^3{}_B = |I^3{}_0| \angle 360$
  - $I^3{}_C = |I^3{}_0| \angle 720$
- $I^3{}_{SUM} = 3 \cdot |I^3{}_0| \angle 0$

Brief Summary

- ***Must*** **understand how "your" system works – this is the first step in managing EMI**

DRAW A PICTURE !

- **Understand how nuisance signals couple – electric, magnetic, currents**
- **Filtering – use only the bandwidth you need**
- **Grounding – separate signal grounds from "other" grounds**
- **It is all about the currents – pretty much**

Bottom Line to EMI Management

All EMI Mitigation Solutions Must be Engineered!

- **Every situation is unique**
- **No "one-size-fits-all" solution, No standard "cook-book" solution**
- **A complete system approach is needed considering the full facility: the EMI sources, the instrumentation systems, and the potential points of entry of EMI signals**
  - Many external EMI sources
  - But, often we create our own EMI unintentionally
- **If you chase the wrong problem, you will find it difficult to solve EMI issues**
- **And:** ***DRAW A PICTURE !***

Thank Your For Your Kind Attention

Good Luck and Good Fortune
as
You Go Forward to Explore the Undiscovered Country

“Second Star to the Right
and
Straight On ’Til Morning”

The Future – The UNDISCOVERED COUNTRY

Questions?

QUESTIONS ABOUT EMI

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