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CST Unscreened verses Screened Power Converter Cables <u>Preliminary</u> Study

3D SUITE 2023

Jason Watkiss - EMC Specialist

13/04/23

EMC & COMPLIANCE INTERNATIONAL



Change Register

Document Revision	Change Author	Date	Affected Slides	Comments
0	Jason Watkiss	13.04.23	All	Initial Issue



Agenda

RF CE Reminder

- **O 2** Measurement Approach
- 03 ^{3D} Model

01

- 04 Model Results
- **Conclusions**
- 06 References
- **7** Back Up Slides

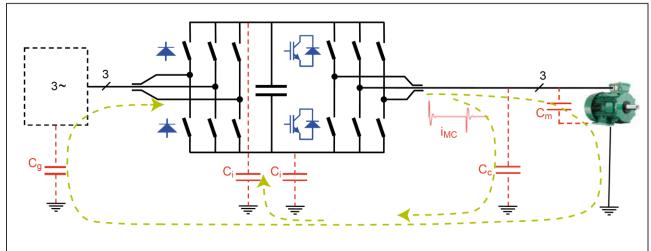


RF CE Reminder



RF CE Reminder

Illustration 2 - Common mode currents



- Cm : Common mode structural capacitance of the motor
- Cc : Common mode capacitance between the cable and its shield or the environment
- ----: HF leakage current paths
- Ci : The structural capacitances between active parts of the inverter and earth
- C_g : Structural capacitance between the power supply and the earth.

Common Mode Current Paths

Nidec: Guide to best practices - Motor-drive systems -Reference: 5626 en - 2018.11 / a

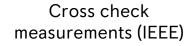


02

Measurement Approach



Impedance to Ground



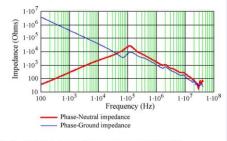


Fig. 7. Main impedances of the ac motor used (AEG750W).

EMI Study of Three-Phase Inverter-Fed Motor Drives, Bertrand Revol, James Roudet, Jean-Luc Schanen, Senior Member, IEEE, and Philippe Loizelet, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 47, NO. 1, JANUARY/FEBRUARY 2011

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Measurement Approach

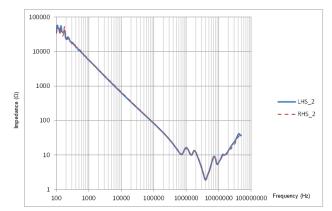


Figure 12 (Comparison between RHS and LHS three phase generator impedance to ground)

From the above graph using reference 21, the ESR and ESL of the 30nF can be calculated to be equal to: ESR = $2.05\Omega \& ESL = 52nH$ assuming fo = 4MHz.

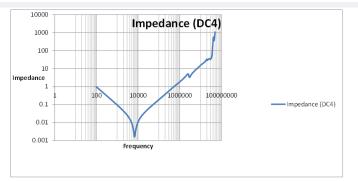


Figure 25 (DC link Capacitor Impedance – Single Channel)

From the above graph using reference 21, the ESR and ESL of the 1.64mF can be calculated to be equal to: ESR = $0.0019\Omega \& ESL = 315nH$ assuming fo = 7 kHz.



3D Model



Objective

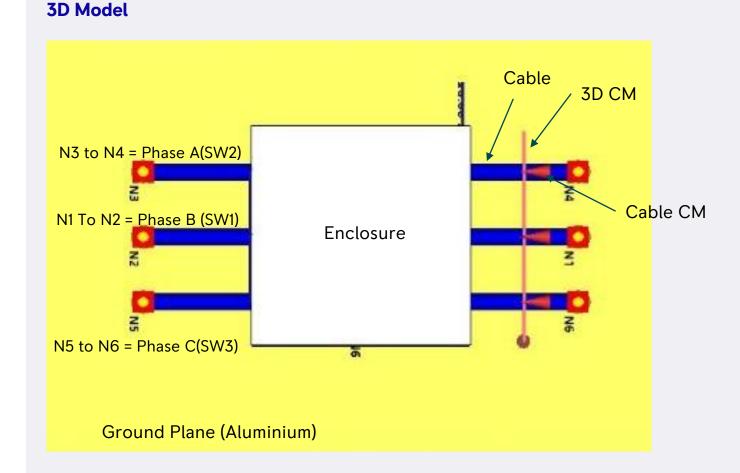
Setting the Scene

Model Summary Introduction

- Unscreened verses Screened AWG '000' cable study for a VFD application:
 - Screened cable uses a Copper Foil wrap.
 - Unscreened (230123) model uses Auto sampling co-simulation technique
 - Screened (180223) model uses <u>Nyquist sampling</u> co-simulation to reduce electronic file output size.
- Model also includes a simple Stainless Steel Enclosure, to see if unscreened cable + enclosure is sufficient for a VFD application.



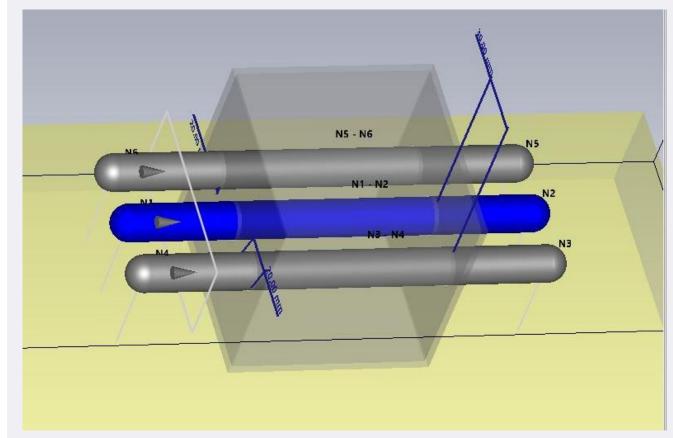
Top View





3D Model

- Cable Length 200mm
- Enclosure (100mmx100mmx100m; 2mm wall thickness, Steel (1008)



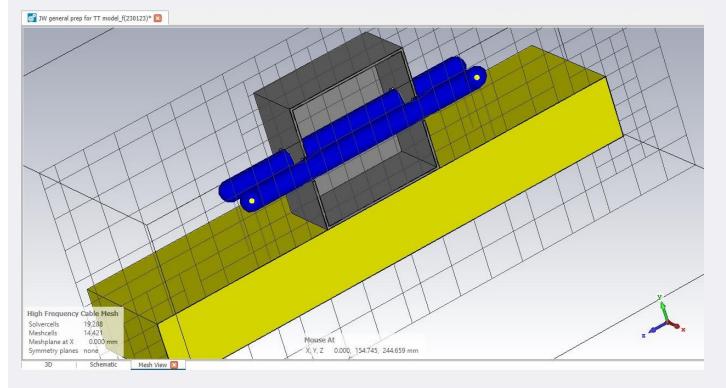
Enclosure View





From 230123 Model.

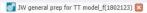
Mesh View

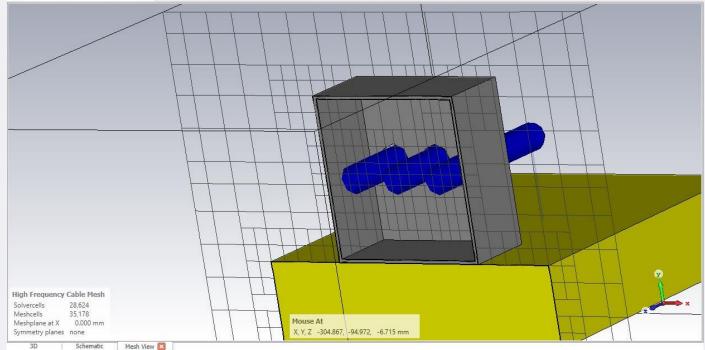




Mesh View

From 180223 Model.





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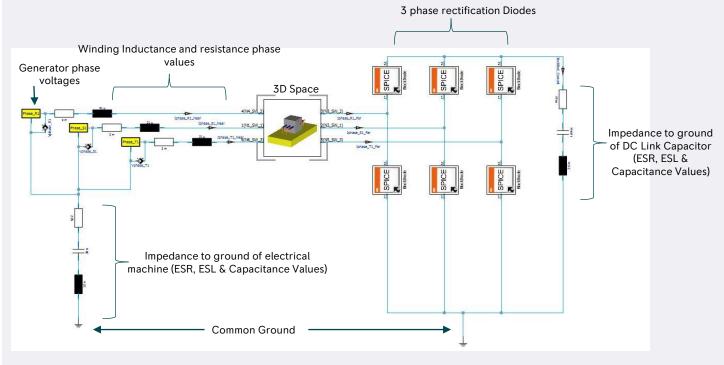
Mesh View



Unscreened **Schematic**

Unscreened Schematic

Co-simulation technique



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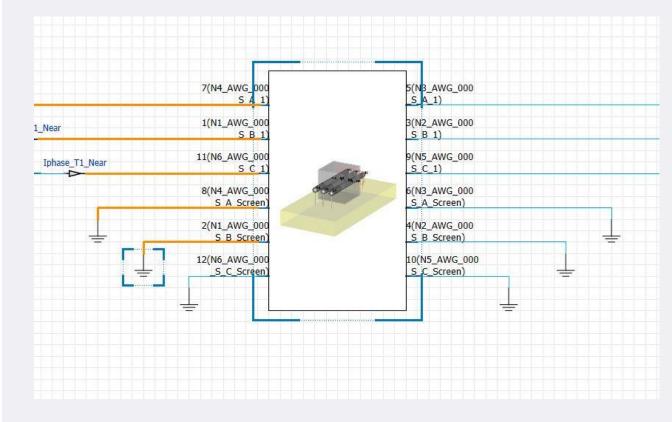
Time Domain specialized solver for cable modelling



Screened Schematic

Screened Schematic

Changes shown below





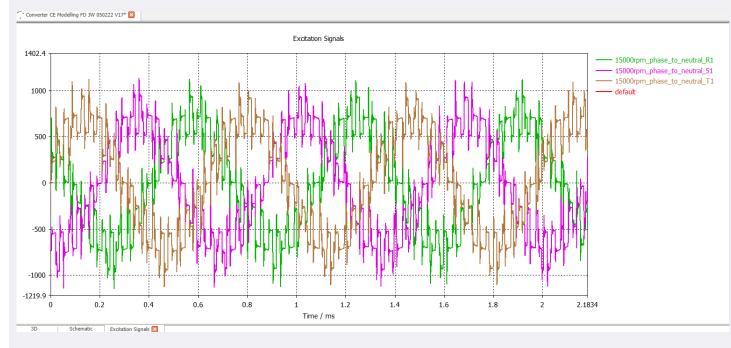
Excitation Signals

Monotonic Zeroed Repetition of Cycles

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Excitation Signals

- E-Fan-X measured data
- Generator Phase Voltages @ 1500rpm
- 2.6ms



15000rpm = 1500Hz (Electrical Frequency) = 0.666ms x 4 cycles = 2.66ms (3ms)



Unscreened Cable Construction

• 000 AWG

Unscreened Cable

3D Schematic	Edit Cable Bundles					×	
Cross Section × y [mil] 000_AWG	1 Y X						
y [mil] 000_AWG 500 †	New Cable Bundle Subdivide Delete						= contains
100	Cable Bundles	Name: Phase_B			Renar	ne Local Units: [mm]	
400 +	Phase_B Phase_A	🖋 Traces 🥇 Segments 🐉	Bundle				
300-	Phase_C				B 1 C C	Add Cable	
300		Name Type	X <random></random>	Y <random></random>	Rotation [d <random></random>	Edit Cable Type	
		SW_1 000_AWG	<random></random>	<random></random>	<random></random>	Rename	
200	Edit Cable Type	0.3W_1 000_AND	X	standoniy	(Tundoin)		
100+	Name: 000_AWG	Rename Local units:				Remove Cable	
0+		Rename Local Units:				New Bundle	
	Conductor		~			Delete Bundle	
-100		Cle				Duplicate	
-200	Material Cu					Compress	
-200	Defined by: Diameter V 409.6	5	[mil]				
	Insulator			1		Auto Bundle	
-300	☐ Included Shape type: W	rap	~				
-400 -	Material PE			0	k Close	Apply Help	
-500	Thickness: 136.6142		[mi]				6
	Preview	Ok Close Apply	Help	0 . 4	Raster=10.000	Meshcells=14,421 Nor	mal mr
					1490 01-0-1		ر 13:



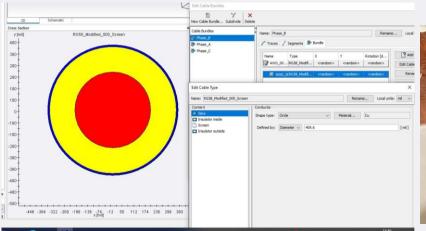
Screened Cable

Screen								
Screen type	: Foil sp	iral wrapped	- v			Consider tra	nsfer admitt	ance
Tape widt	1:	10.0		[mil]	Turn:		Left	`
Inner m	aterial	PE	0.051	[mil]	() Wrap angle [Deg]:		45.0	
Outer m	aterial	Cu	10.0	[ml]	() Overla	ip width:		[mil
		_ t			⊖ Gap w	idth:	2286457	[mil
Model type	: Analyt	ical formula	~					
Export scr	een model							-8
1000	ŧ	ncy [Hz]: 1	.0G				rves ance ng effectiver	ness
100								
						Data: Axis X: Scale:	Magn Logarith Mega	~ nic
[m/mdo] 10		- - - - - - - - - - - -				Axis X:	Logarith Mega standard	~ ~
[m/mh0] ngeM						Axis X: Scale: Format: Axis Y:	Logarith Mega standard	~ ~
[m/mto] uBeW 0.			0.1 ency [MHz]		 100000	Axis X: Scale: Format:	Logarith Mega standard	~ ~

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Screened Cable Construction

Layer	Туре	Materia l	Tape Width	Shape Type	Dimensions	Note
Conductor 000 AWG	N/A	Cu	N/A	Circular	409.6mil	Diameter
Insulator	N/A	PE	N/A	Wrap	136.6mil	Thickness
Screen	Foil spiral wrapped	Cu	N/A	Outer Material	10mil	Thickness
		PE	10mil	Inner Material	0.051mil	Thickness
Insulator Outside	N/A	PVC	N/A	Wrap	0.5mil	Thickness





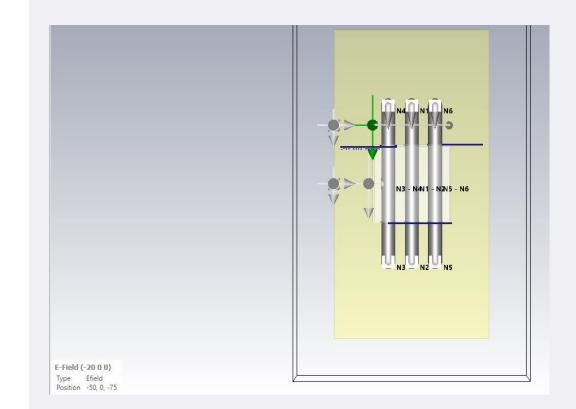


Cable (Near)

H-Field same location as E-Field

Probe Locations

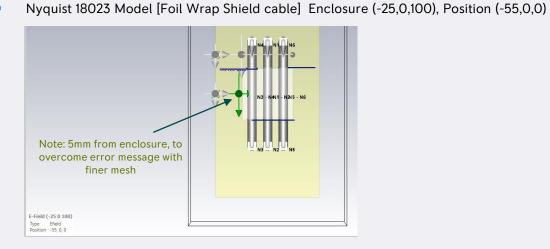
Cable (-20,0,0), Position (-50,0,-75)





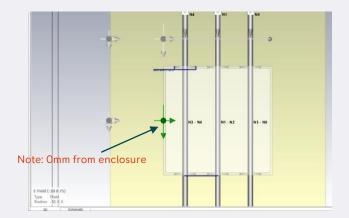
Enclosure (Near)

H-Field same location as E-Field



Probe Locations

Auto sample Model 230123 [Unshielded Cable] Enclosure (-20,0,75), Position (-50,0,0)





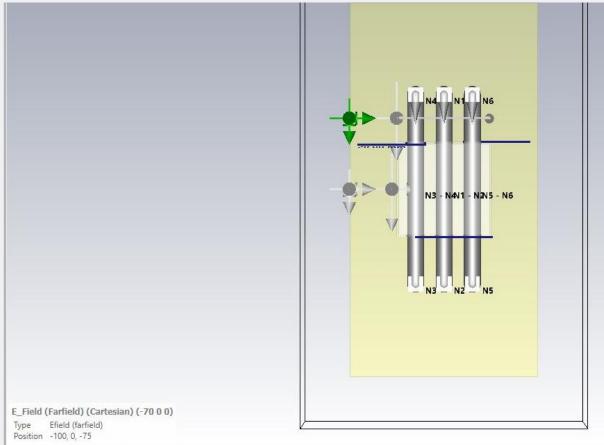
Cable (Far)

H-Field same location as E-Field

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Probe Locations

Enclosure (-70,0,0), Position (-100,0,-75)



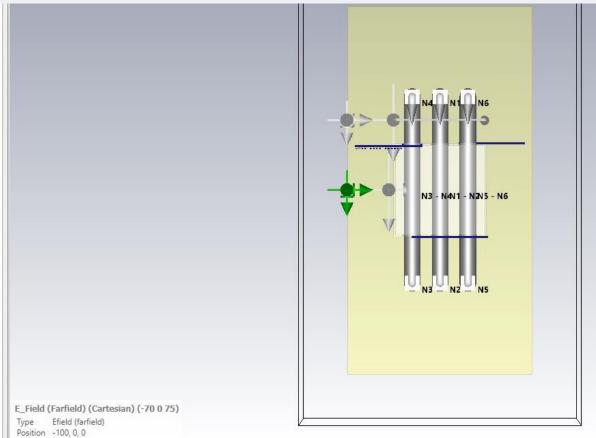


Enclosure (Far)

H-Field same location as E-Field

Probe Locations

Enclosure (-70,0,75), Position (-100,0,0)

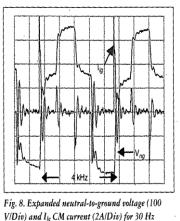




Results



Overview Trace



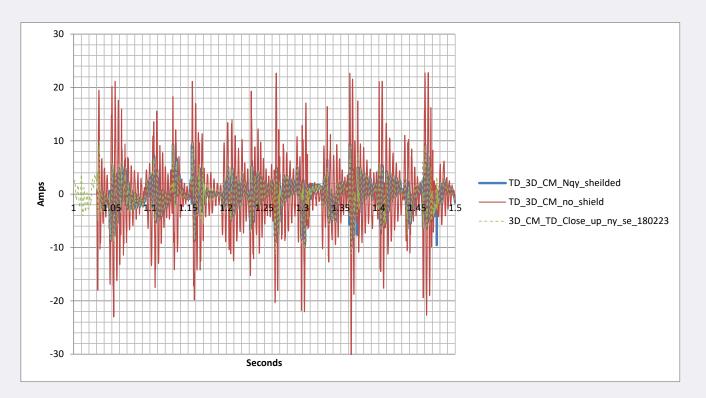
output {"0" at offset 4 div; 50 µs/Div}.

EMI Emissions of Modern PWM ac Drives – Gary L.Skibinski, Russel J.Kerkman, and Dave Schlegel

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3D CM – TD

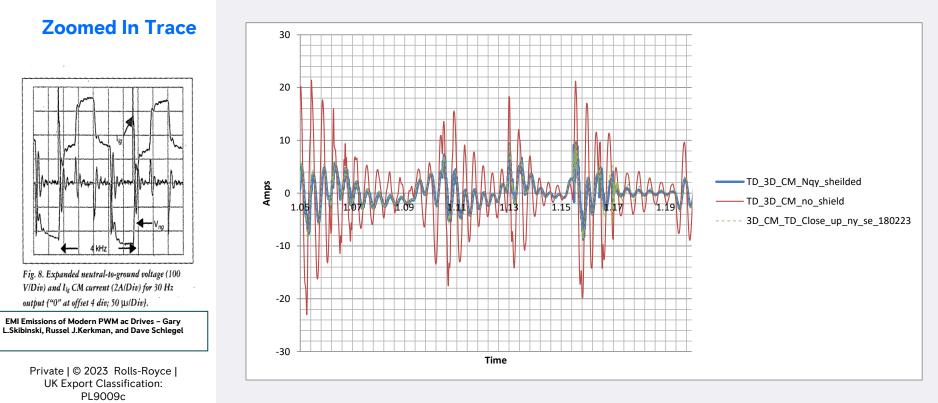
No shield verses Foil Wrap Shield





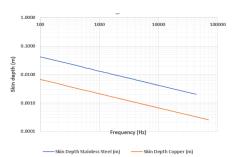
3D CM – TD

No shield verses Foil Wrap Shield

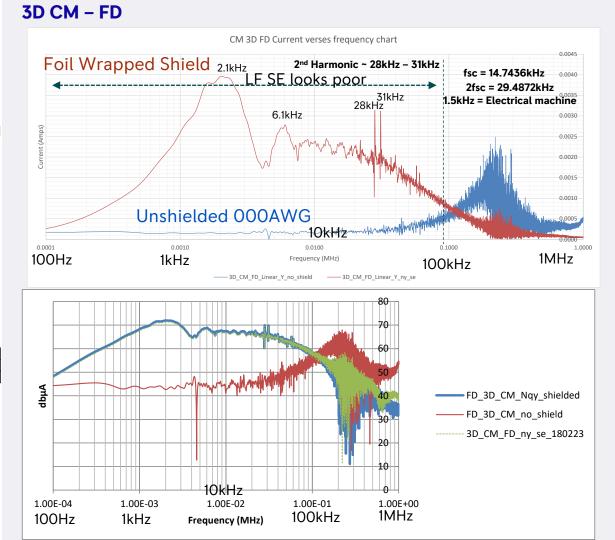




100Hz to 1MHzFoil Wrap Shield verses no-shield



Skin Depth Cut off Frequency	kHz
Stainless Steel enclosure (0.002m thick)	43.54
Copper Foil Screen Thickness (0.000254m thick)	69.49





Auto sample (230123)

Cable Phase Current – TD

Unscreened Model.

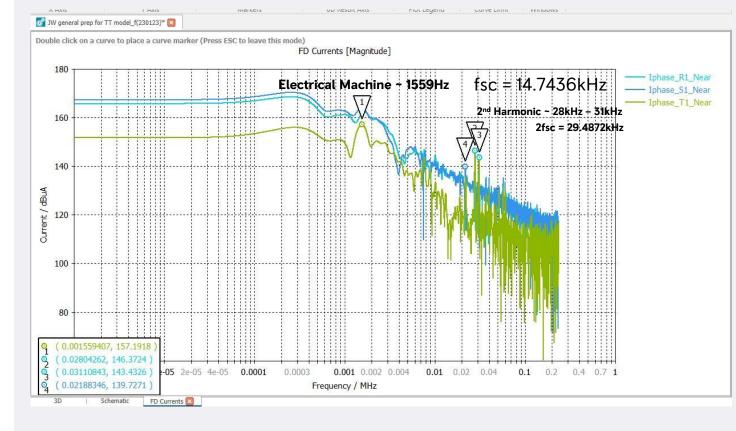
💕 JW general prep for TT model_f(230123)* 🔀 TD Currents 200 Iphase_R1_Near ----- Iphase_S1_Near 150 -100 50 Current / A 0 -50 -100 --150 -200 0.5 1.5 2 2.5 3 0 1 Time / ms 3D Schematic TD Currents Parameter List × Messages Component/Task Parameter List × Parameter List



Auto sample (230123)

Cable Phase Current – FD

Unscreened Model.

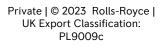




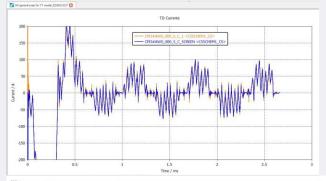
Nyquist (180223)

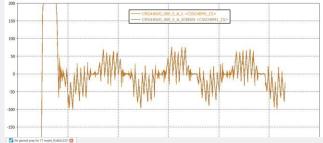
Foil Wrap Shield Model.

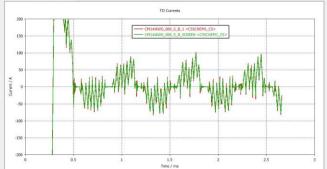
Screen Current = Phase Current



Cable Phase Current – FD





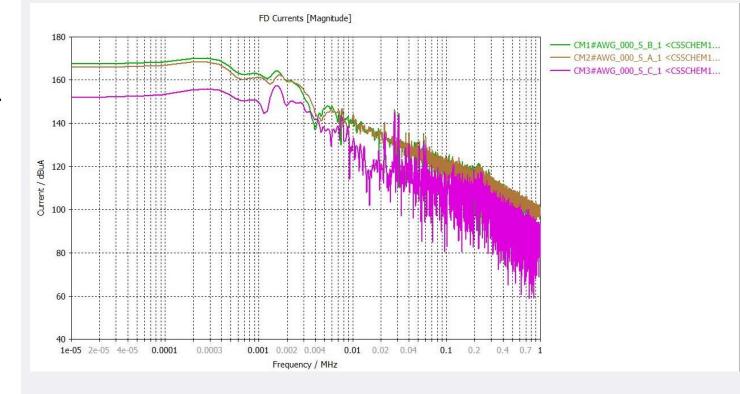




Cable Phase Current – FD

Nyquist (180223)

Foil Wrap Shield Model.





No shield verses Foil Wrap Shield

- E-field with Shielded cable & enclosure is much lower.
- In the lower frequency band (100Hz to 1kHz) the enclosure with no shield is effective, however, at approximately 1.5kHz, the enclosure provides less shielding, and so thereafter, the cable without a shield is better.
- Order of EMC performance in lower frequency band(100Hz to 1kHz):
 - 1. Shielded cable + Enclosure
 - 2. Shielded cable
 - 3. Enclosure + no cable shield
 - 4. No cable shield

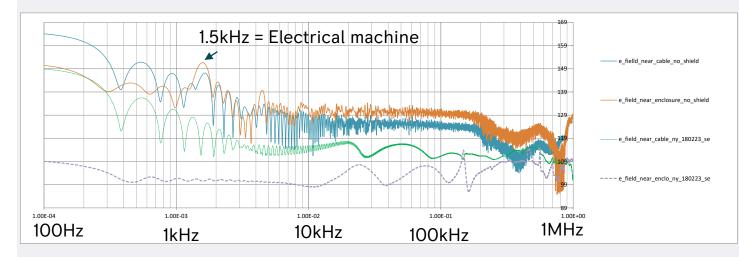
Order of EMC performance in higher frequency band (1kHz to 1MHz):

- 1. Shielded cable + Enclosure
- 2. Shielded cable
- 3. No cable shield
- 4. Enclosure + no cable shield

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E-Field – Near

No shield verses Foil Wrap Shield



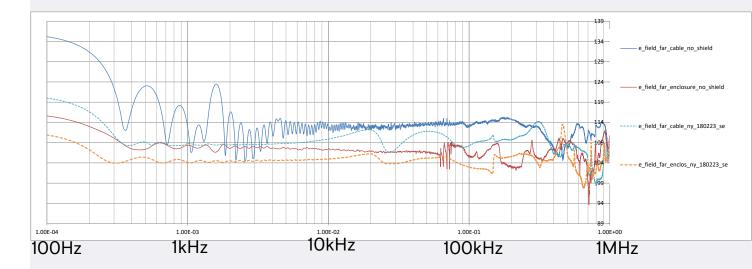


No shield verses Foil Wrap Shield

- E-field with shield & enclosure is much lower.
- However, a unshielded cable located in an metallic enclosure will provide a reasonable amount of electric shielding.

E-Field – Far @ 70mm

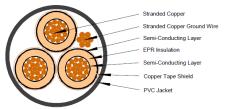
No shield verses Foil Wrap Shield





Conclusion





https://www.basicwire.com/

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Conclusions

- Although, the Copper Foil Cable Wrap reduces the cable common mode (CM) current amplitude in TD (Time Domain), the Copper Foil Wrap Shield appears to show that the RF CM Conducted Emissions (CE) in FD (Frequency Domain) is worse at low frequencies.
- Foil Wrap Shield cable reduces the CM RF RE (Radiated Emissions) Electric Field.
- However, unshielded cable with enclosure may be an adequate comprise, but more modelling work is required:
 - Include:
 - (a) braided shield
 - (b) drain wire
 - (c) Trefoil orientation in classic VFD cable study.
- Perform physical tests to validate modelling work.



05

References



References

- References
 - Henry W.OTT (EMC)
 - EMI Study of Three-Phase Inverter-Fed Motor Drives, Bertrand Revol, James Roudet, Jean-Luc Schanen, Senior Member, IEEE, and Philippe Loizelet, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 47, NO. 1, JANUARY/FEBRUARY 2011
 - EMI Emissions of Modern PWM ac Drives Gary L.Skibinski, Russel J.Kerkman, and Dave Schlegel



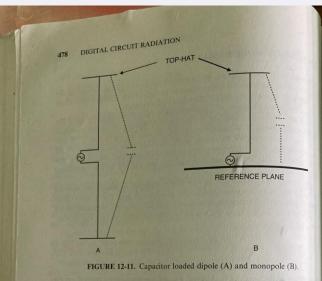
Back up slides



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Backup Slides

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For the case where the observation is made at a distance r perpendicular to the axis of the antenna ($\theta = 90^{\circ}$), using MKS units, Eqs.12-6 can be rewritten as

$$E = \frac{12.6 \times 10^{-7} (f l I_{cm})}{r}.$$

Equation 12-7 shows that the radiation is proportional to the frequency. length of the antenna, and the magnitude of the common-mode current the antenna. The primary method of minimizing this radiation is to limit common-mode current, none of which is required for the normal operation

Therefore common-mode (dipole) radiation can be controlled by following methods:

1. Reducing the magnitude of the common-mode current

2. Reducing the frequency or harmonic content of the current 3. Reducing the antenna (cable) length

rent must be determined to than a sine wave, the Fourier series of current must be determined before substitution into Eq. 12-7 (See Seche 12.1.3)



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Backup Slides

