CST Unscreened verses Screened Power Converter Cables
Preliminary Study

3D SUITE 2023

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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

01

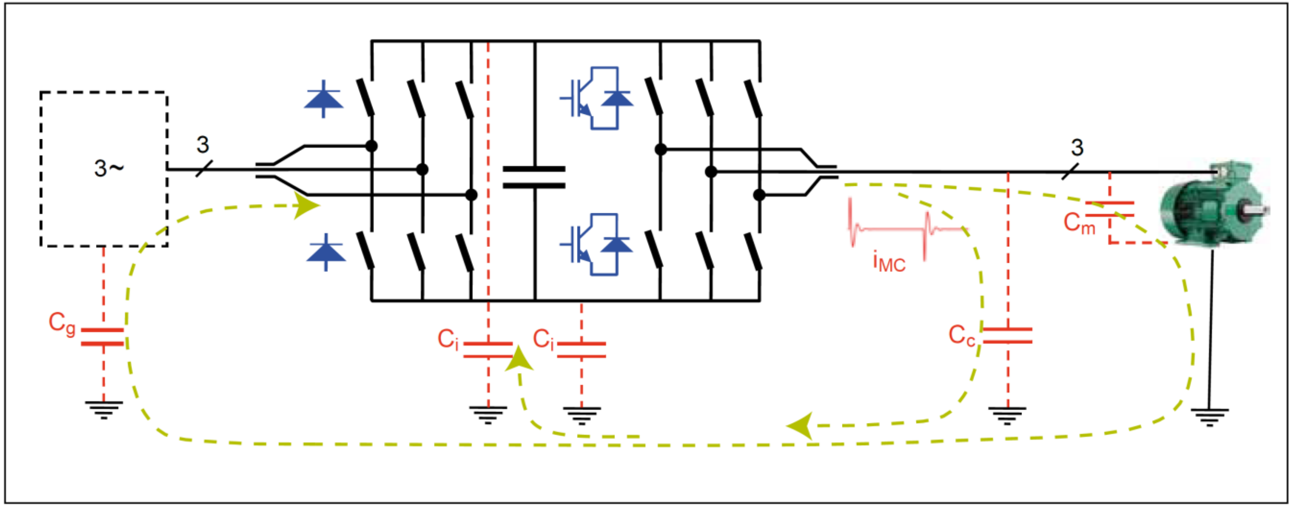
RF CE Reminder

RF CE Reminder

Common Mode Current Paths

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

Illustration 2 - Common mode currents



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

02

Measurement Approach

Impedance to Ground

Cross check measurements (IEEE)

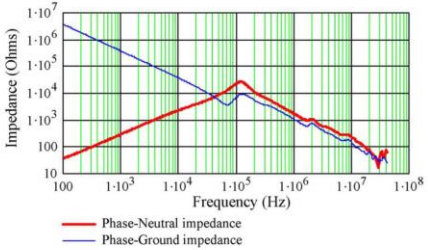


Fig. 7. Main impedances of the ac motor used (AEG750W).

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

Measurement Approach

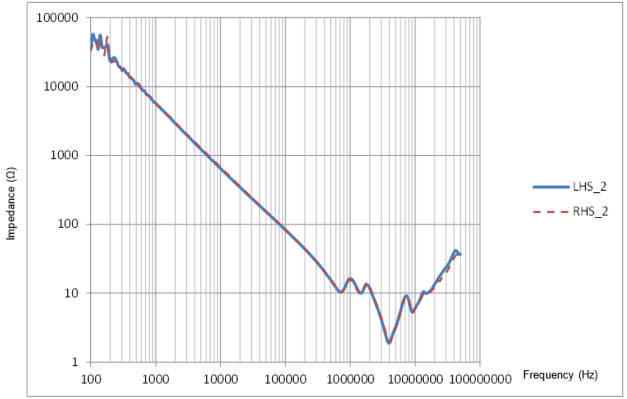


Figure 12 (Comparison between RHS and LHS three phase generator impedance to ground)

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

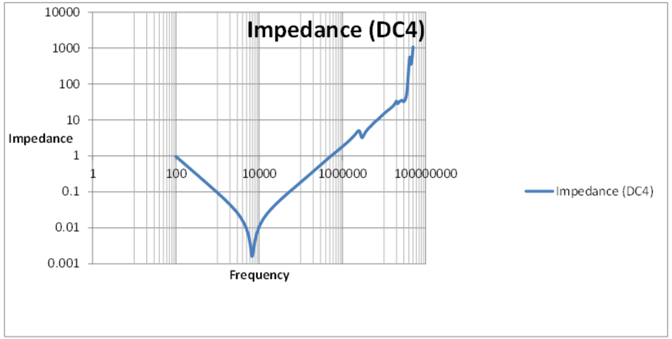


Figure 25 (DC link Capacitor Impedance – Single Channel)

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

01

3D Model

Objective

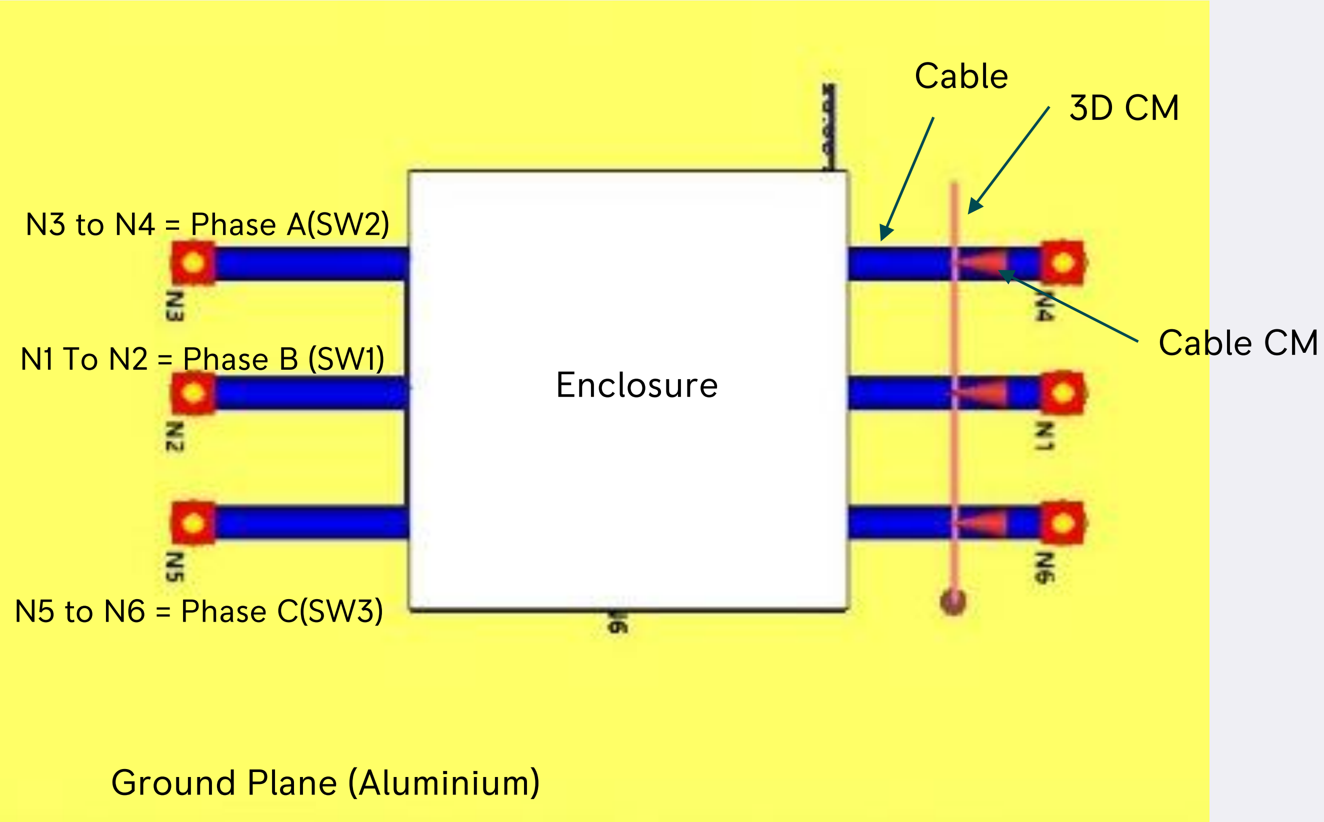
Setting the Scene

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 Nyquist sampling 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.

3D Model

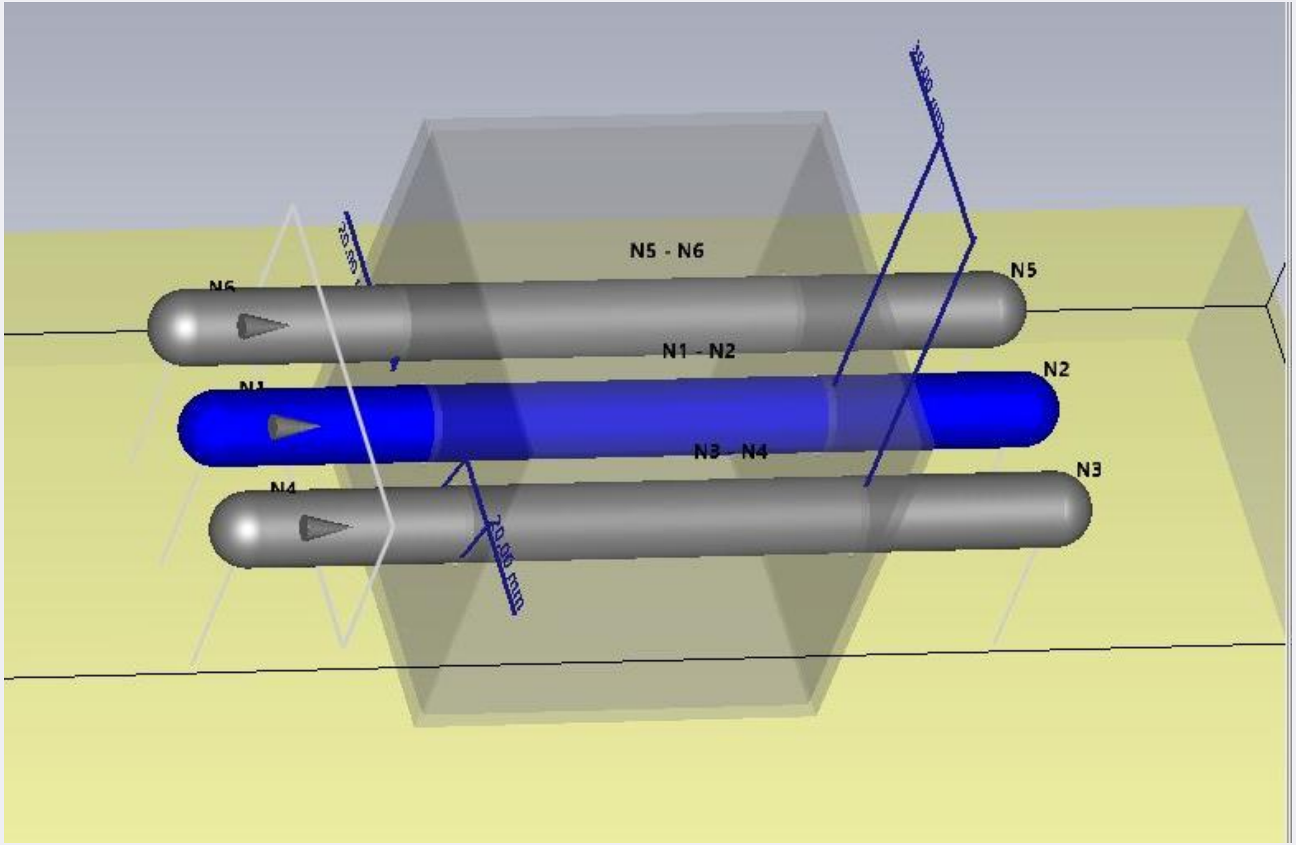
Top View



Enclosure View

3D Model

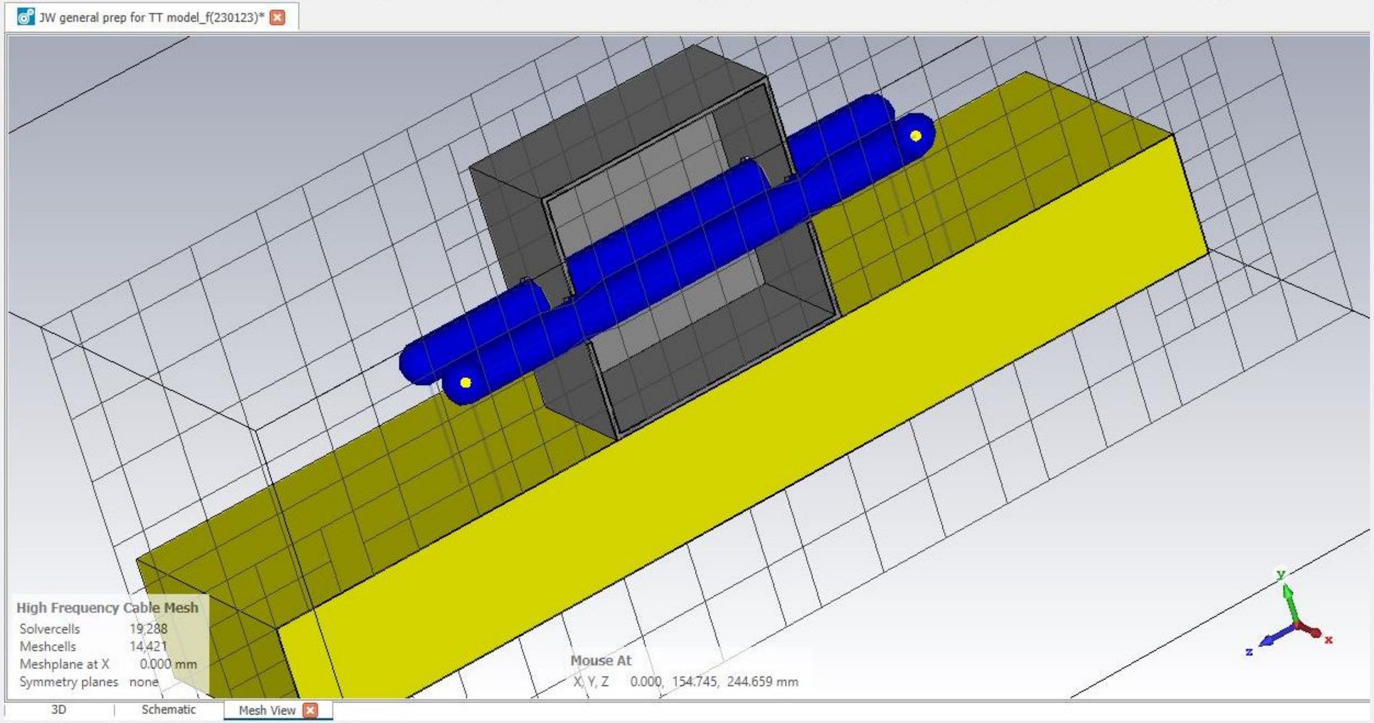
- Cable Length 200mm
- Enclosure (100mmx100mmx100m; 2mm wall thickness, Steel (1008)



Mesh View

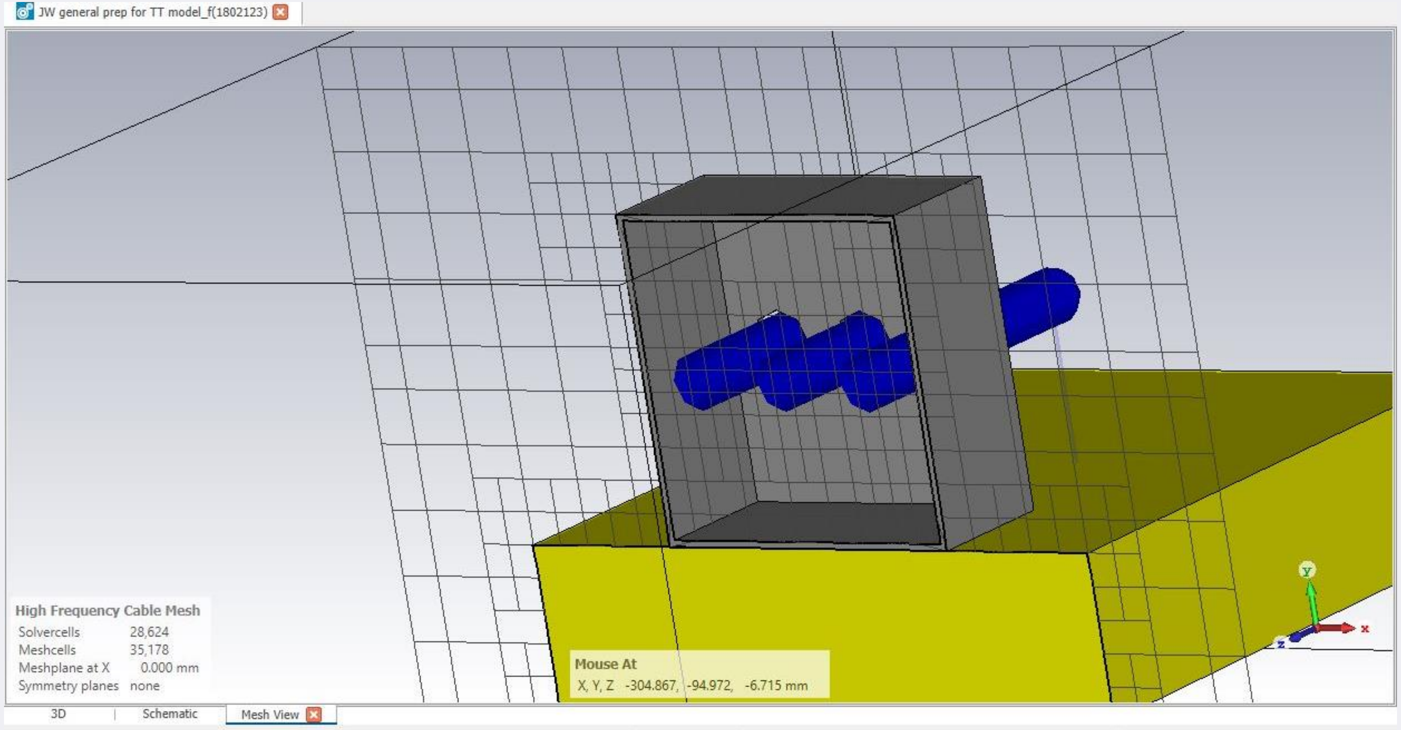
Mesh View

- From 230123 Model.



Mesh View

- From 180223 Model.

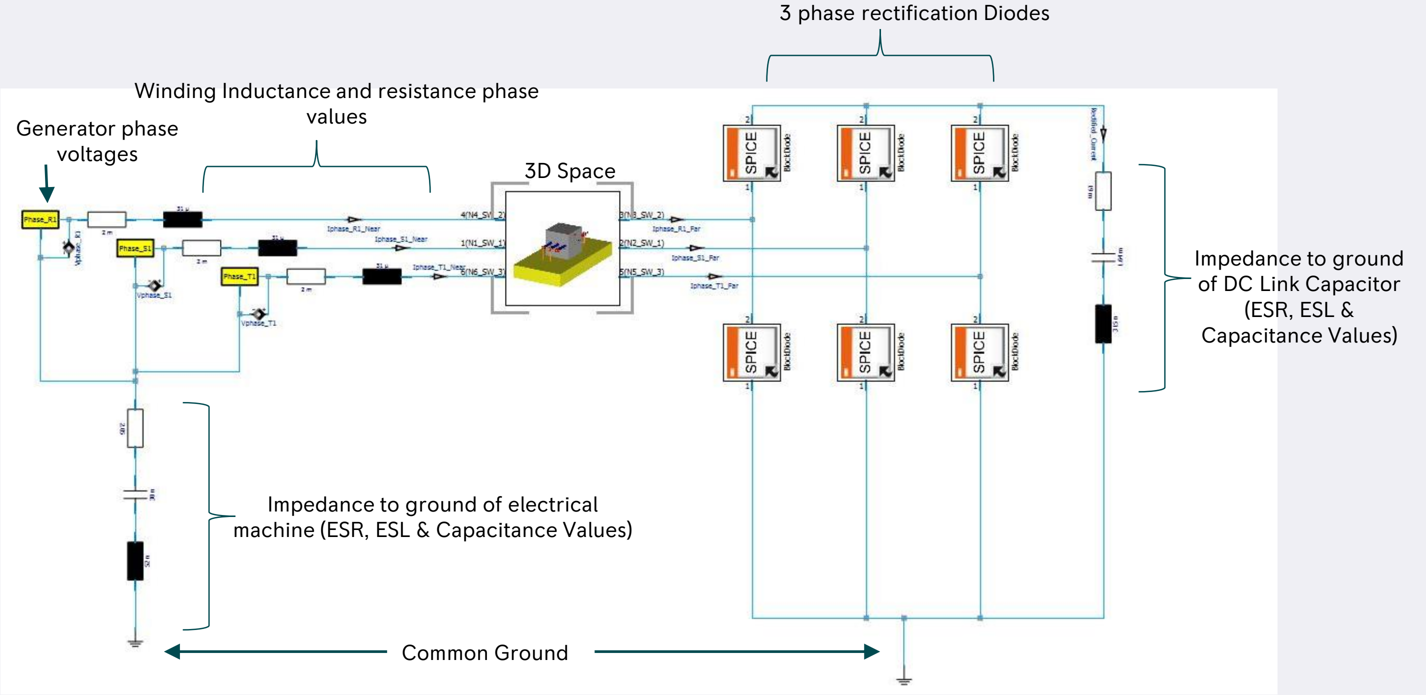


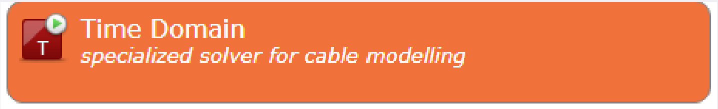
Mesh View

Unscreened Schematic

Unscreened Schematic

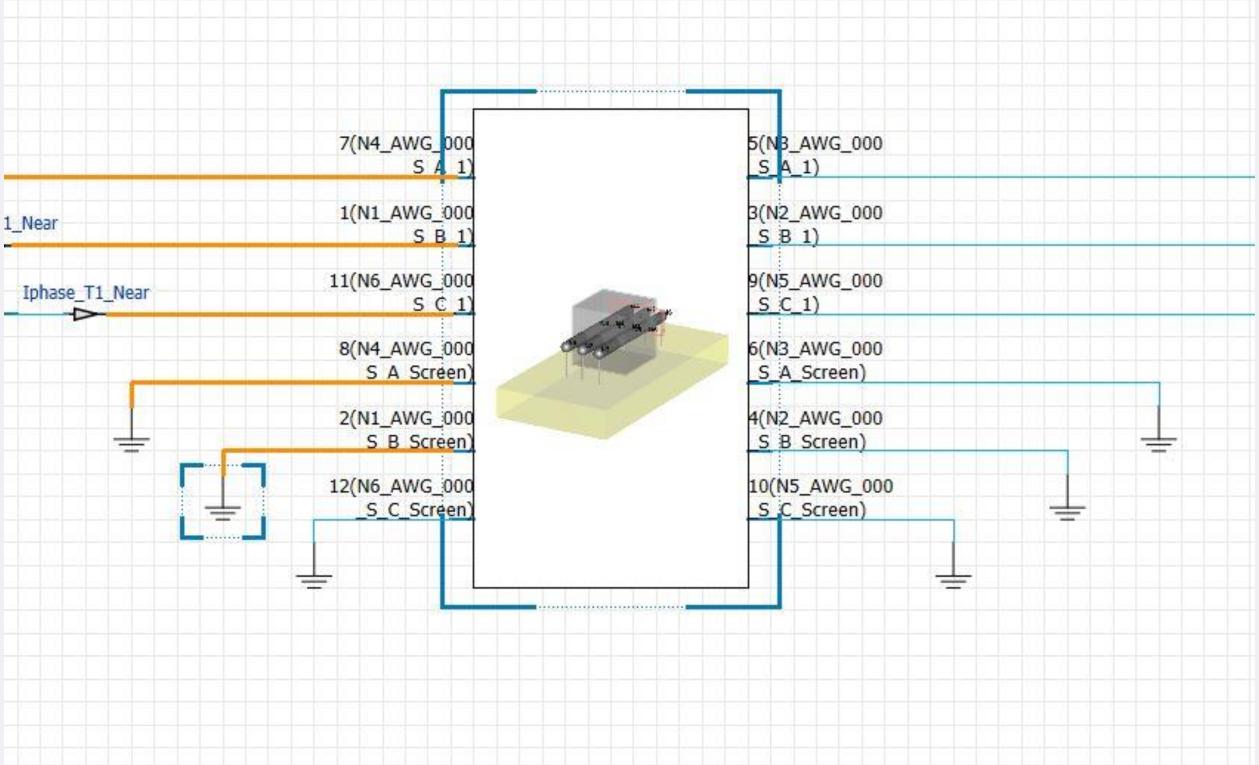
- Co-simulation technique





Screened Schematic

- Changes shown below



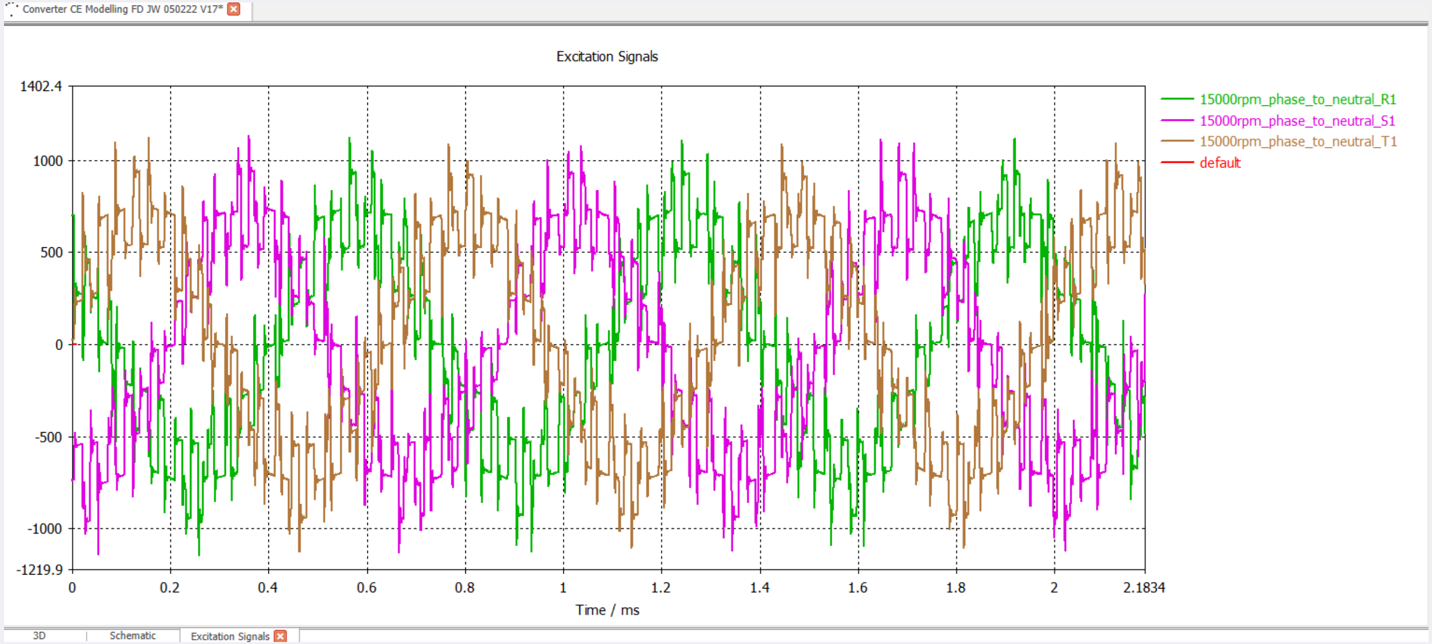
Screened Schematic

Excitation Signals

Monotonic
Zeroed
Repetition of Cycles

Excitation Signals

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

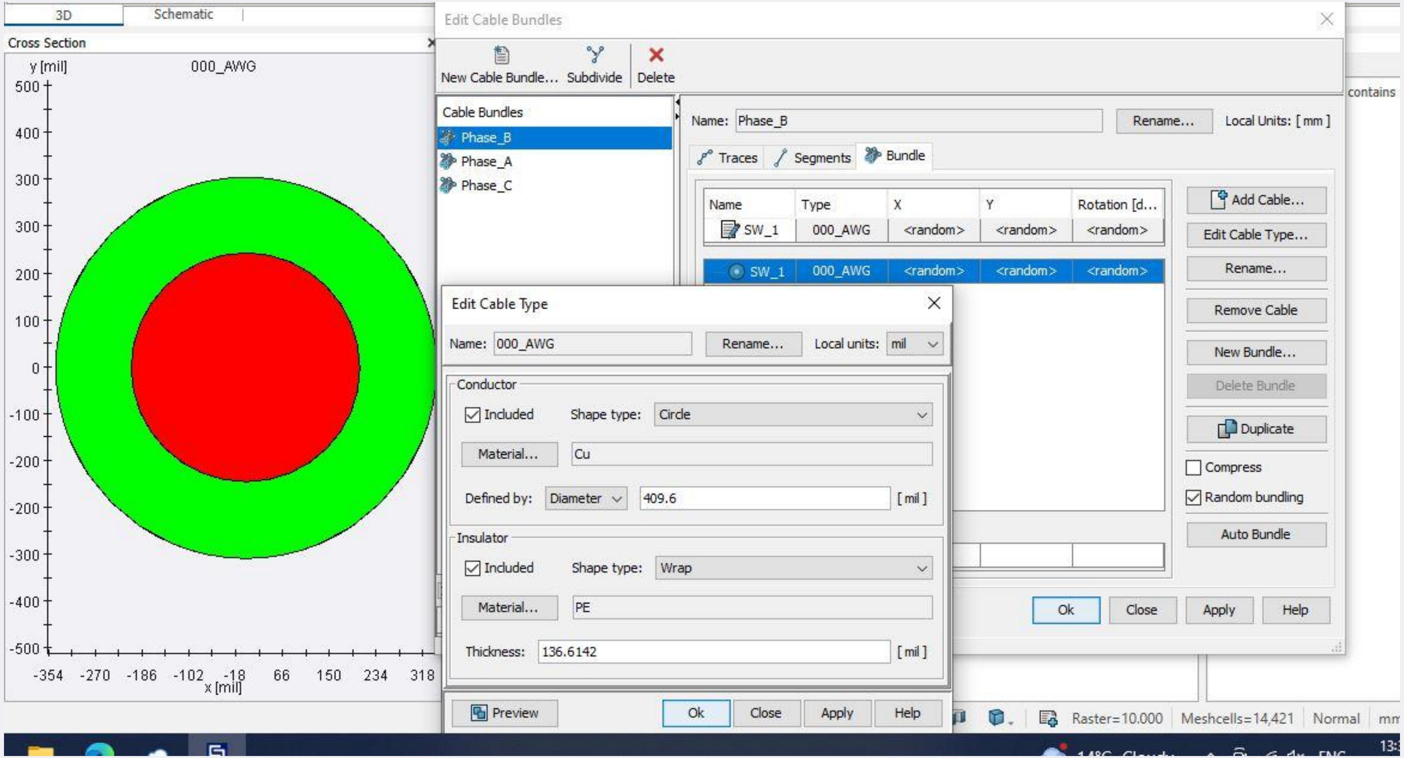


15000rpm = 1500Hz (Electrical Frequency) = 0.666ms x 4 cycles = 2.66ms (3ms)

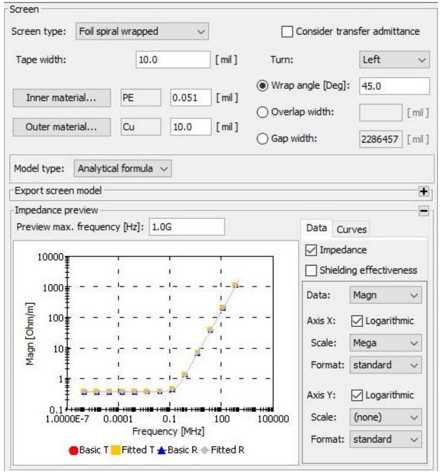
Unscreened Cable Construction

- 000 AWG

Unscreened Cable

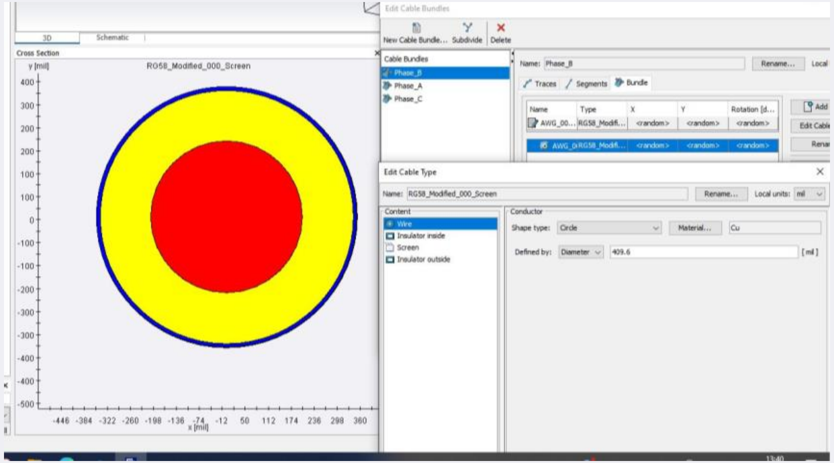


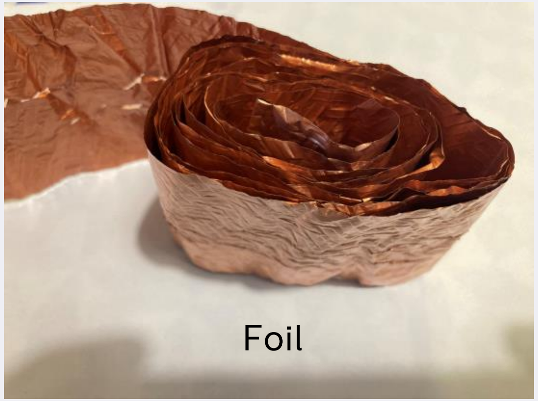
Screened Cable



Screened Cable Construction

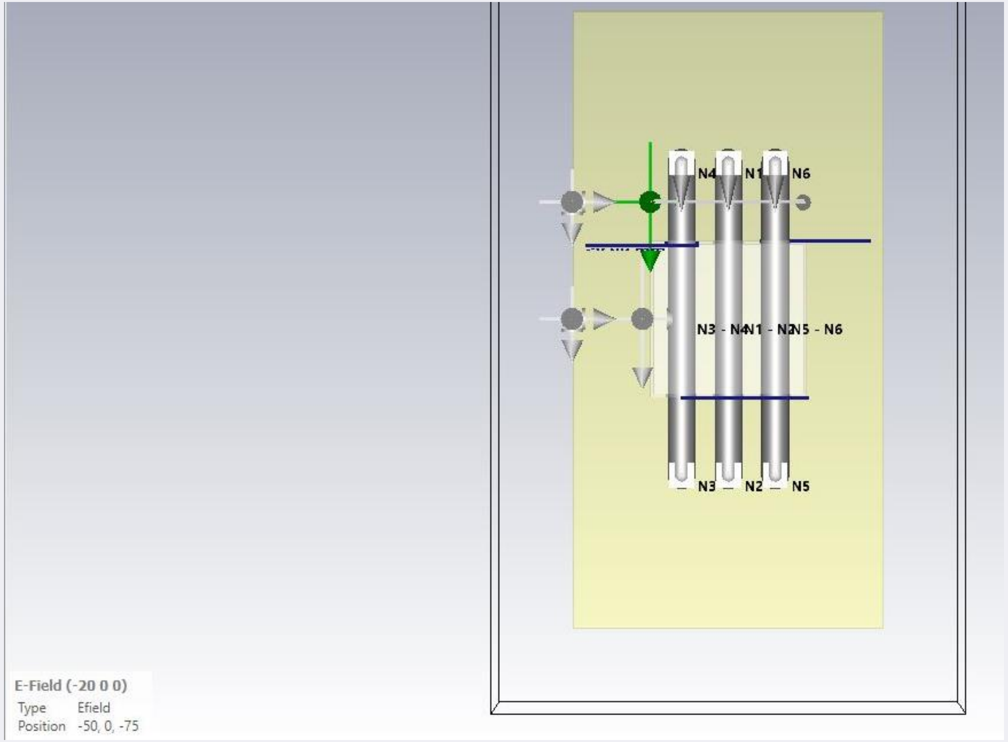
Layer	Type	Material	Tape Width	Shape Type	Dimensions	Note
Conductor 000 AWG	N/A	Cu	N/A	Circular	409.6mil	Diameter
Insulator	N/A	PE	N/A	Wrap	136.6mil	Thickness
Screen	Foil spiral wrapped	Cu	N/A	Outer Material	10mil	Thickness
		PE	10mil	Inner Material	0.051mil	Thickness
Insulator Outside	N/A	PVC	N/A	Wrap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





Probe Locations

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

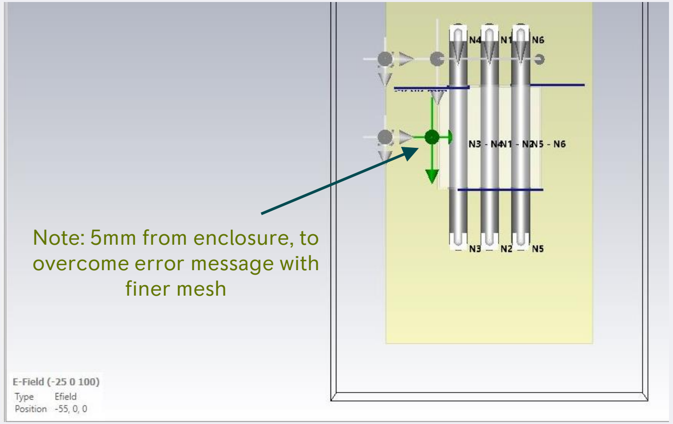


Cable (Near)

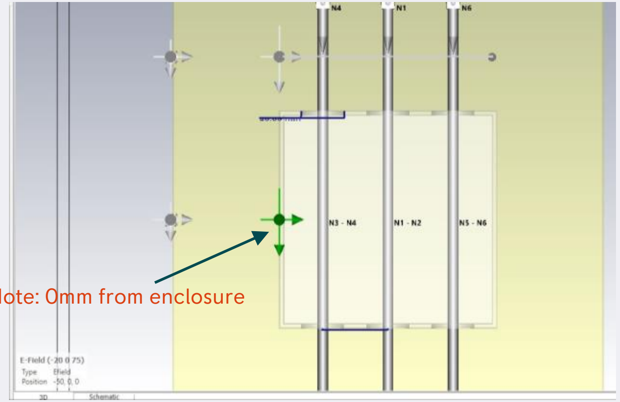
H-Field same location as E-Field

Probe Locations

- Nyquist 18023 Model [Foil Wrap Shield cable] Enclosure (-25,0,100), Position (-55,0,0)



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

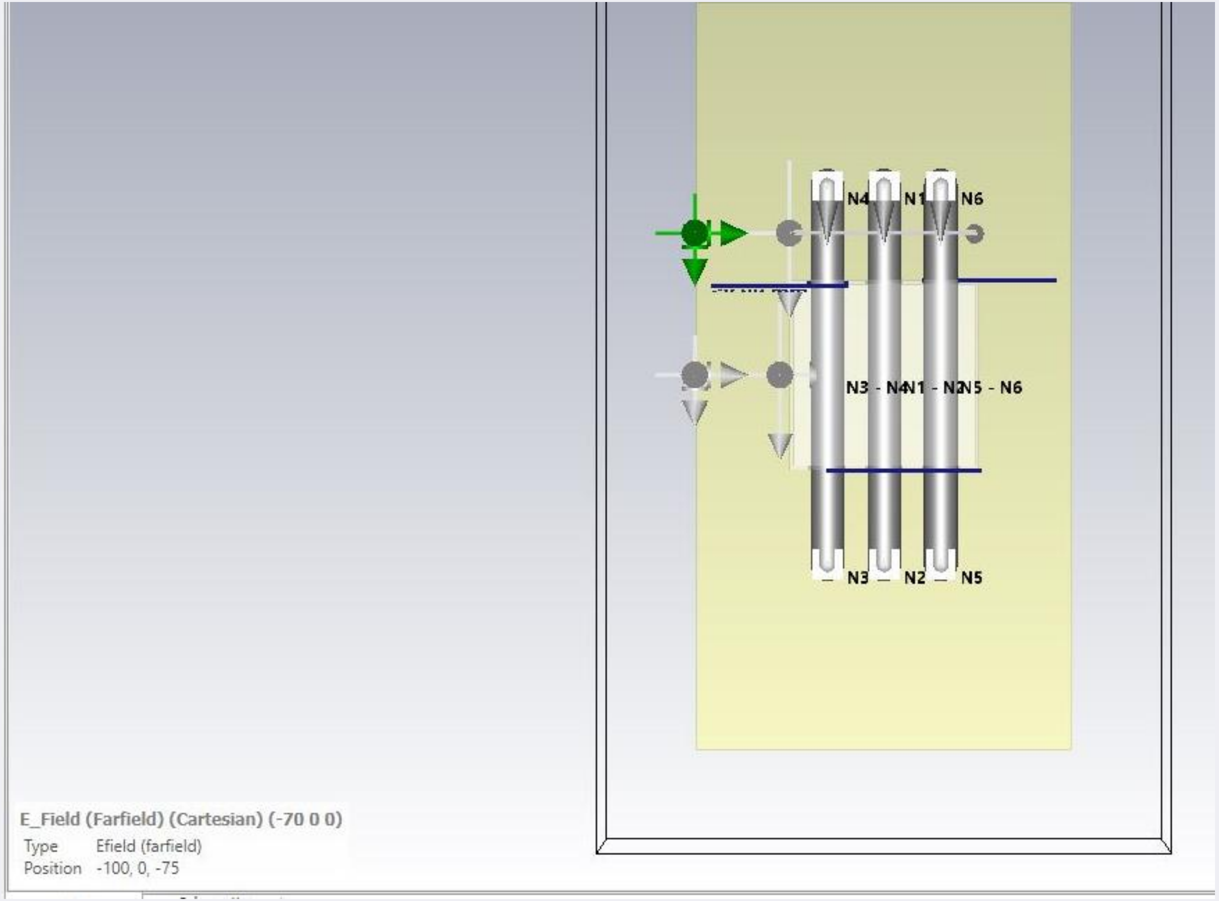


Enclosure (Near)

H-Field same location as E-Field

Probe Locations

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

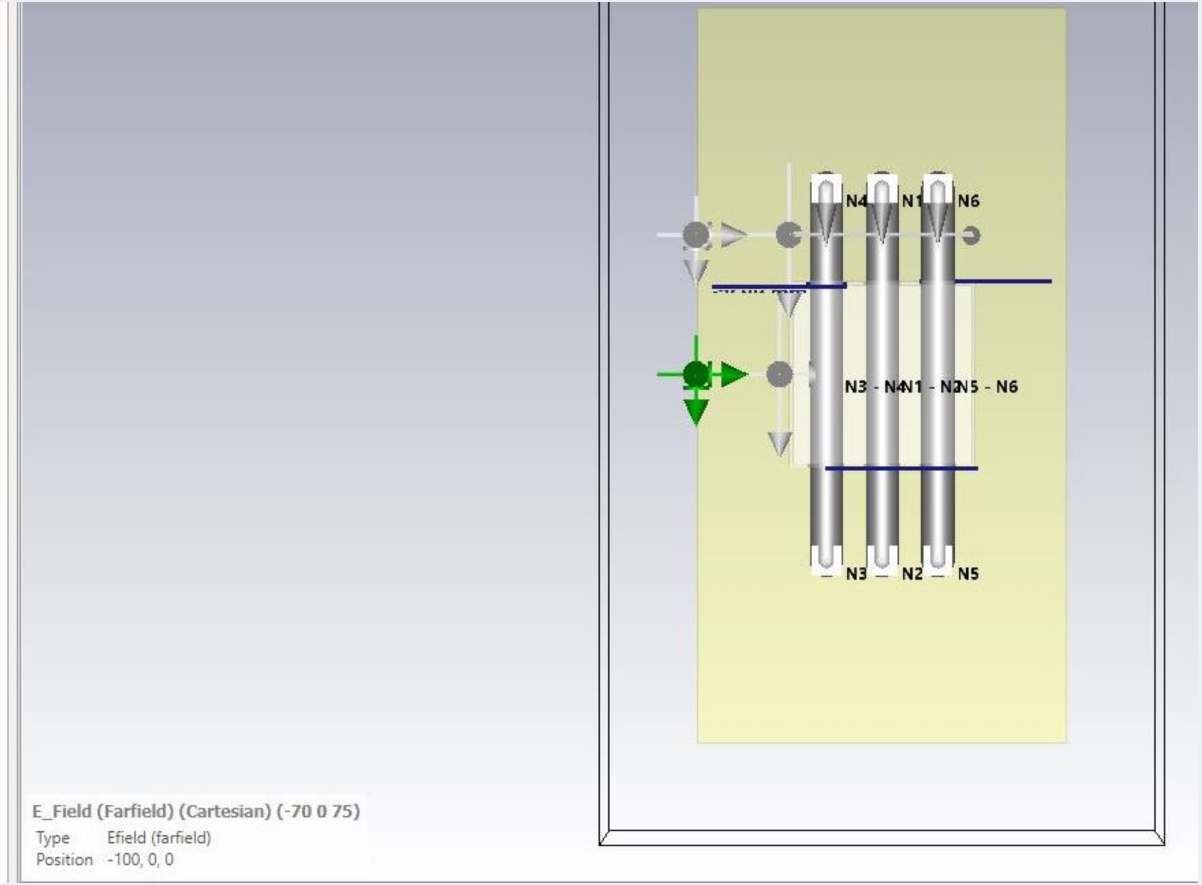


Cable (Far)

H-Field same location as E-Field

Probe Locations

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



Enclosure (Far)

H-Field same location as E-Field

02

Results

3D CM – TD

- No shield verses Foil Wrap Shield

Overview Trace

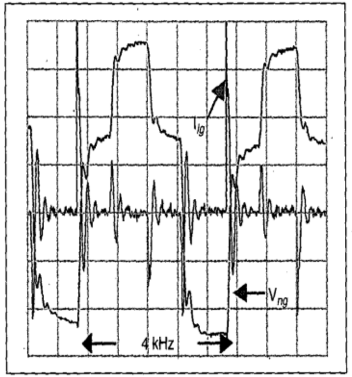
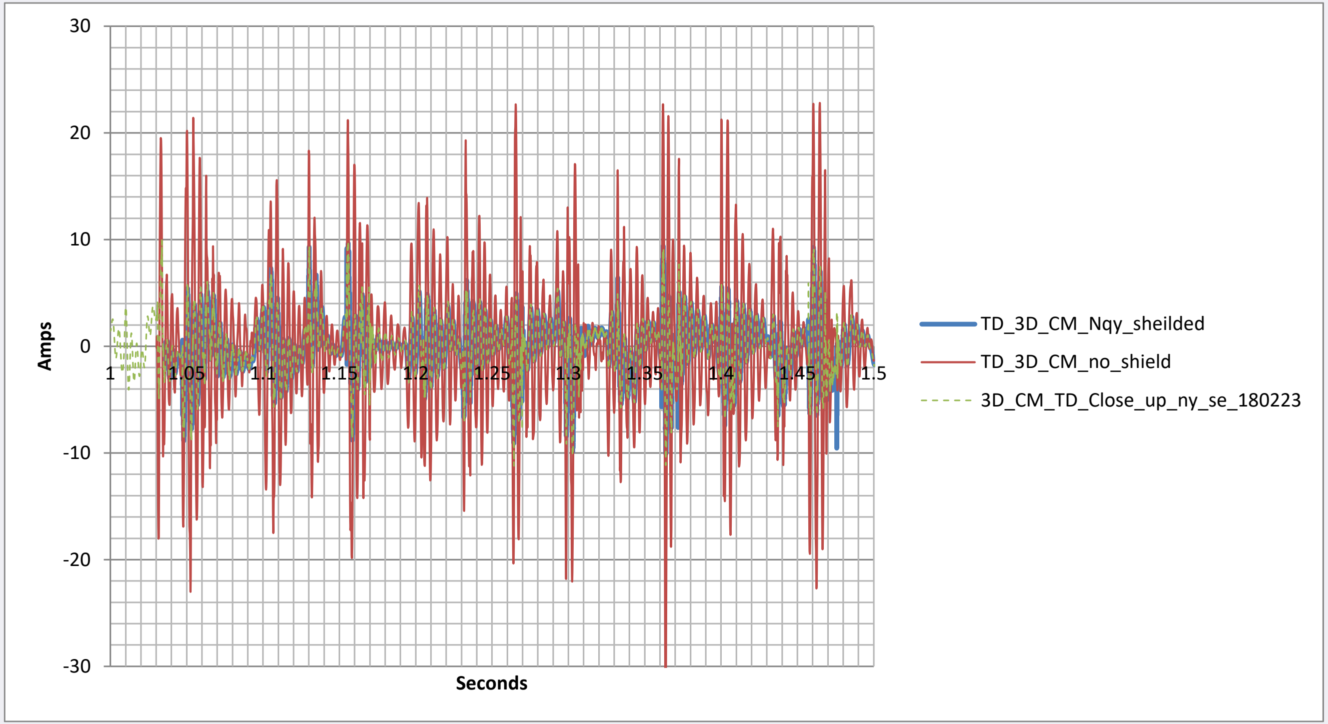


Fig. 8. Expanded neutral-to-ground voltage (100 V/Div) and I_{lg} CM current (2A/Div) for 30 Hz output {"0" at offset 4 div; 50 µs/Div}.

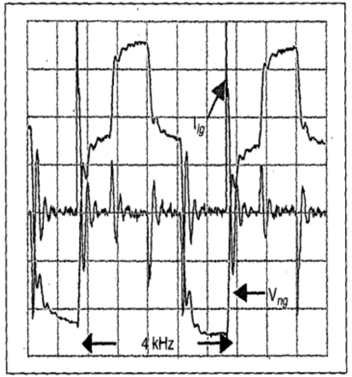
EMI Emissions of Modern PWM ac Drives – Gary L.Skibinski, Russel J.Kerkman, and Dave Schlegel



3D CM – TD

- No shield verses Foil Wrap Shield

Zoomed In Trace



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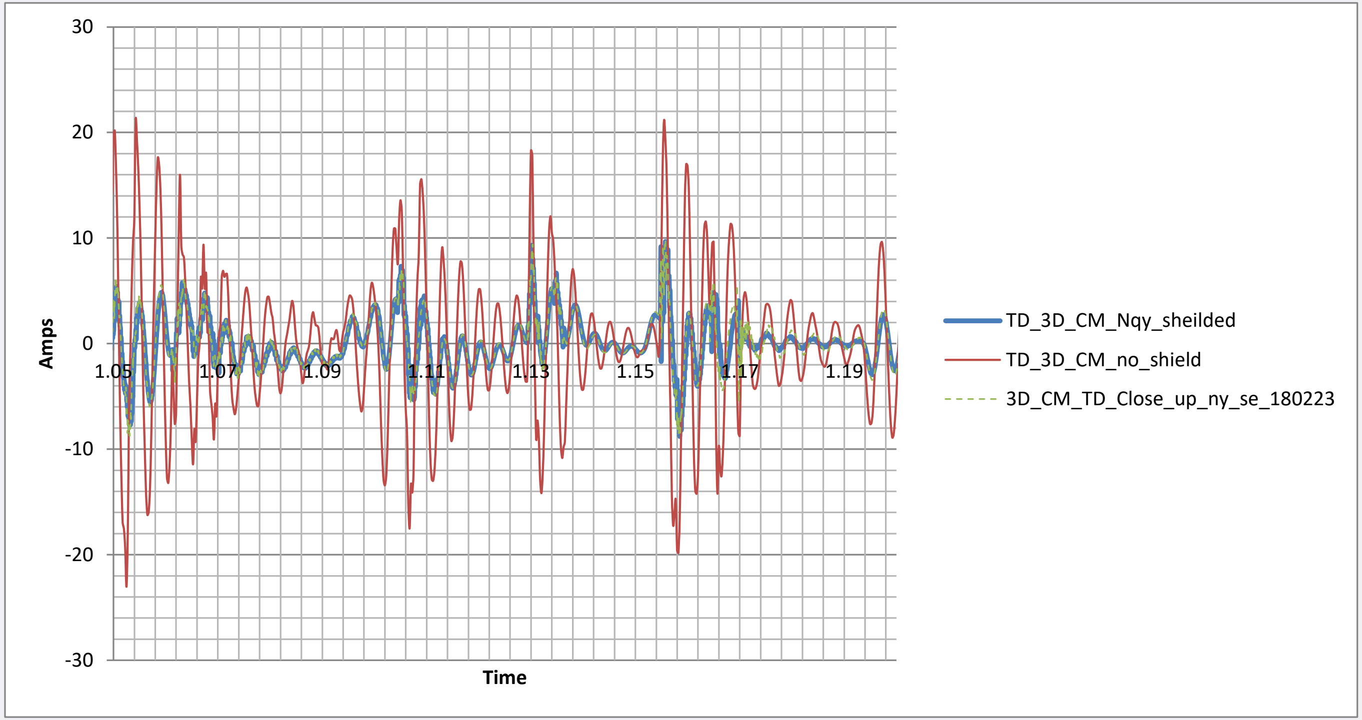
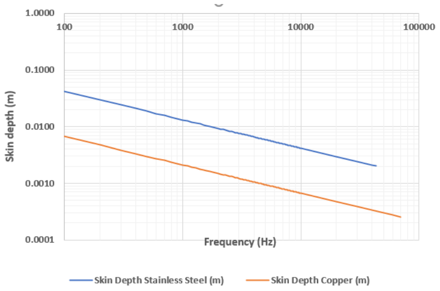
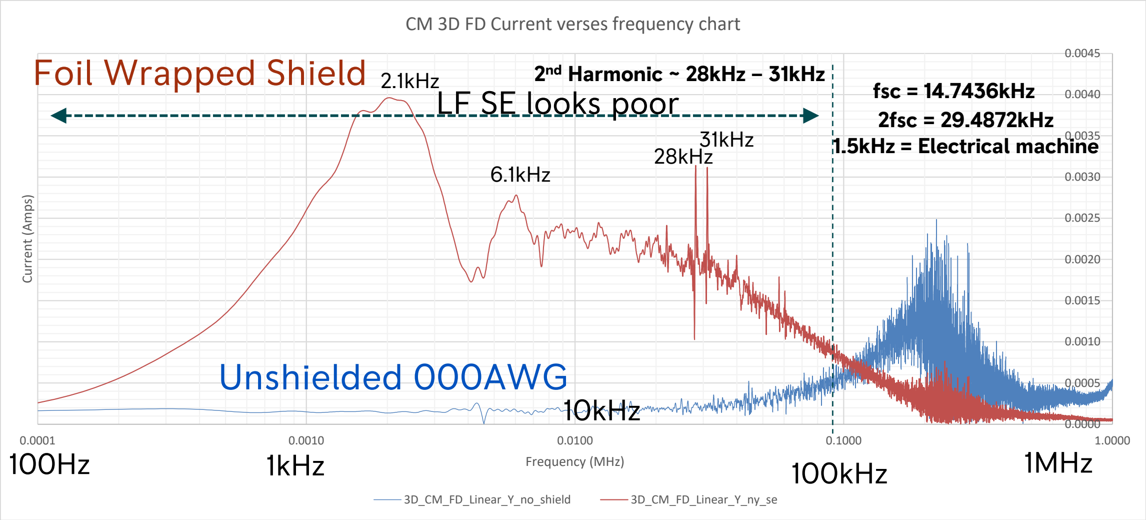


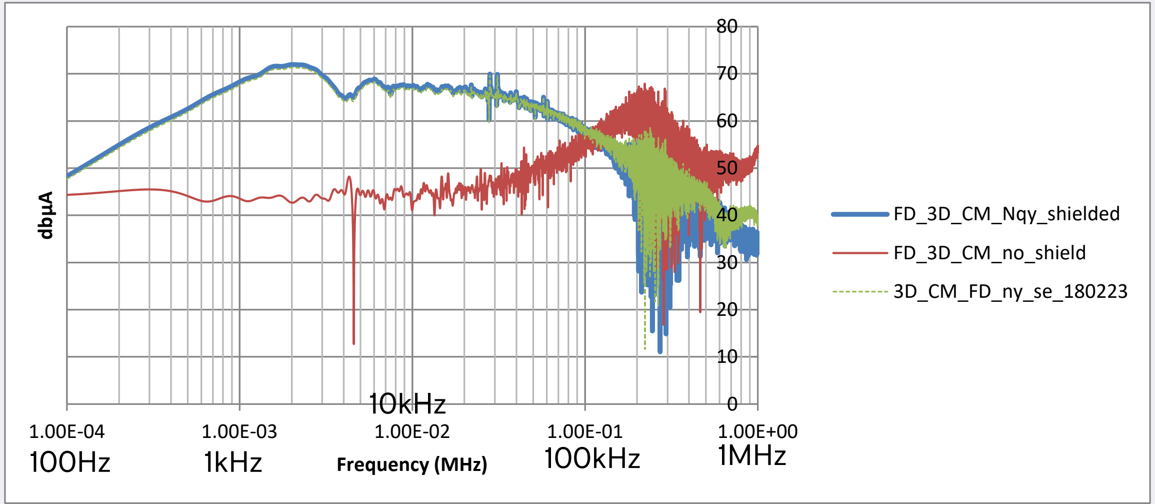
3D CM – FD

- 100Hz to 1MHz
- Foil 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

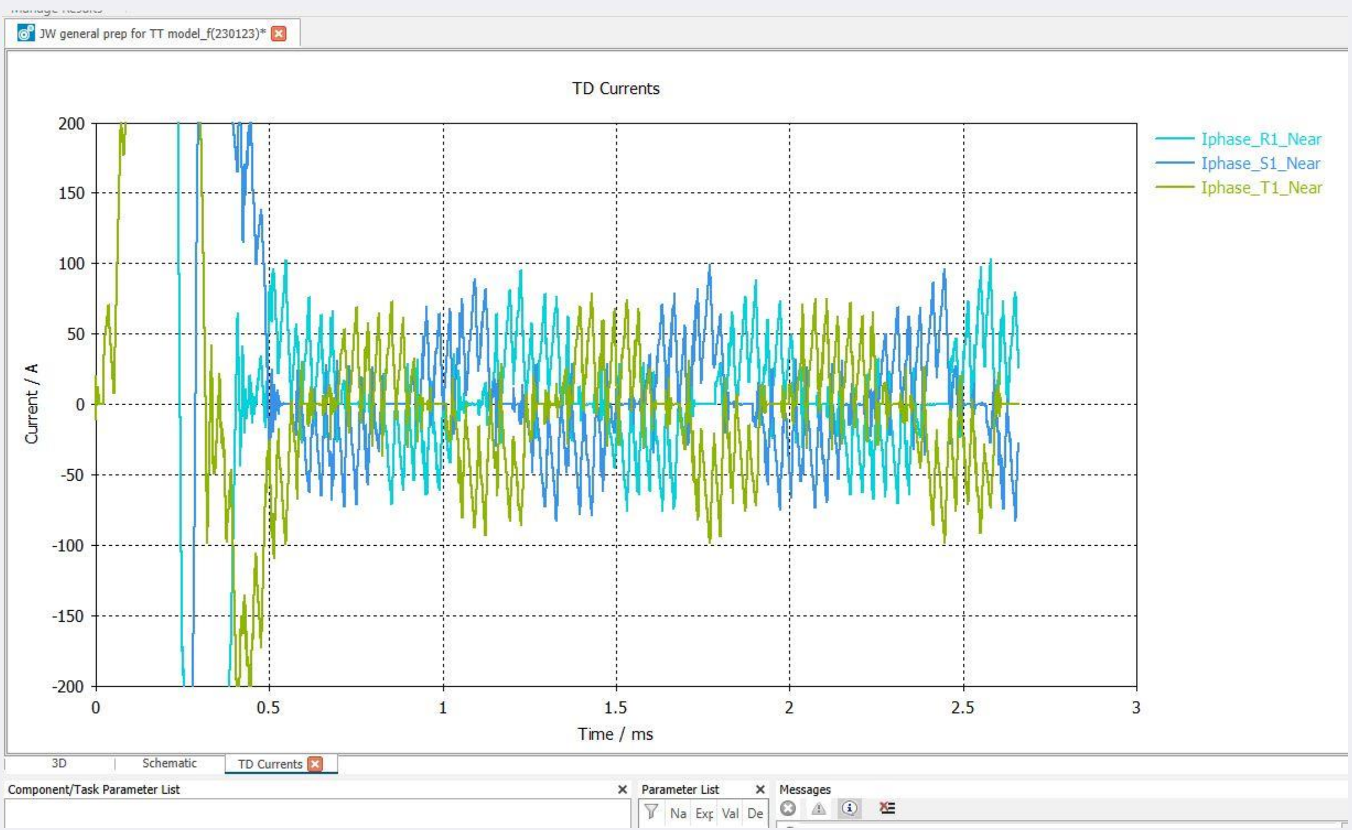




Auto sample (230123)

Unscreened Model.

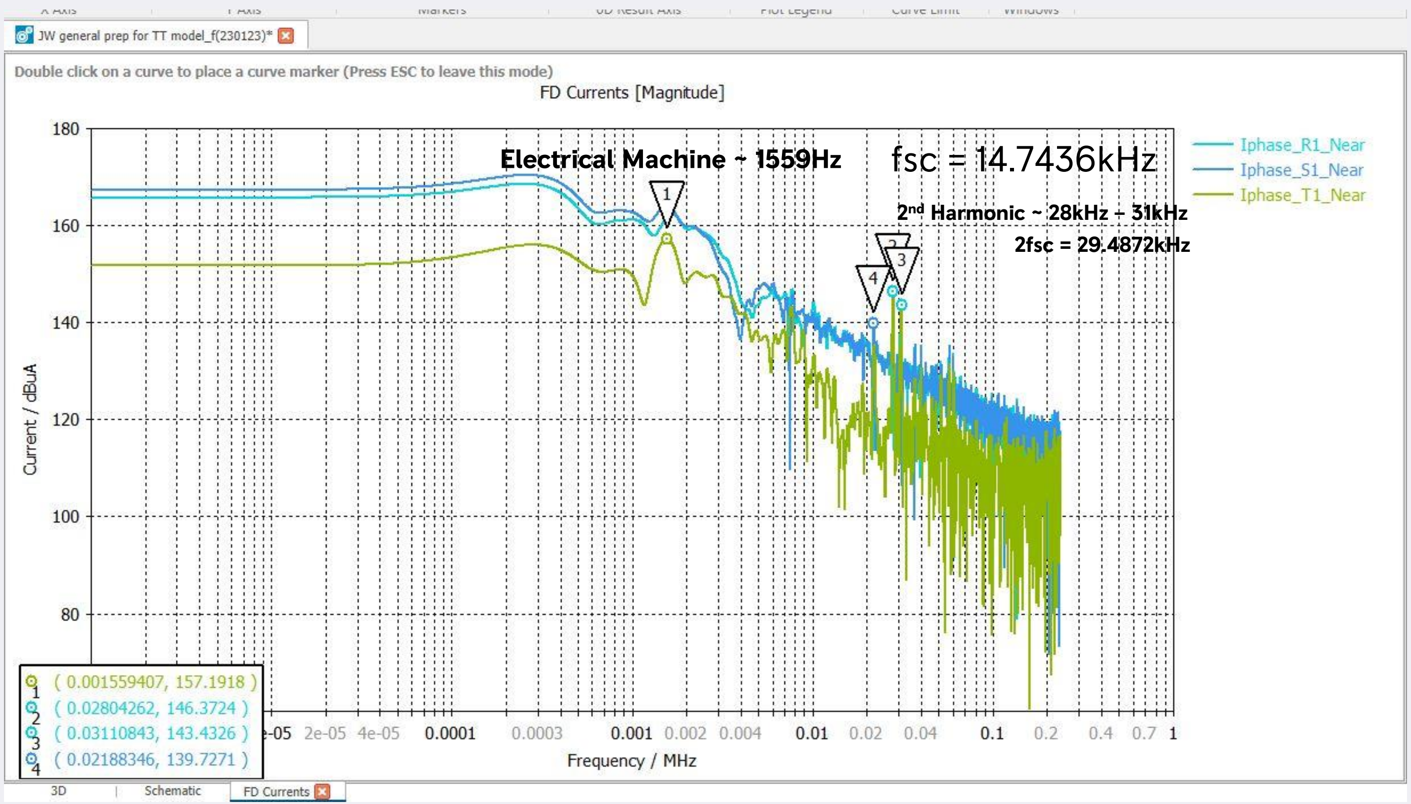
Cable Phase Current – TD



Cable Phase Current – FD

Auto sample (230123)

Unscreened Model.

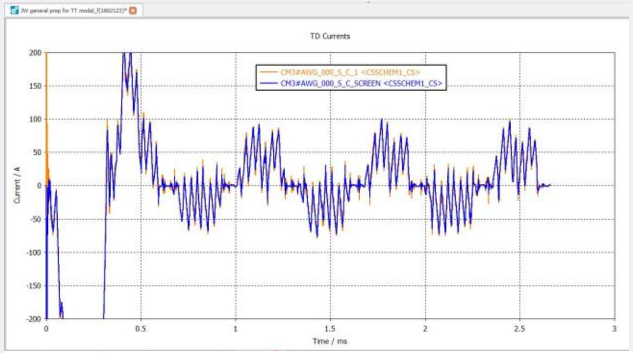


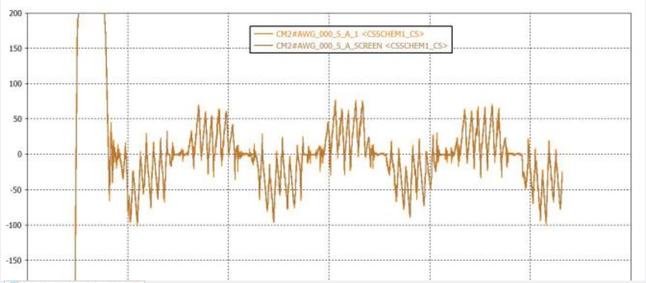
Cable Phase Current – FD

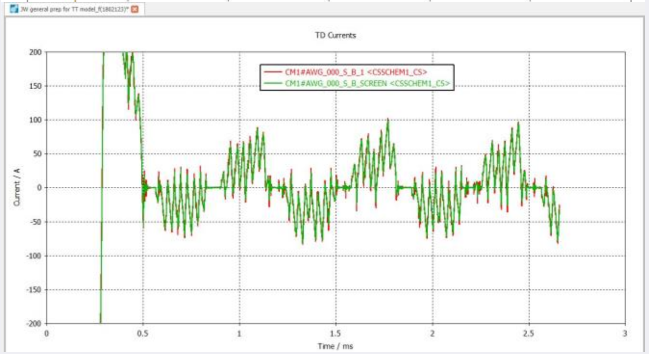
Nyquist (180223)

Foil Wrap Shield Model.

Screen Current = Phase Current



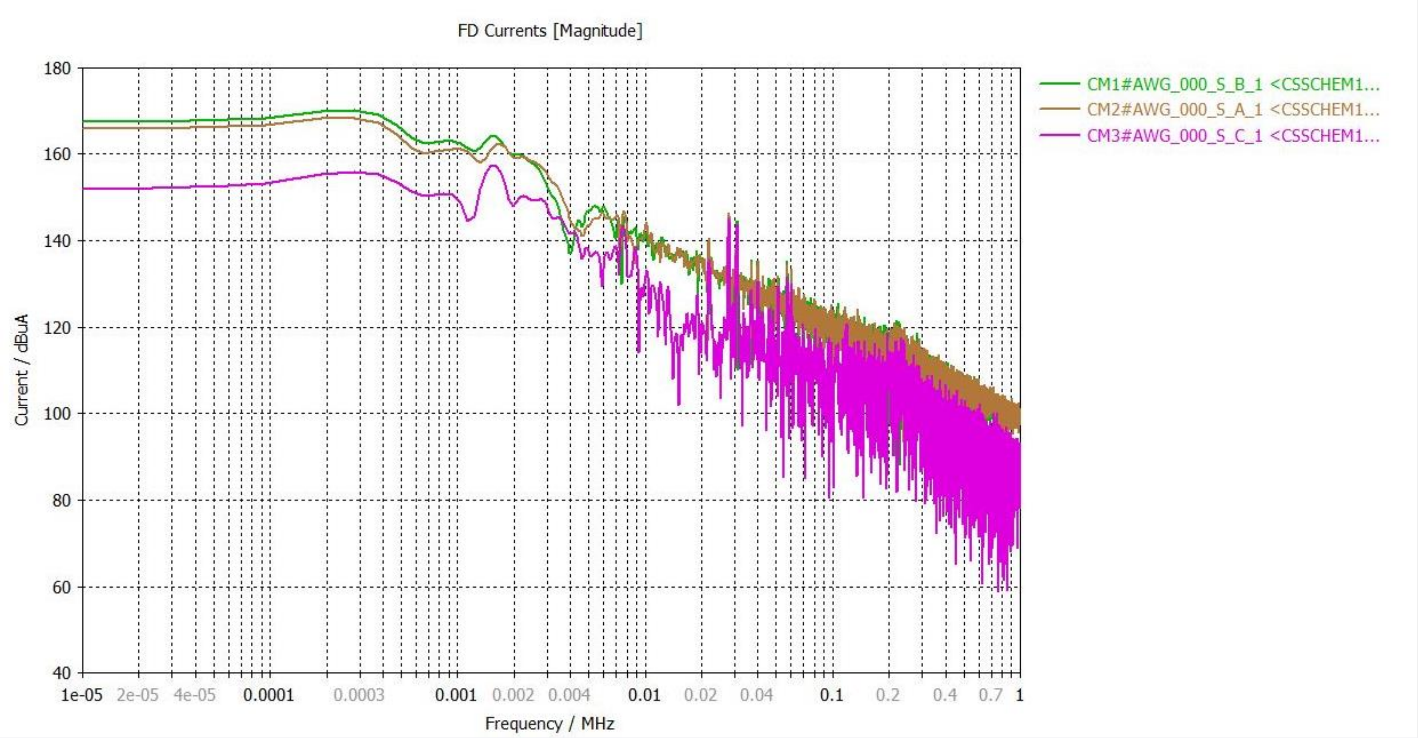




Cable Phase Current – FD

Nyquist (180223)

Foil Wrap Shield Model.



No shield verses Foil Wrap Shield

- E-field with Shielded cable & enclosure is much lower.

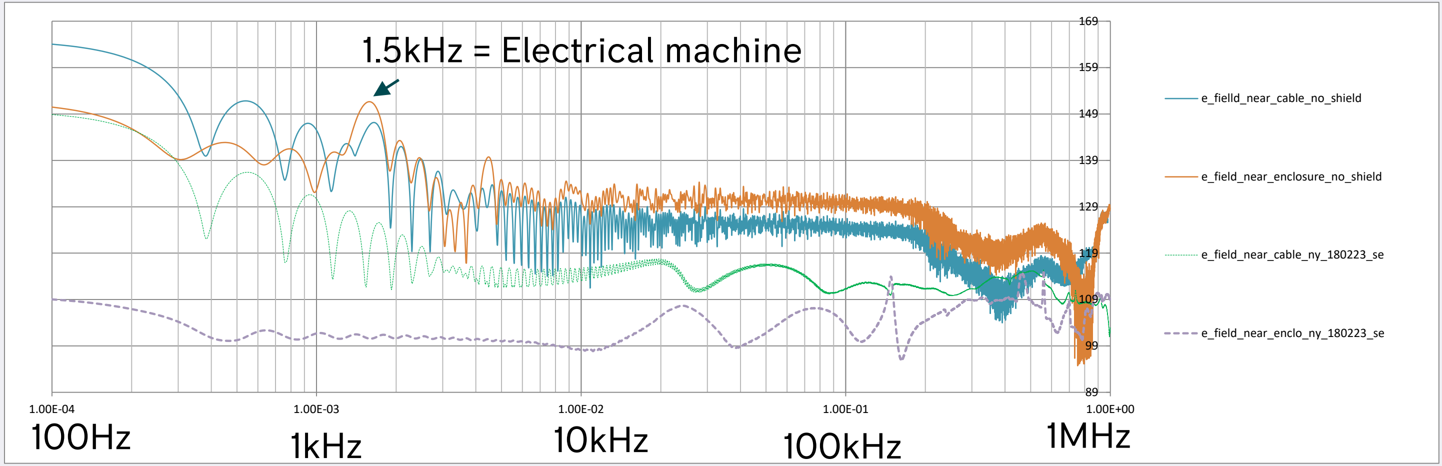
- In the lower frequency band (100Hz to 1kHz) the enclosure with no shield is effective, **however, at approximately 1.5kHz, the enclosure provides less shielding, and** so thereafter, the cable without a shield is better.

- **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

E-Field – Near

- No shield verses Foil Wrap Shield

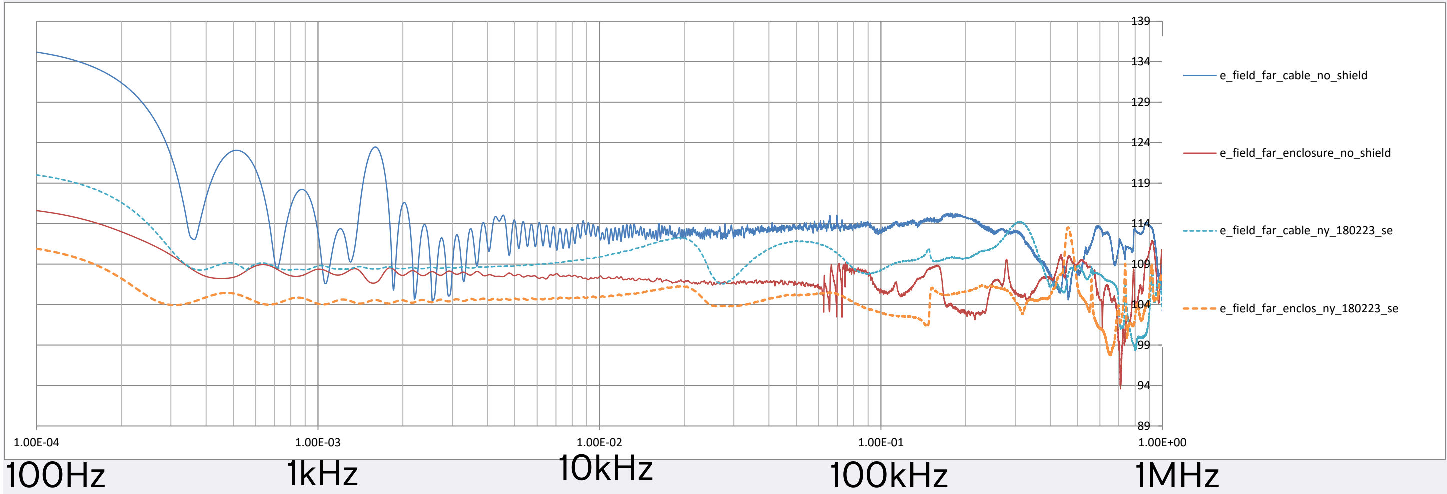


No shield verses Foil Wrap Shield

- 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



04

Conclusion

Conclusions

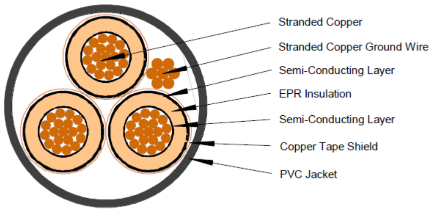
- Although, the Copper Foil Cable Wrap reduces the cable common mode (CM) current amplitude in TD (Time Domain), the Copper Foil Wrap Shield appears to show that the RF CM Conducted Emissions (CE) in FD (Frequency Domain) is worse at low frequencies.

- 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.



https://www.basicwire.com/

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

06

Back up slides

Backup Slides

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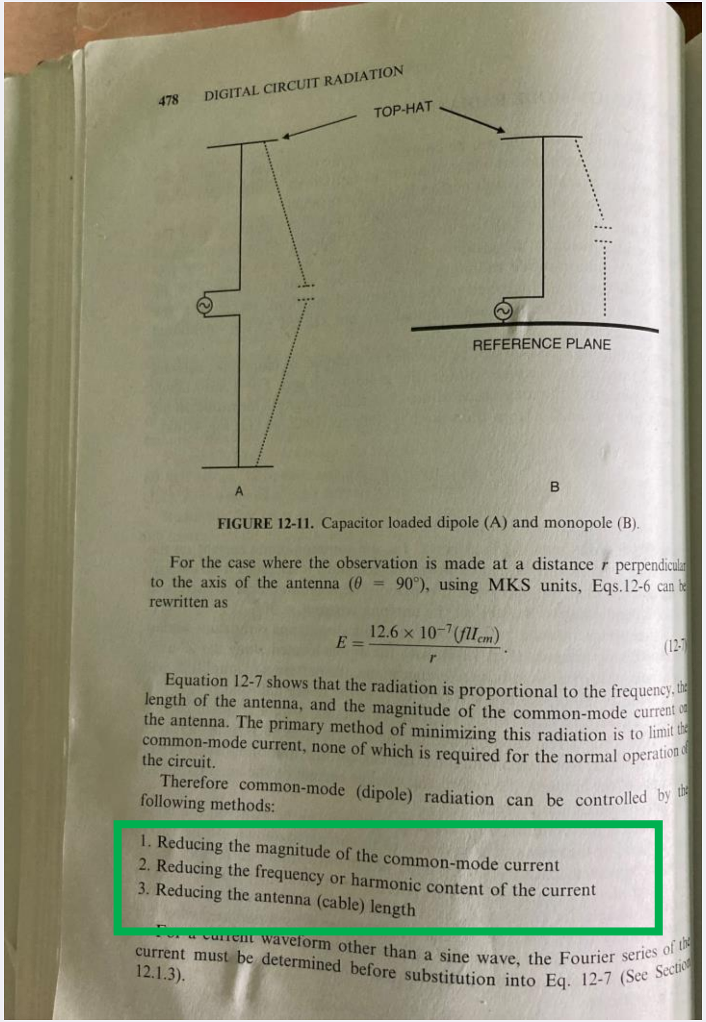

478 DIGITAL CIRCUIT RADIATION

FIGURE 12-11. Capacitor loaded dipole (A) and monopole (B).

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

$$E = \frac{12.6 \times 10^{-7}(f l I_{cm})}{r}. \qquad (12\text{-}7)$$

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

Therefore common-mode (dipole) radiation can be controlled by the 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

For a current waveform other than a sine wave, the Fourier series of the current must be determined before substitution into Eq. 12-7 (See Section 12.1.3).

Backup Slides

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