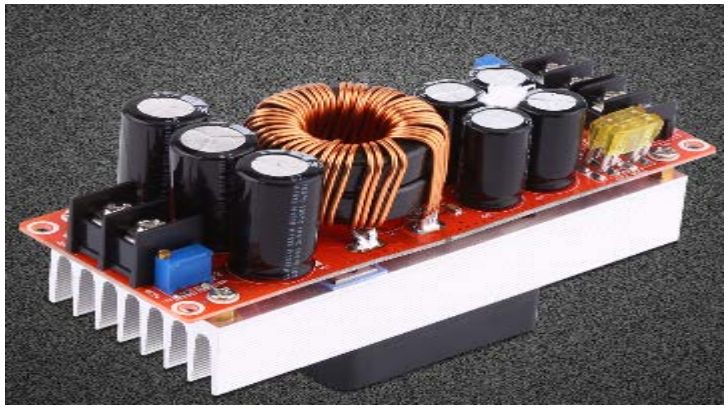
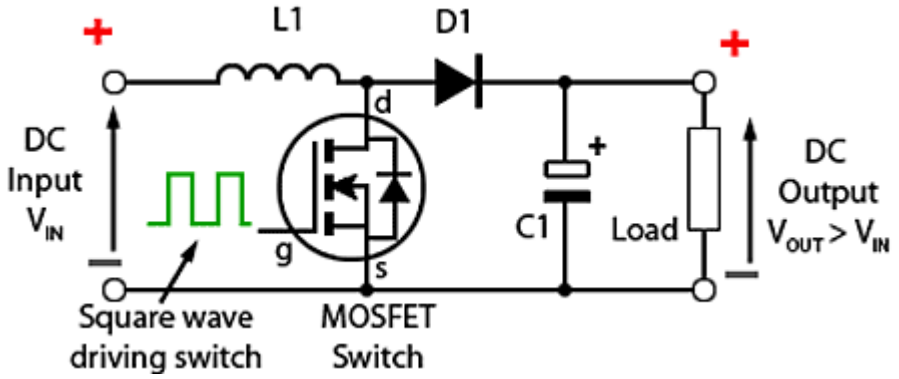
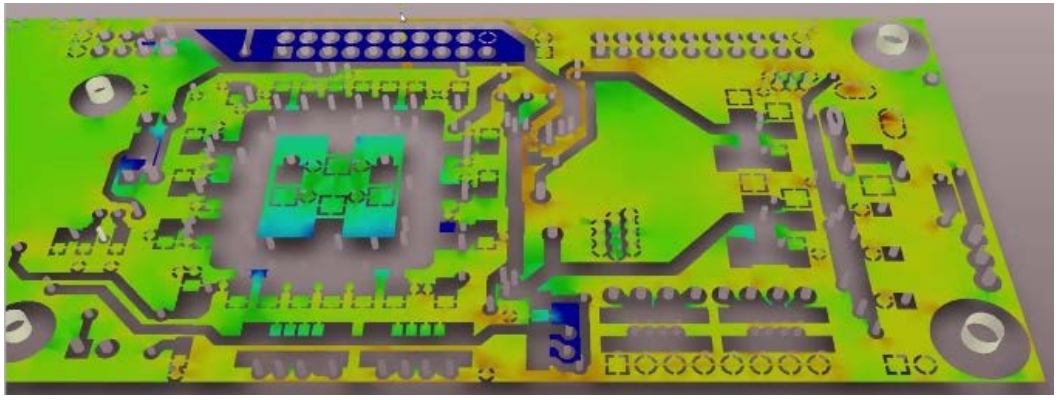
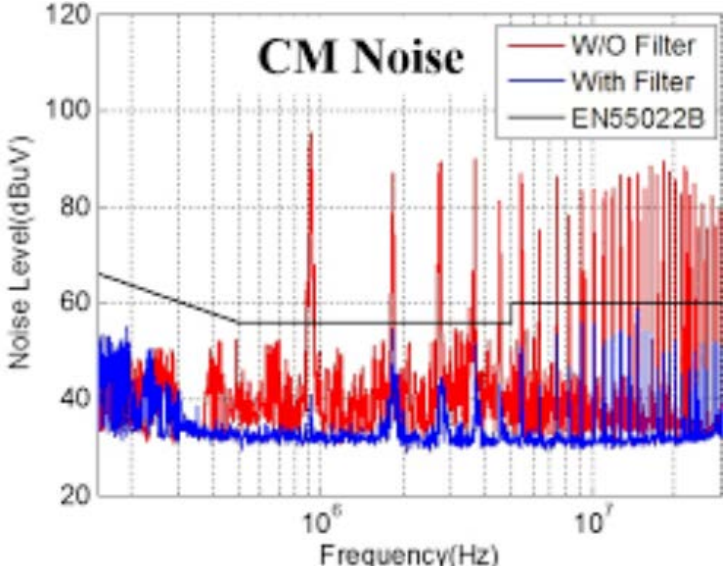




EMI model for 1kW 3 phase boost converter

Wai Keung Mo Univ. of Southern Denmark





Acknowledgments

This project was funded as part of the PET-PhD project, involving the companies Danfoss A/S, Lodam A/S and Force Technology (Delta).

We are grateful for their technical assistance in terms of inspiring discussions and equipment supports.

The project was funded by Region Syddanmark.

Background of PET-PhD subproject

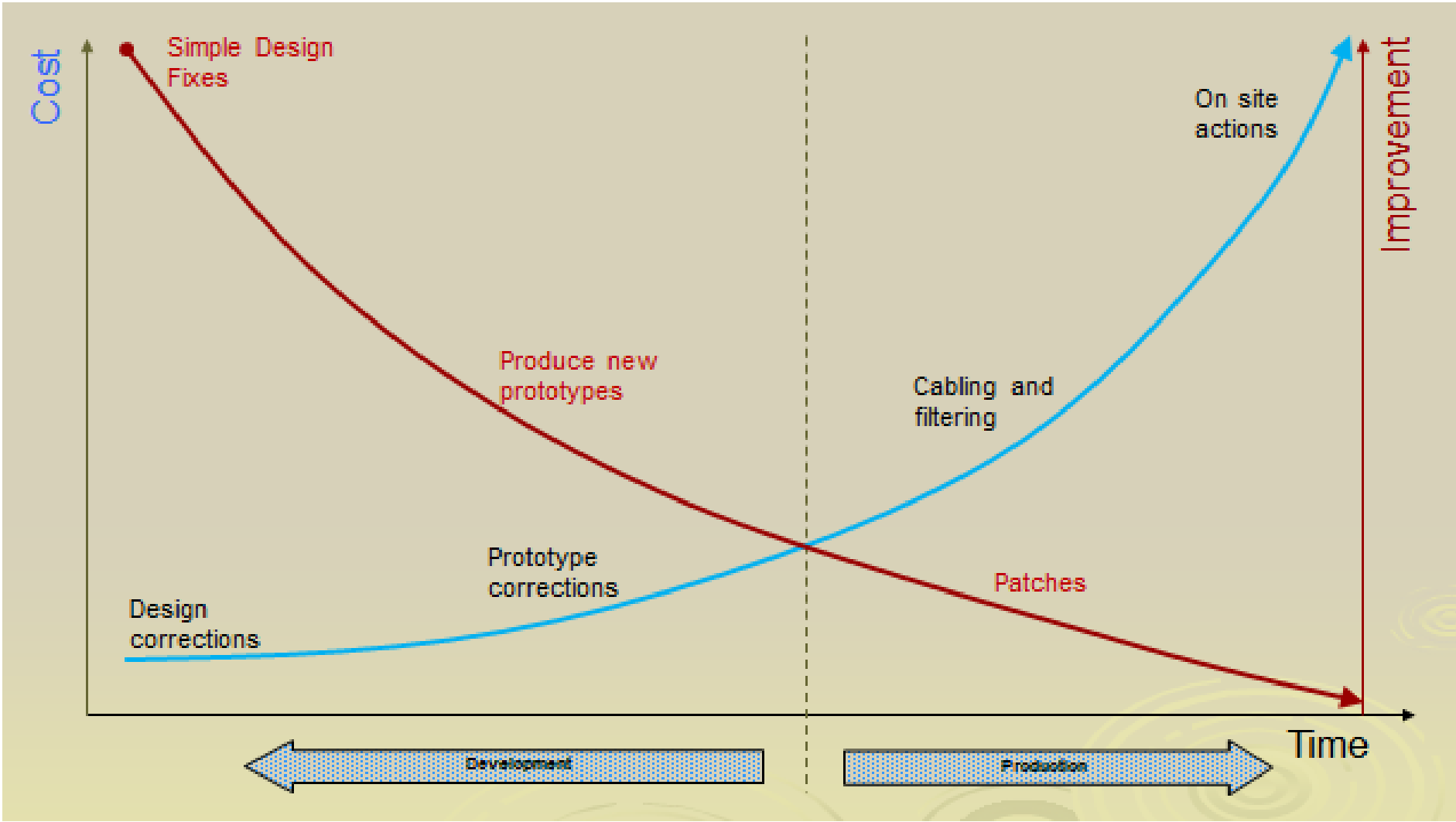
This project was started at the beginning of 2015 and finished at the end of 2017.

The major target of this subproject was to investigate a ”Model Based Design” approach to predict EMI noise emission and optimize RFI filter for DC to DC converter.

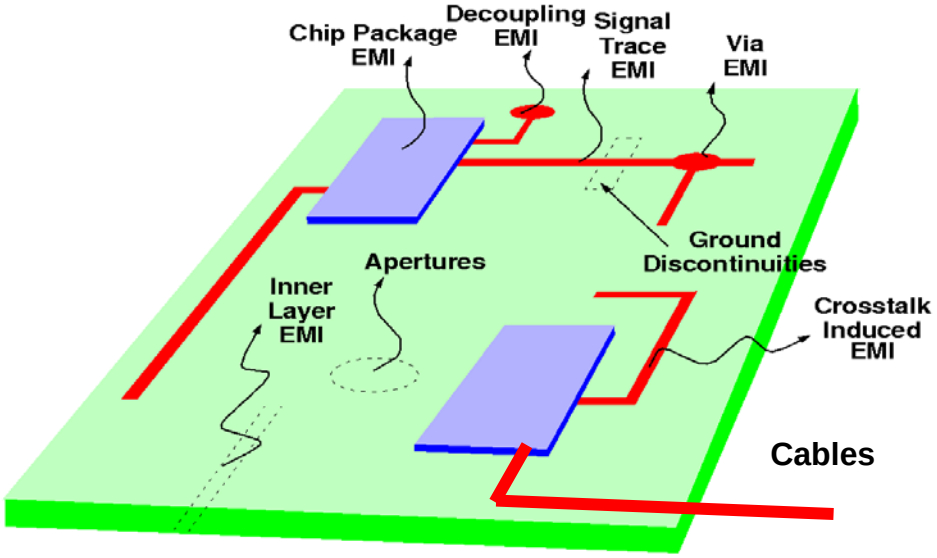
Agenda

- Introduction
- A preventive approach for EMI issue
- Methodology
- EMI model of 1kW 3 phase boost converter
- Experimental and simulation results
- Result comparison between EMI experiment and simulation
- Conclusions

EMC in design progress



A preventive approach for EMI problems

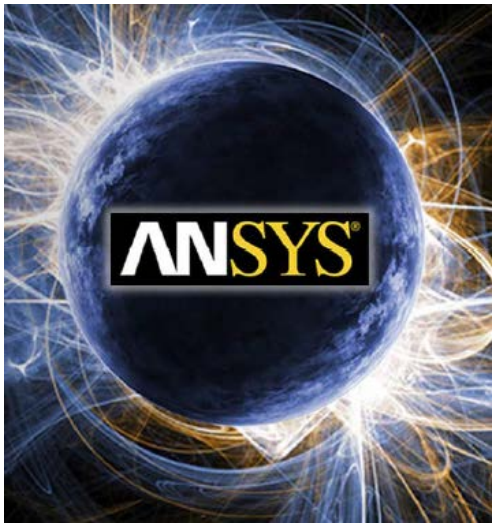


Methodology

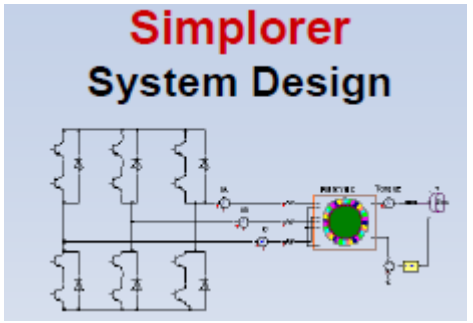
A preventive approach for EMI problems

24 hrs EMC consultant = Appropriate EMI simulation

ANSYS



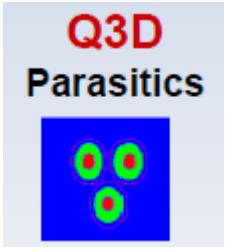
Complete conducted EMI simulation solution

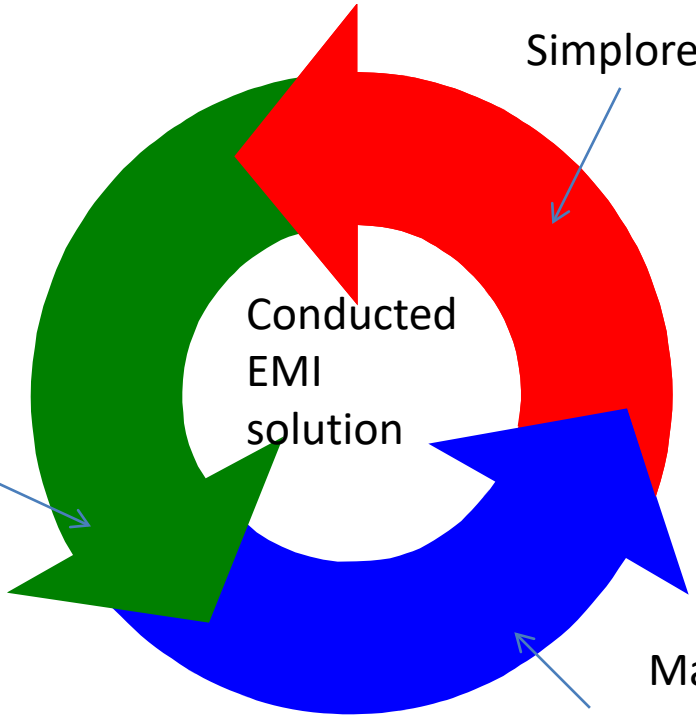


Simplorer

PCB layout modelling and simulating as well as converting into spice model

Q3D

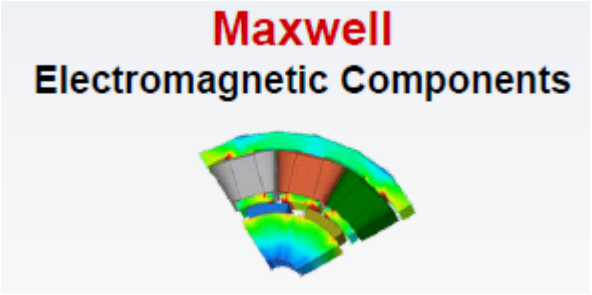




Electrical circuit modelling, simulating and analyzing virtual system prototype as well as co-simulation with Q3D and Maxwell

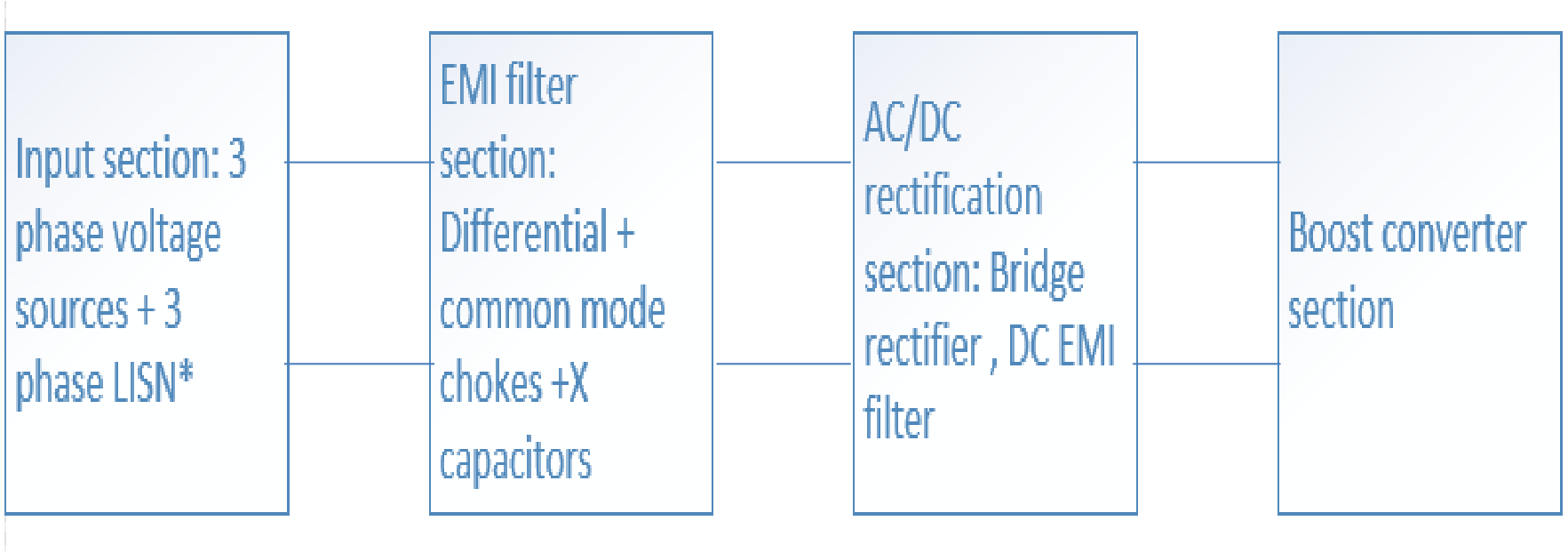
Maxwell

Modelling and Simulation non-linear magnetic devices under transient analysis



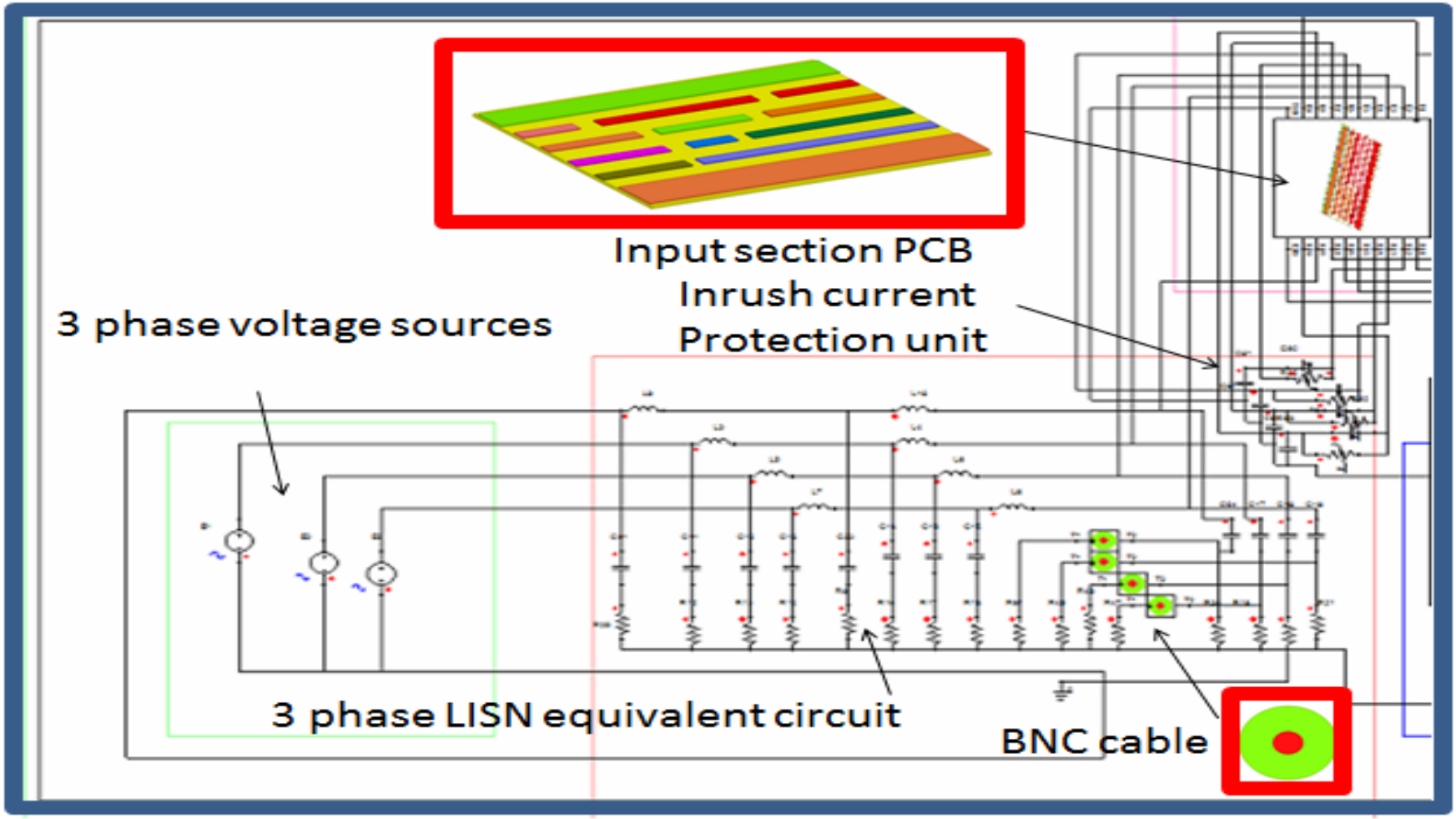
EMI model of 1kW 3 phase boost converter

EMI model of 1kW 3 phase boost converter

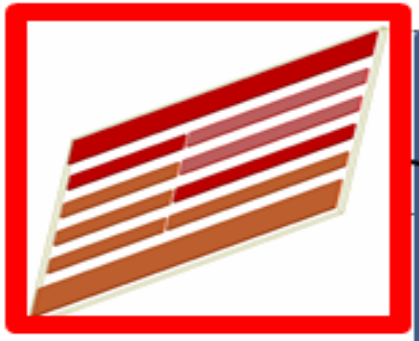


Note *: LISN= Line Impedance Stabilization Network

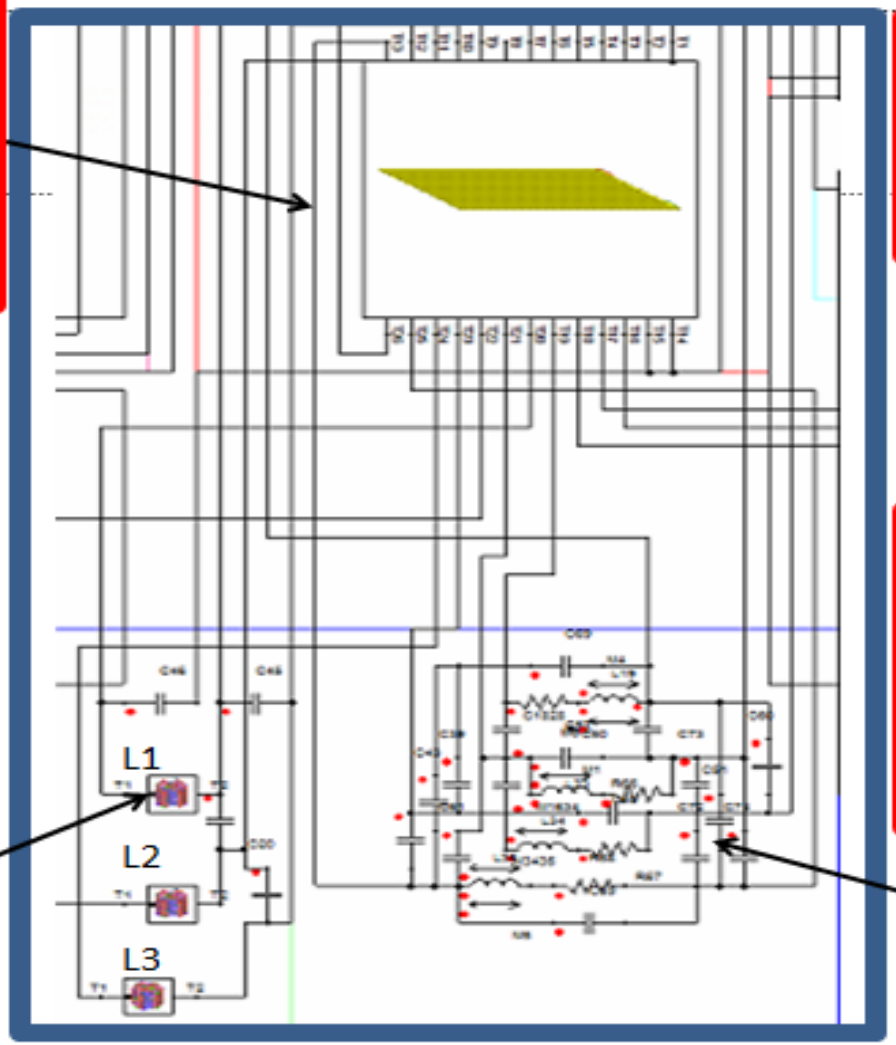
Input section

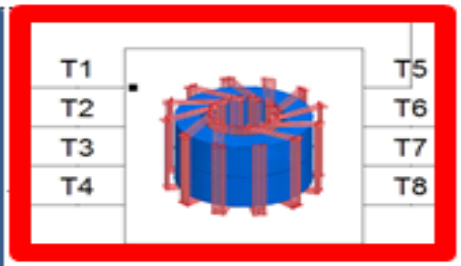


EMI filter section

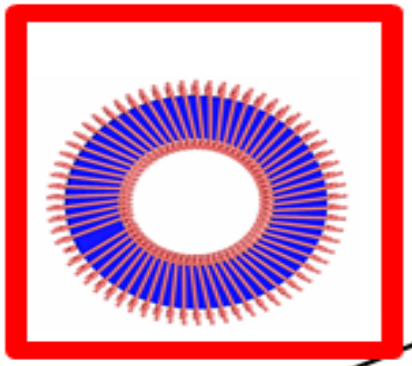


EMI filter PCB



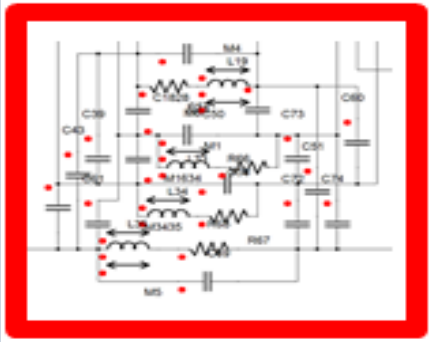


L4



Differential mode choke

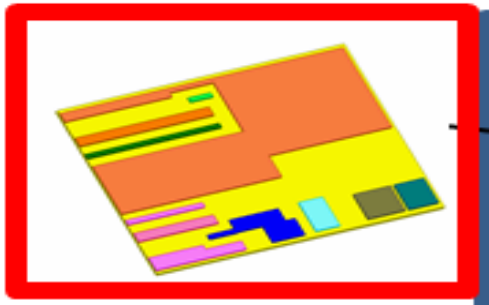
N=40, Core material=MS105125-2



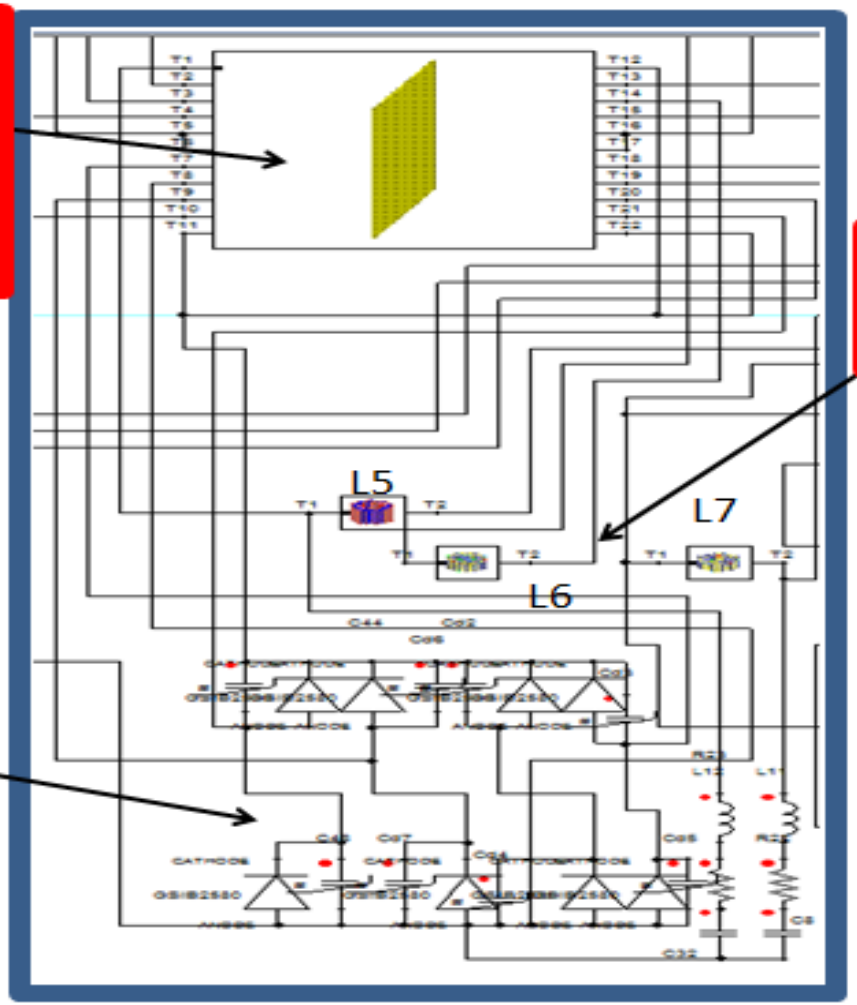
Common mode choke

N_{L1}=N_{L2}=N_{L3}=N_{N1}=14 , Core material=N87

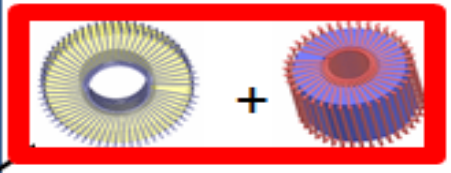
AC/DC rectification section



Rectification section PCB



Input bridge rectification unit

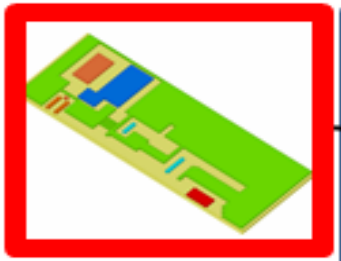


DC EMI filter

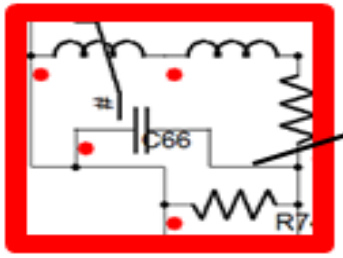
L5: (N=72, MS-1570125-2)

L6=L7:(N=75, T184-26)

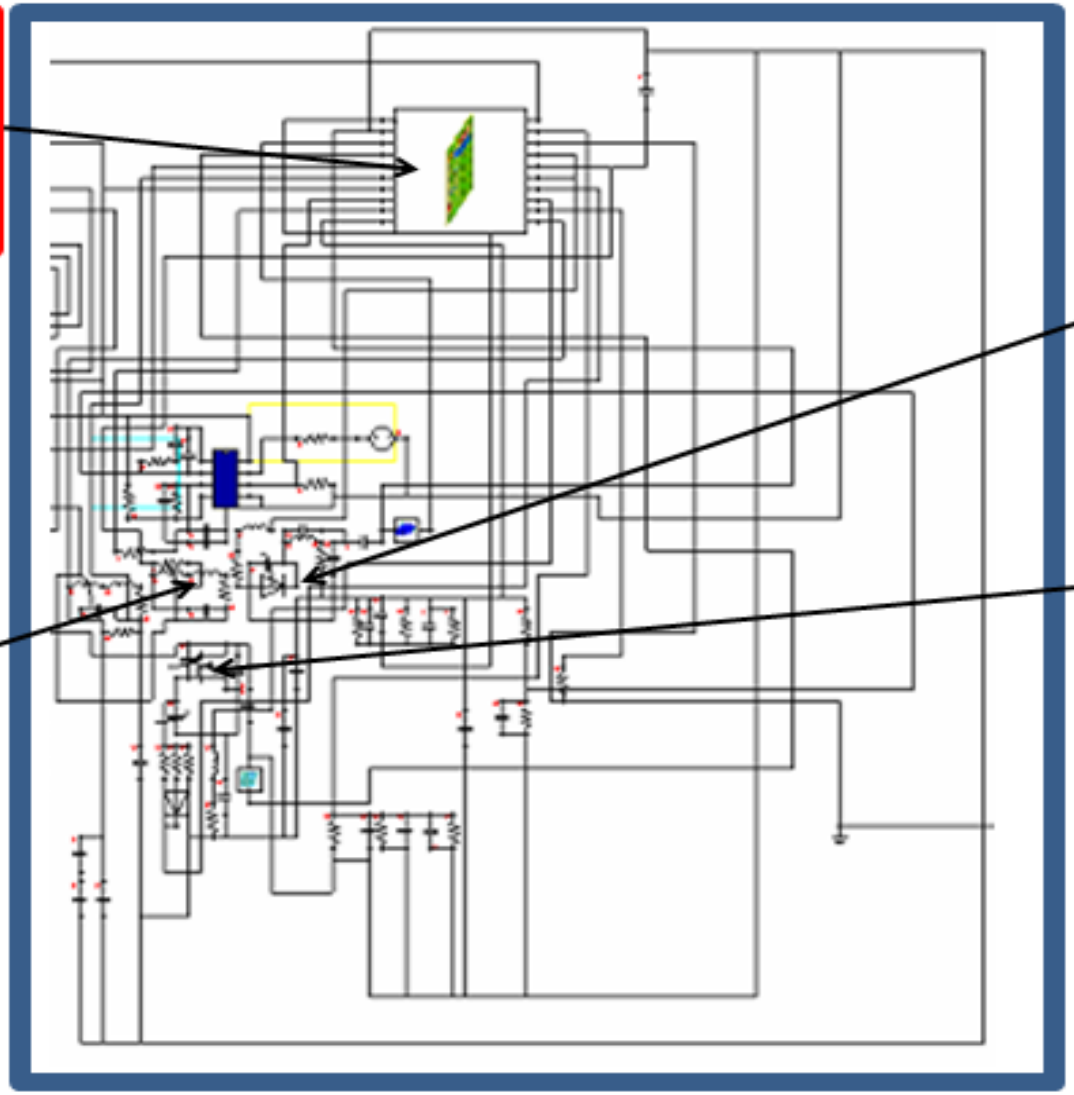
Boost converter section

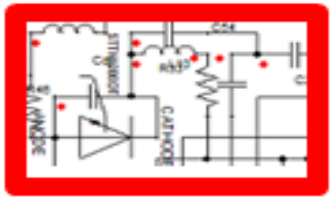


PCB for Boost Converter unit

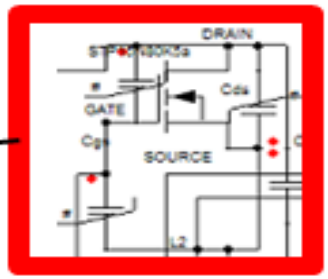


Boost inductor



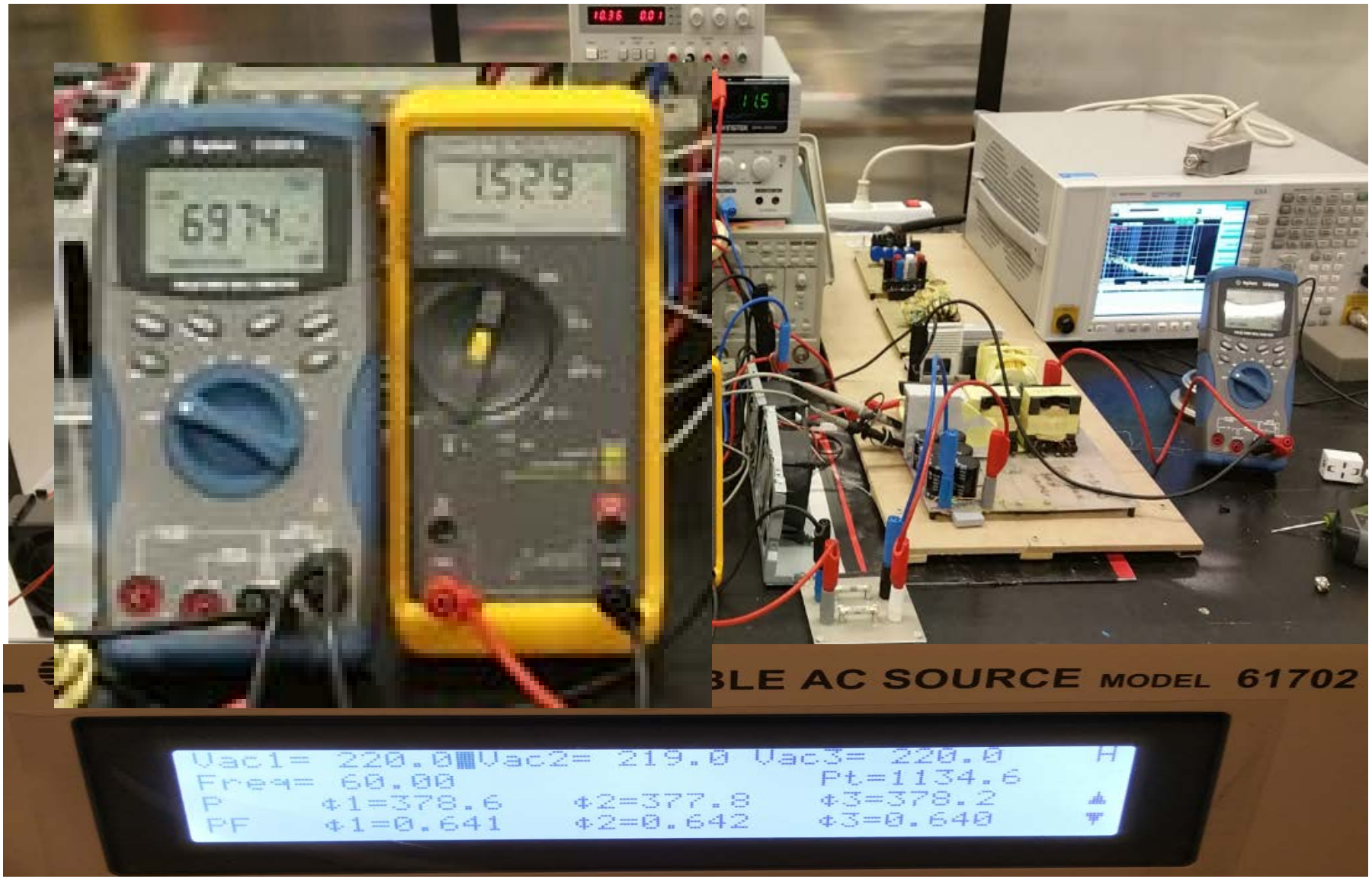


Boost diode



Power mosfet

Experimental and simulation results



1kW 3 Phase Boost converter

Electrical specifications:

1. Input voltage=3x220Vac (Line to neutral)
2. Output voltage =700V
3. Output current=1.5A
4. Operation frequency = 10kHz

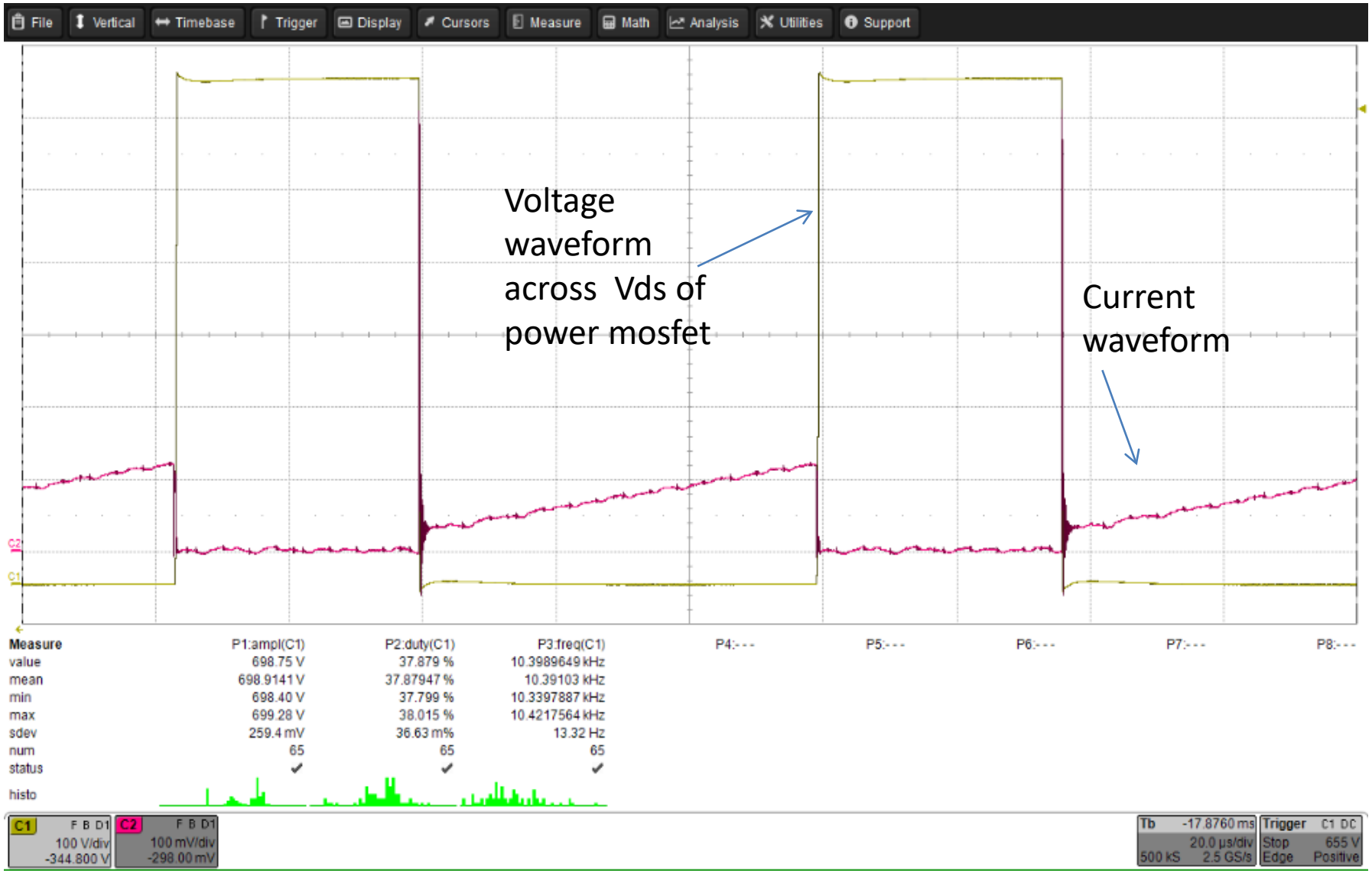
Key power components

- PowerMosfet: STP15N80k5
- Boost diode: STTH1008DTI
- PWM controller: UC3843B
- Boost inductor :

  2x PQ50/50 (N97), N=260

The overall efficiency = 94% @ 1KW

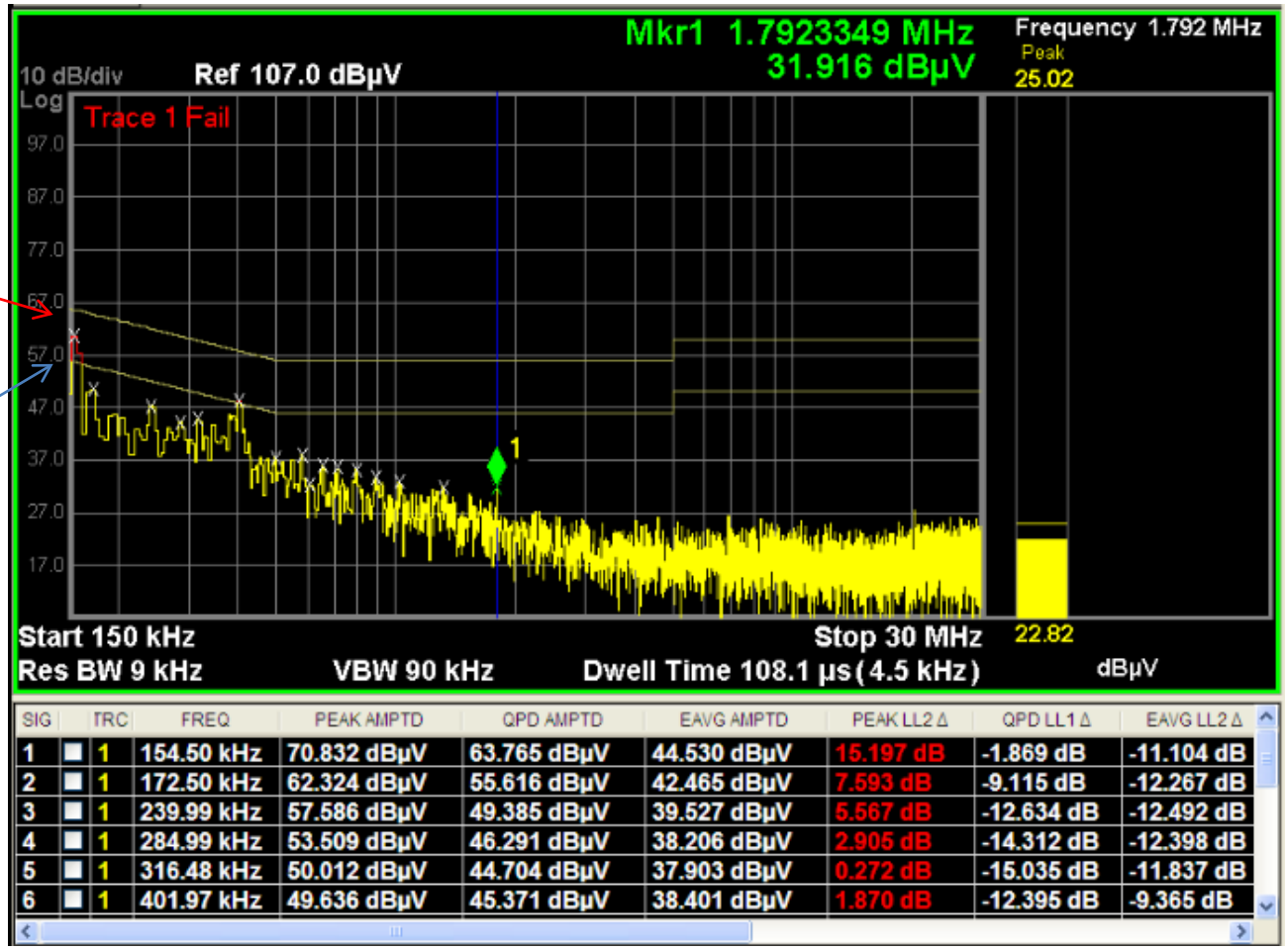
Experimental results
(transistor switching waveforms)



L1 line conducted emission level

EN55011 Class B(QP)

EN55011 Class B(AV)

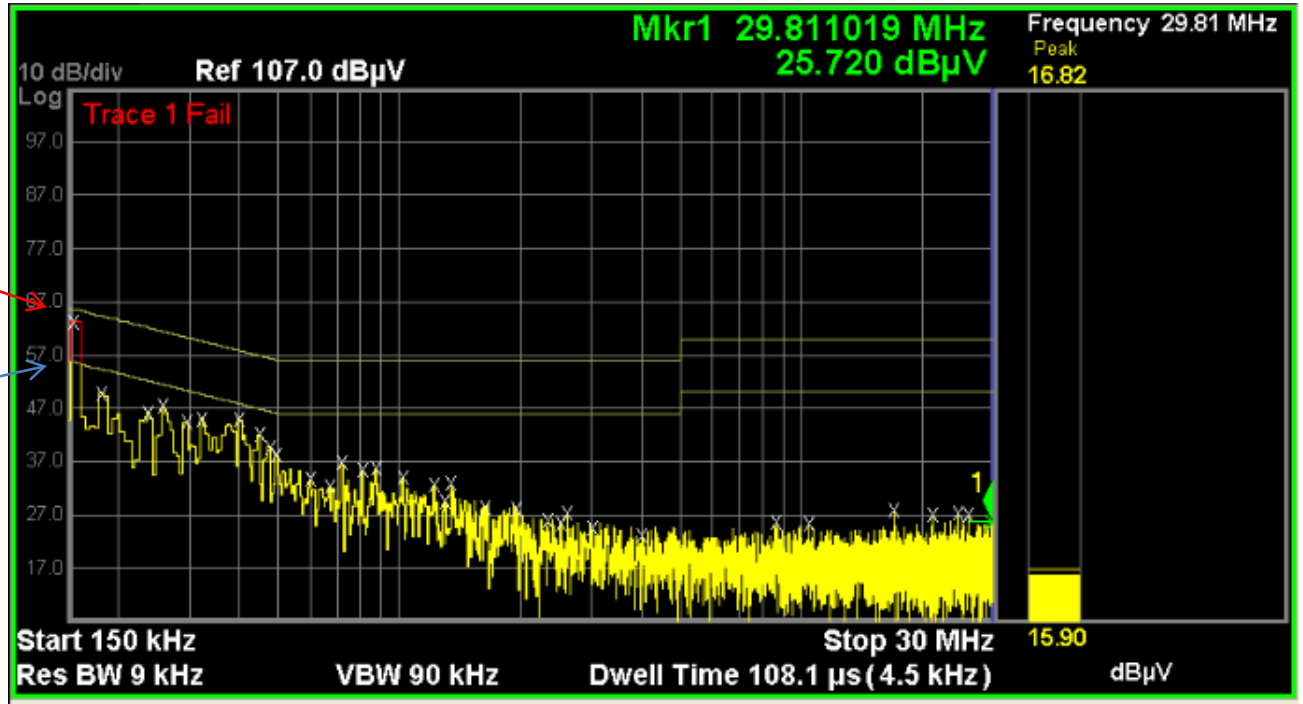


SIG	TRC	FREQ	PEAK AMPTD	QPD AMPTD	EAVG AMPTD	PEAK LL2 Δ	QPD LL1 Δ	EAVG LL2 Δ
1	1	154.50 kHz	70.832 dBµV	63.765 dBµV	44.530 dBµV	15.197 dB	-1.869 dB	-11.104 dB
2	1	172.50 kHz	62.324 dBµV	55.616 dBµV	42.465 dBµV	7.593 dB	-9.115 dB	-12.267 dB
3	1	239.99 kHz	57.586 dBµV	49.385 dBµV	39.527 dBµV	5.567 dB	-12.634 dB	-12.492 dB
4	1	284.99 kHz	53.509 dBµV	46.291 dBµV	38.206 dBµV	2.905 dB	-14.312 dB	-12.398 dB
5	1	316.48 kHz	50.012 dBµV	44.704 dBµV	37.903 dBµV	0.272 dB	-15.035 dB	-11.837 dB
6	1	401.97 kHz	49.636 dBµV	45.371 dBµV	38.401 dBµV	1.870 dB	-12.395 dB	-9.365 dB

L2 line conducted emission level

EN55011 Class B(QP)

EN55011 Class B(AV)

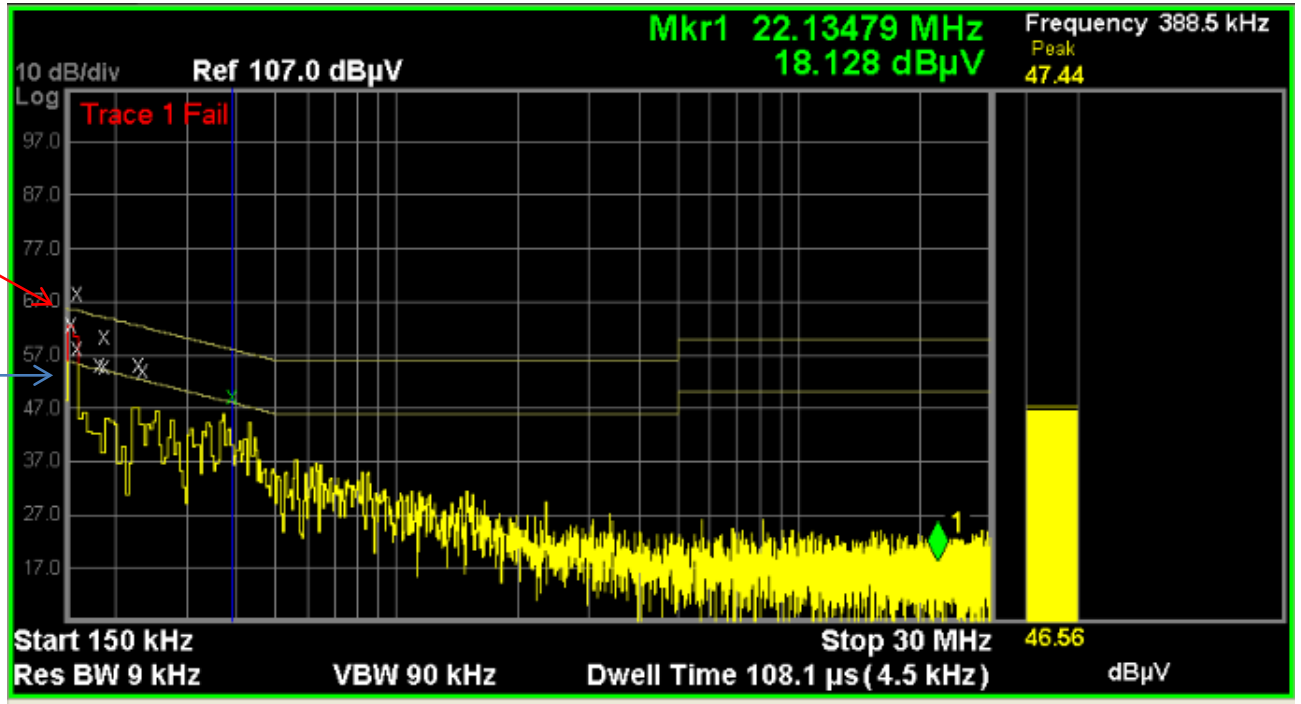


SIG	TRC	FREQ	PEAK AMPTD	QPD AMPTD	EAVG AMPTD	PEAK LL2 Δ	QPD LL1 Δ	EAVG LL2 Δ
1	1	154.50 kHz	64.881 dBµV	59.677 dBµV	44.178 dBµV	9.246 dB	-5.957 dB	-11.456 dB
2	1	181.50 kHz	61.965 dBµV	55.150 dBµV	42.094 dBµV	7.650 dB	-9.165 dB	-12.221 dB
3	1	235.49 kHz	55.260 dBµV	48.751 dBµV	39.698 dBµV	3.085 dB	-13.424 dB	-12.477 dB
4	1	257.99 kHz	53.531 dBµV	46.506 dBµV	38.839 dBµV	2.107 dB	-14.917 dB	-12.585 dB
5	1	293.99 kHz	49.503 dBµV	44.996 dBµV	38.122 dBµV	-0.845 dB	-15.351 dB	-12.225 dB
6	1	320.98 kHz	50.059 dBµV	44.876 dBµV	37.931 dBµV	0.436 dB	-14.748 dB	-11.692 dB

L3 line conducted emission level

EN55011 Class B(QP)

EN55011 Class B(AV)

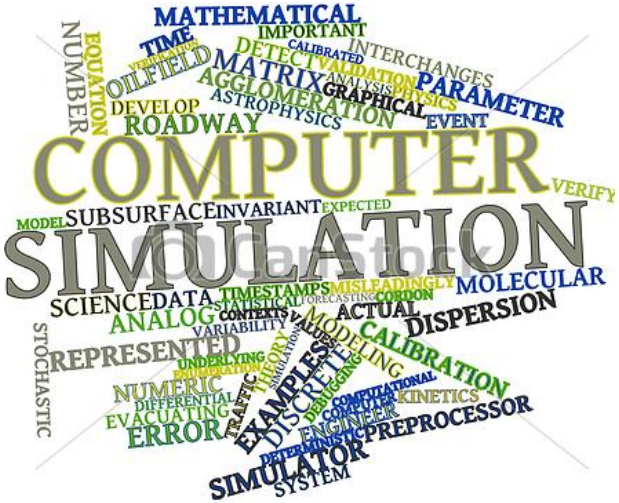


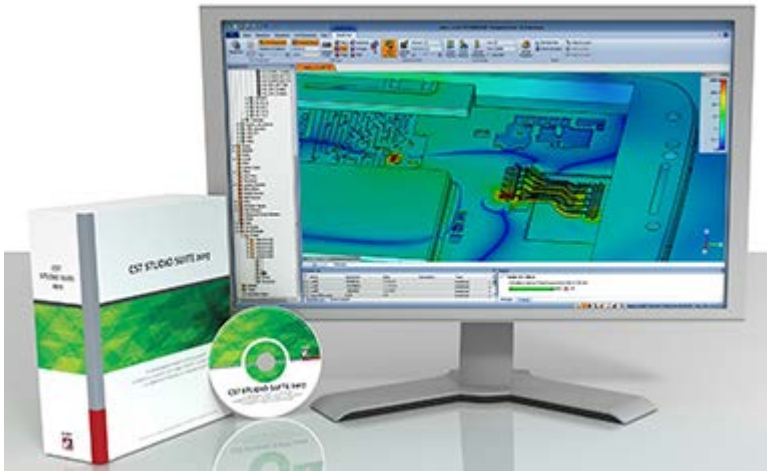
SIG	TRC	FREQ	PEAK AMPTD	QPD AMPTD	EAVG AMPTD	PEAK LL2 Δ	QPD LL1 Δ	EAVG LL2 Δ
1	1	154.50 kHz	70.991 dBµV	63.521 dBµV	43.684 dBµV	15.356 dB	-2.114 dB	-11.950 dB
2	1	159.00 kHz	69.343 dBµV	61.524 dBµV	42.875 dBµV	13.944 dB	-3.876 dB	-12.525 dB
3	1	159.00 kHz	69.611 dBµV	61.489 dBµV	42.791 dBµV	14.211 dB	-3.911 dB	-12.608 dB
4	1	181.50 kHz	63.183 dBµV	55.958 dBµV	41.061 dBµV	8.868 dB	-8.356 dB	-13.253 dB
5	1	186.00 kHz	62.597 dBµV	55.571 dBµV	40.801 dBµV	8.484 dB	-8.543 dB	-13.312 dB
6	1	186.00 kHz	62.077 dBµV	55.544 dBµV	40.844 dBµV	7.963 dB	-8.569 dB	-13.269 dB

Simulation results

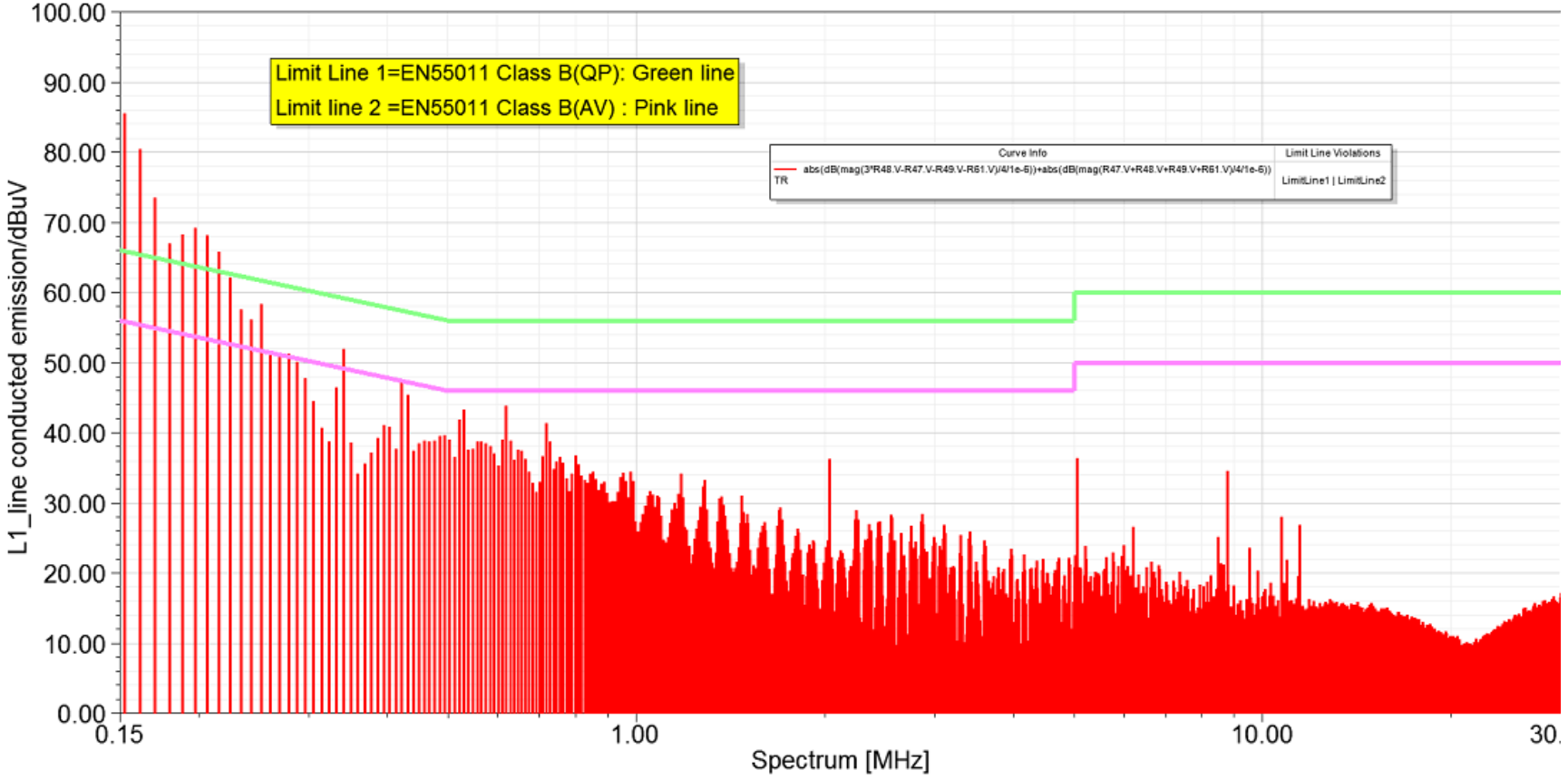
Simulation conditions:

- Vo=697V
- Io=1.529A
- Switching frequency=10kHz
- Vin=220Vrms (line to neutral)

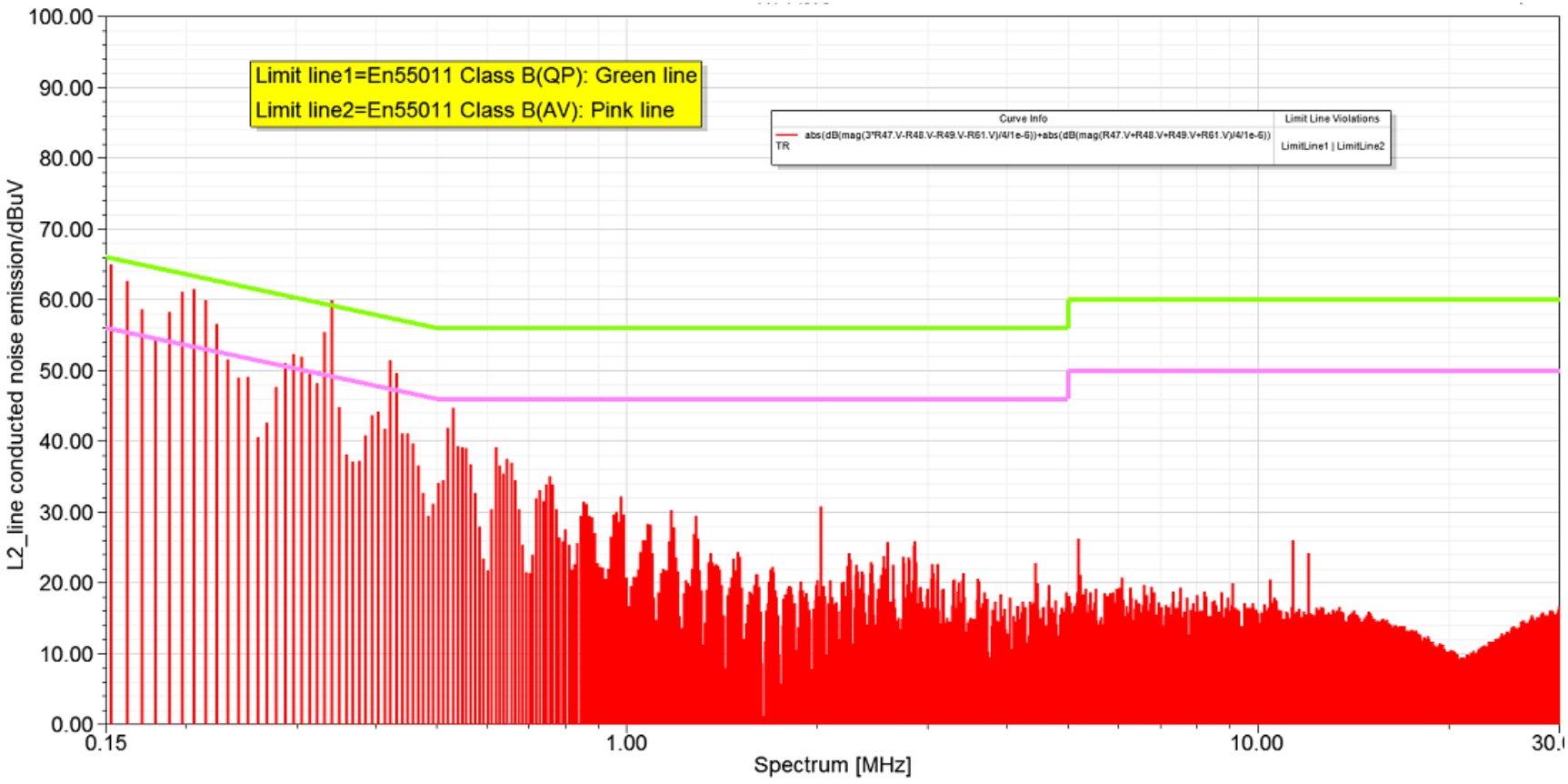




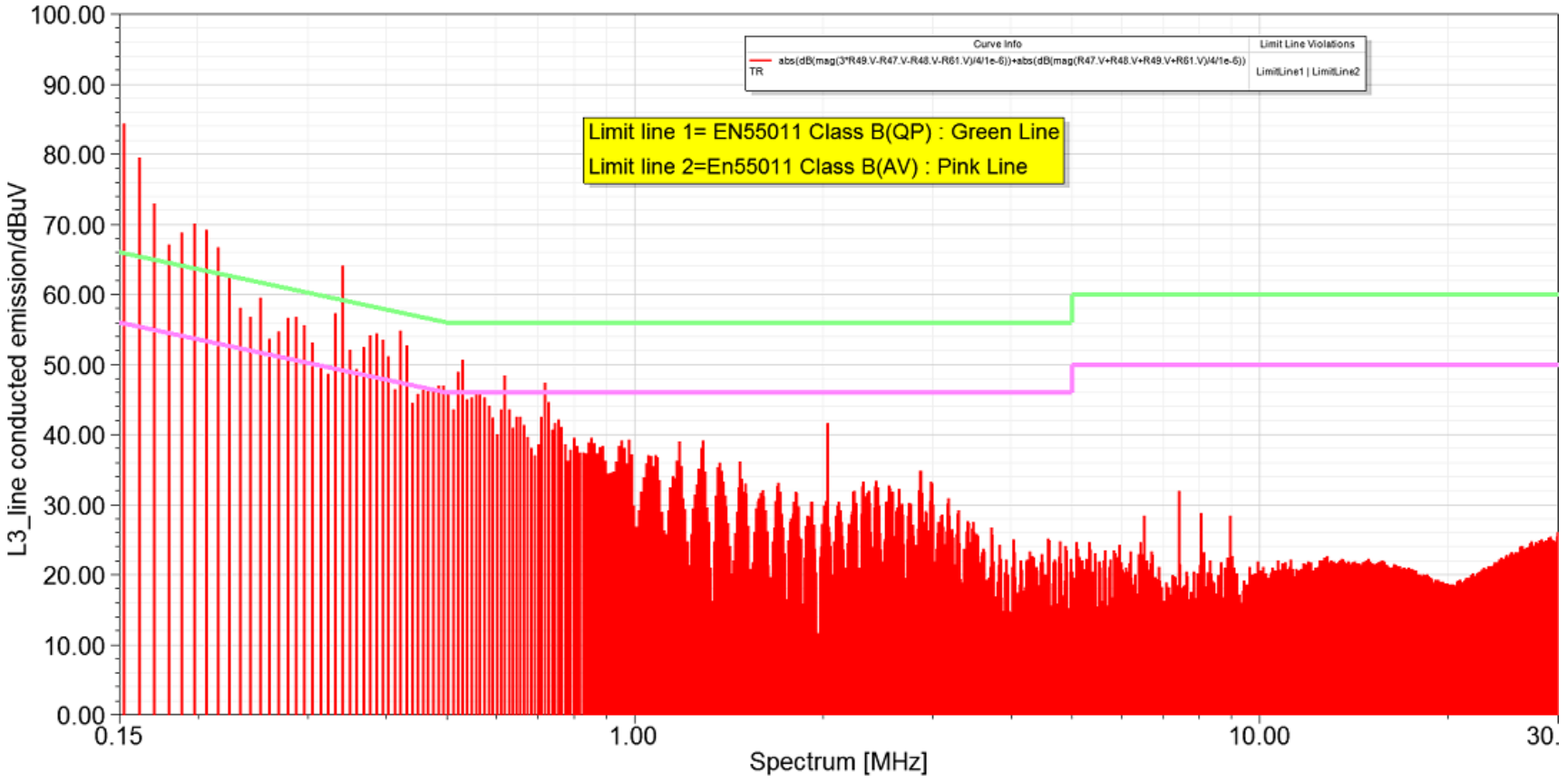
L1 line conducted noise level(Peak emission)



L2 line conducted noise level(Peak emission)



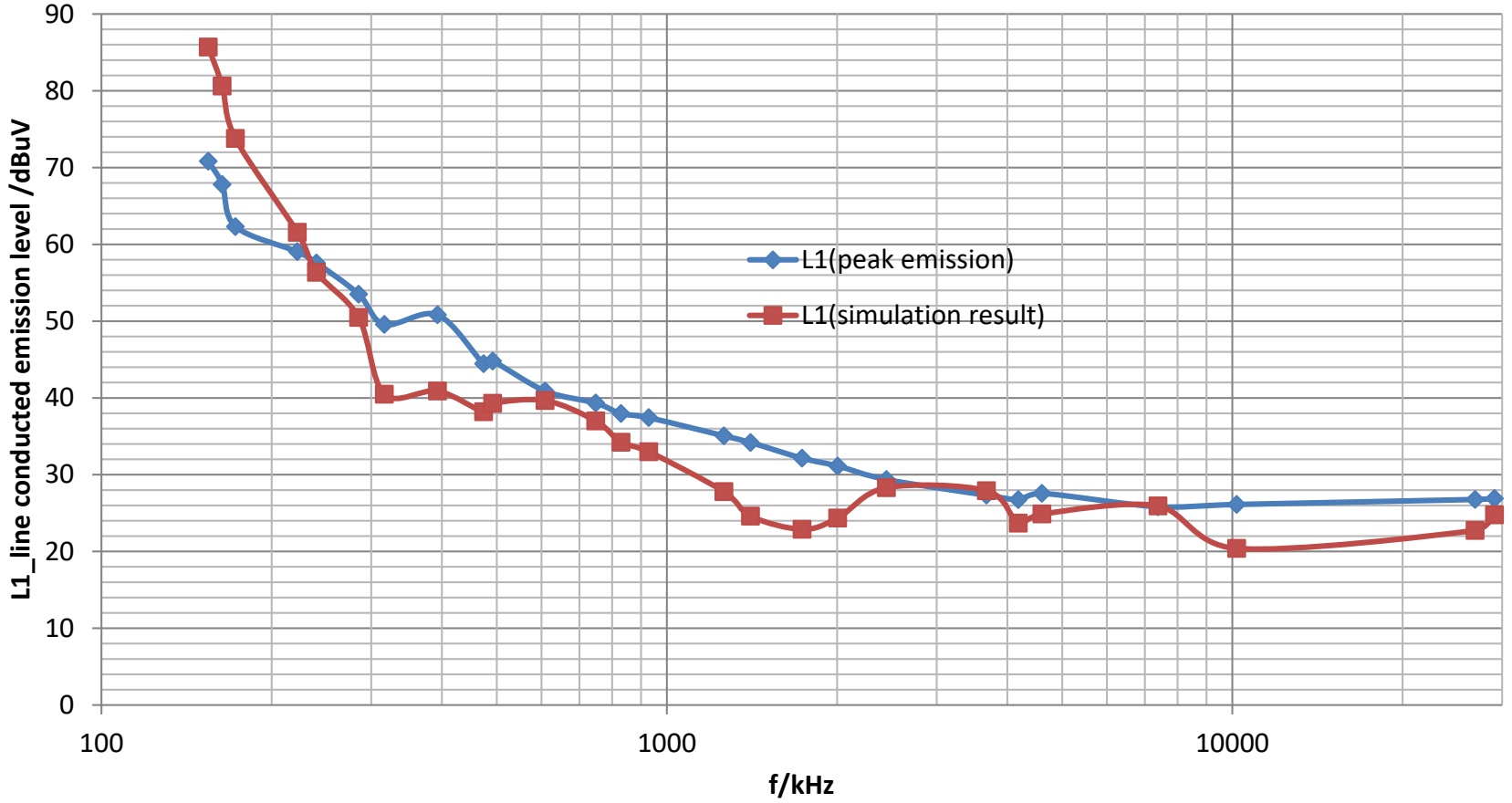
L3 line conducted noise level(Peak emission)



Result comparison between EMI experiment and simulation

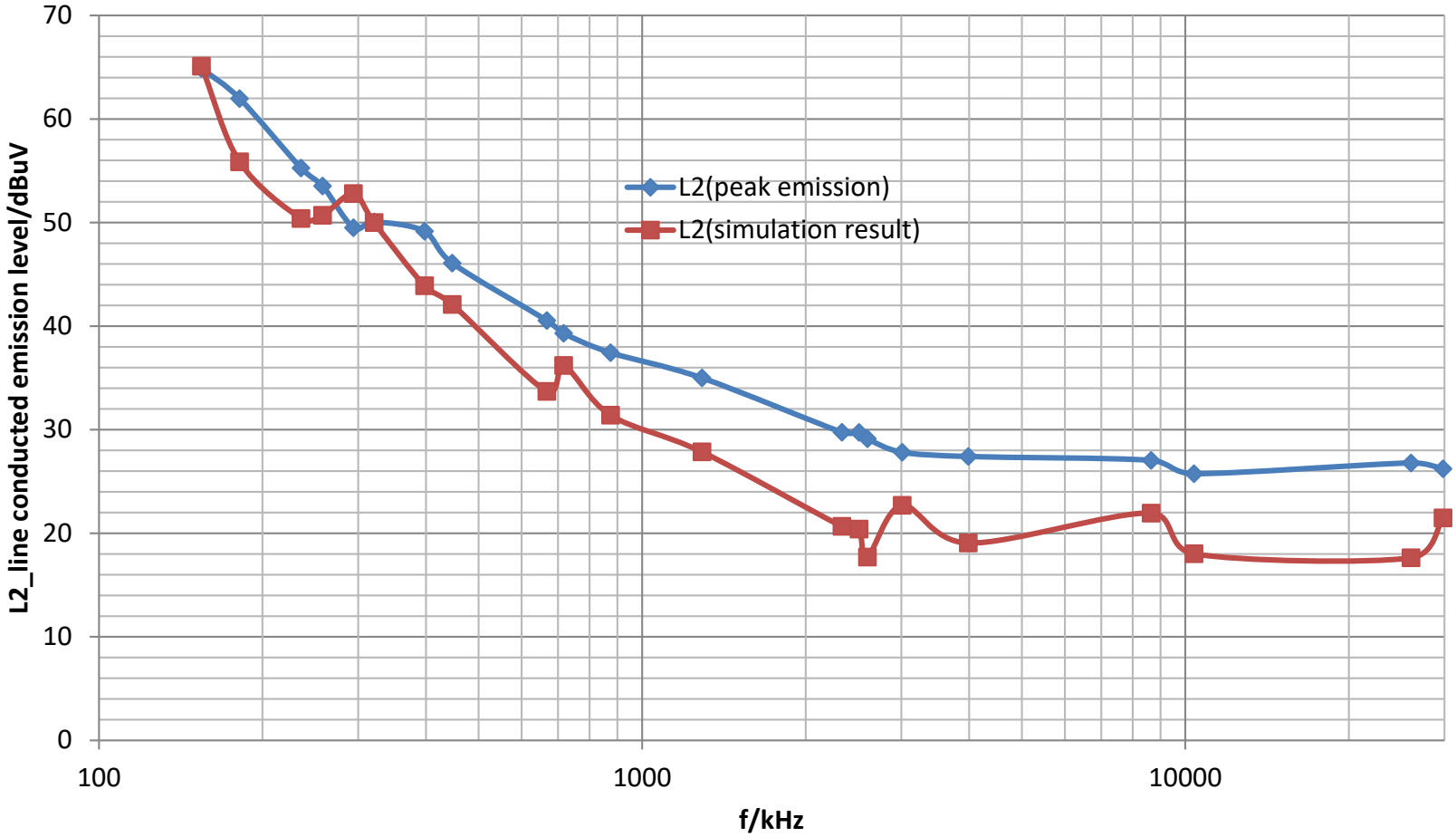
Result comparison between EMI measurement and simulation

(L1 conducted emission level, Vin=220Vac, Vo=697.4V,Io=1.529A)



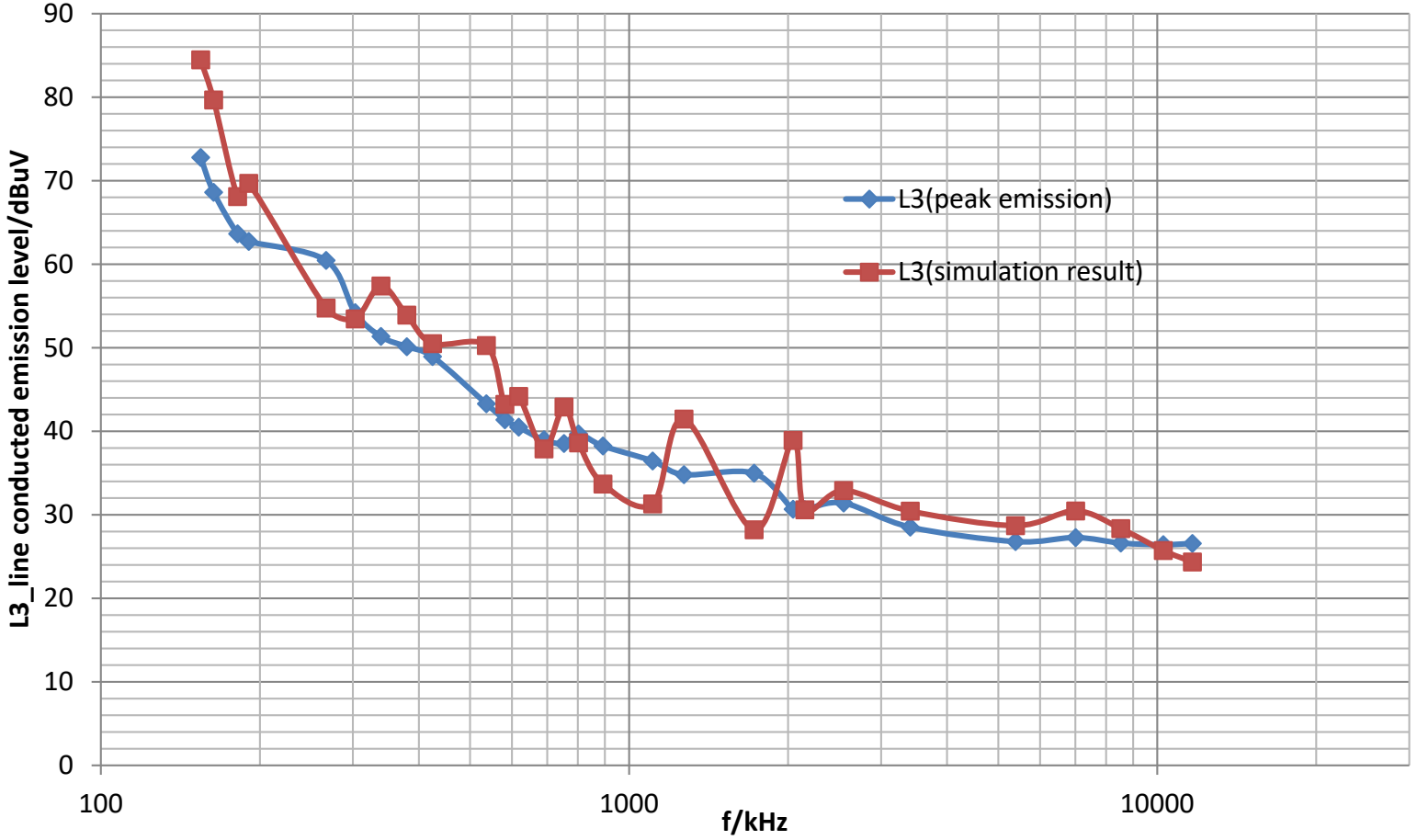
Result comparison between EMI measurement and simulation

(L2 conducted emission level, Vin=220Vac, Vo=697.4V,Io=1.529A)



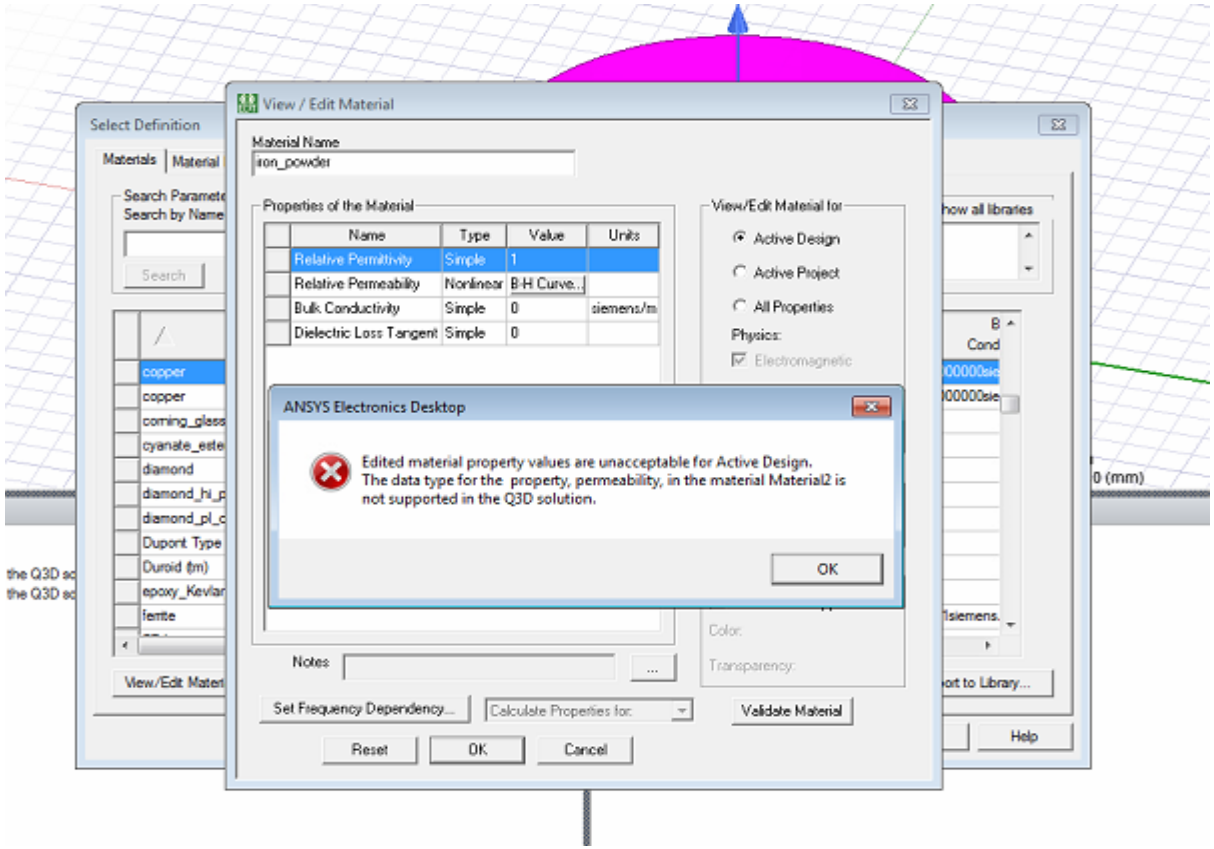
Result comparison between EMI measurement and simulation

(L3 conducted emission level, Vin=220Vac, Vo=697.4V,Io=1.529A)



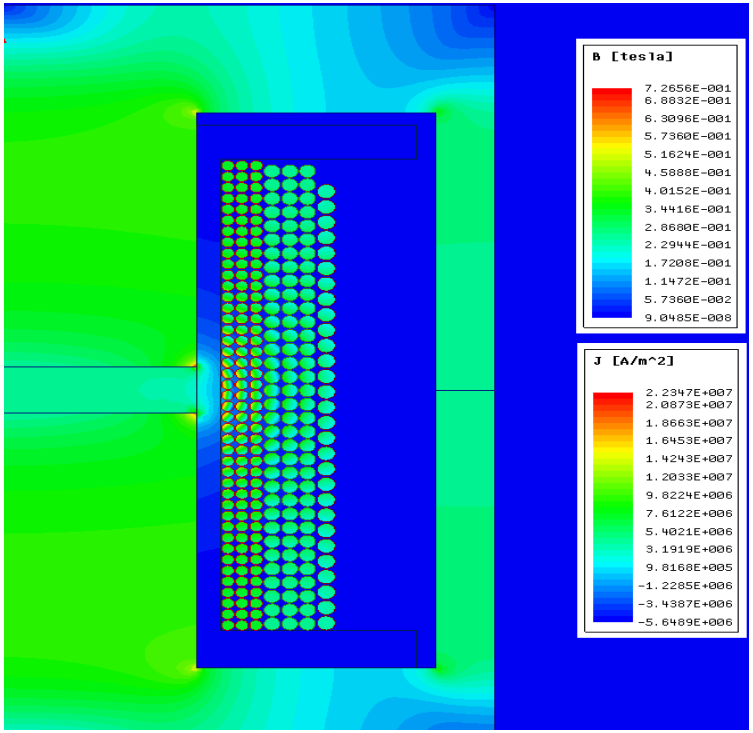
Project challenges I

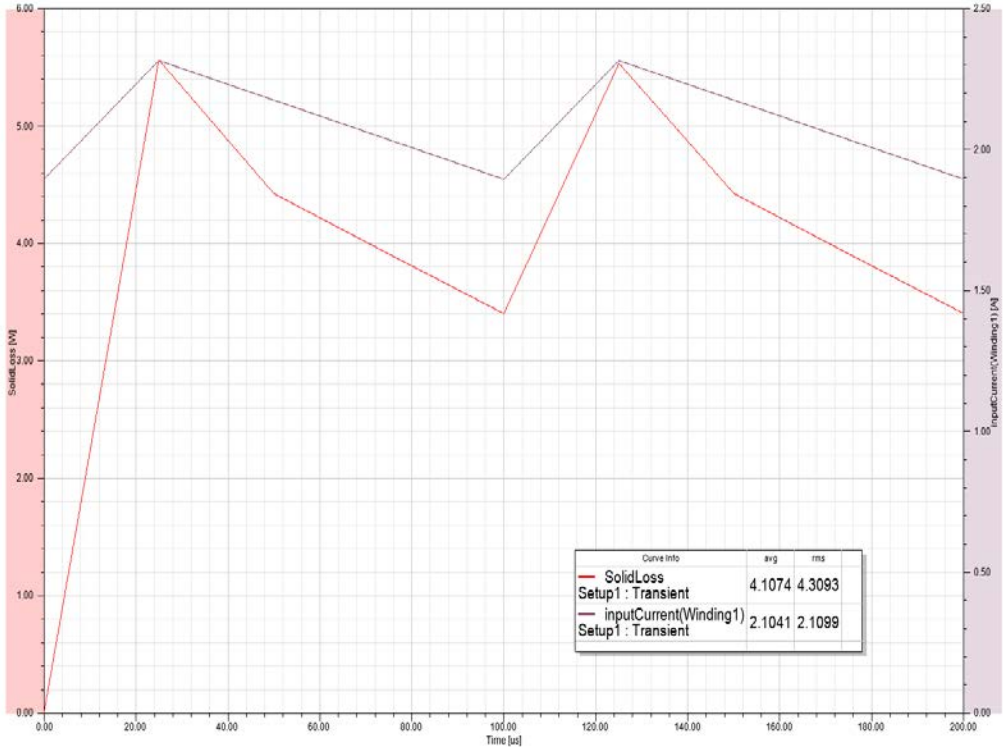
Q3D is the best tool to extract all the parasitic components (RLCG) with given physical dimensions such as PCB and BNC cables; however it is challenging to solve the non-linear magnetic device effectively. For example, the permeability of magnetic material should be a constant.



Project challenges II

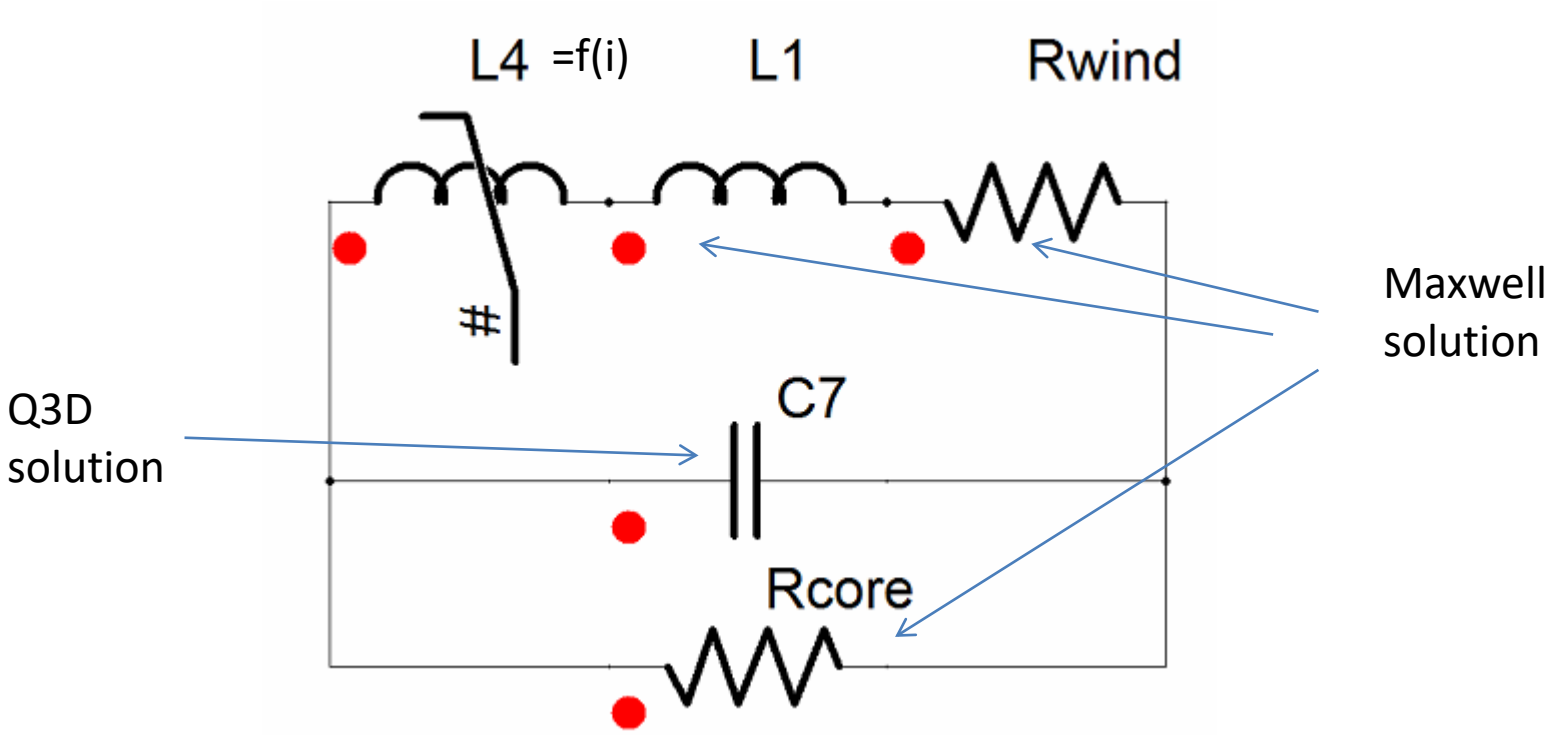
Maxwell is a good tool to solve all the non-linear magnetic devices such as filter inductor or transformer with self-definition of magnetic characteristics such as BH curves. Also, it can perform transient analysis with given current or voltage waveforms as excitation sources; however it consumes huge computer sources for co-simulation with simplorer (2 weeks on a 4 GHz PC….).





The solution of magnetic device model

The effective magnetic device model was done by the equivalent electrical circuit model with merging of all the solutions by Q3D and Maxwell. For example, all the parasitic capacitances were be done by Q3D and all the parasitic inductances and ac winding resistances were be done by Maxwell.



Conclusions

- Overall an EMI model of a 3 phase 1kW boost converter, with appropriate Q3D pcb models of independent sections and non-linear magnetic devices (maxwell models), can predict EMI emission well.
- Minor errors (≈ 12dB) can occur in low frequency ranges (150kHz ≤ f≤ 250kHz) due to ineffective magnetic model for magnetic devices.

Thank you for your attention!

Questions?

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