International IOR Rectifier

# Application Note AN- 1094

# High Frequency Common Mode Analysis of Drive Systems with IRAMS Power Modules

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This Application Note presents analytical evaluation of common mode electrical noise generated in inverters for three-phase motor drives equipped with IRAMS power modules, with the purpose of designing the common mode filter. The benefits in reducing the generated electrical noise when using IRAMS modules are highlighted.

# Introduction

One of the big advantages when using IRAMS modules for drive system design, is the reduction of EMI in the medium - high frequency portion of the spectra.
This comes from the fact IRAMS modules have their internal IMS substrate connected to the negative DC link voltage.
The Aluminum IMS acts as a shield for radiated interferences and, in the meanwhile, constitutes a path to negative DC link for currents generated by the parasitic capacitances between the switching IGBT dice and the IMS substrate, so reducing them to differential mode interference, which is usually filtered by the on board differential EMI filter.
So, when using IRAMS, the only remaining source of common mode interference in the inverter is the coupling between the inverter and the Earth potential due to motor's parasitic capacitances.
This last one is quite easy to model, and its analytical evaluation may provide good level of insight when designing the common mode filter – usually a long try and cut activity getting lot of engineering resources and time.
In this Application Note, a model of the inverter and the motor is presented, which is able to predict, with a decent level of confidence, the common mode EMI, with the purpose of designing the relevant filter.

# The Conducted EMI System Model

First of all, the complete model of the system has to be described, to identify the current paths which contribute to both differential and common mode EMI.
Fig. 1 show the basic connections of the motor and the inverter; common mode and differential mode EMI are measured across the LISN impedances, as required by International Regulations ( more specifically CISPR14 - EN55014 when talking about home appliance drive systems, which constitute the main application area for IRAMS power modules ).
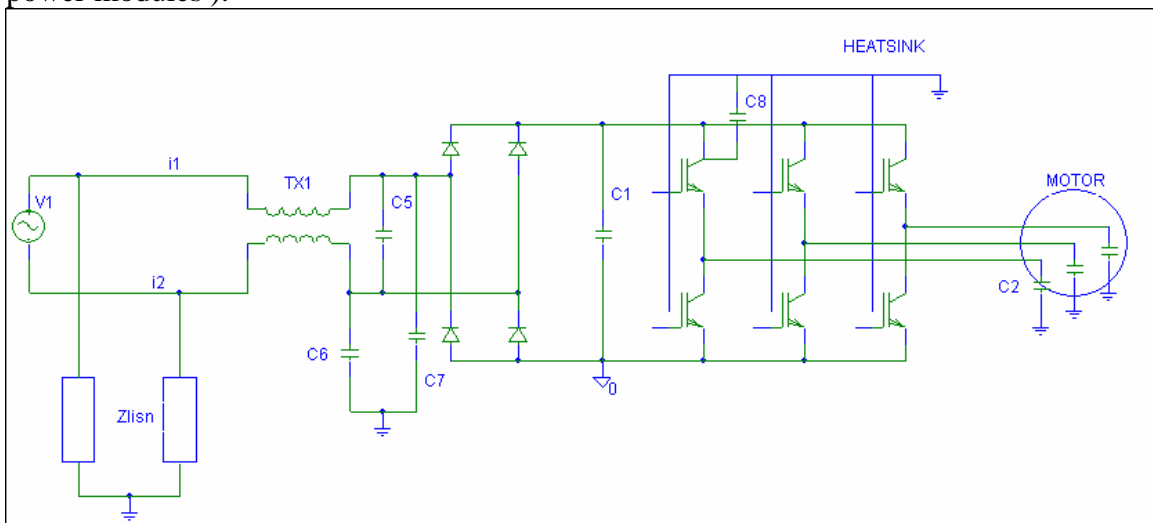


Fig.1

In Fig.1, the two main paths for interference currents are shown for a generic design using discrete devices: one is through the motor parasitic components ( here represented, for sake of simplification, by a single capacitors C2 ) , and the second one through the heatsink ( via C8 in case the heatsink is connected to earth ). This second path is actually short circuited to –DC link when IRAMS modules are used.

According to CISPR14, voltages across Zlisn are read by a RF receiver ; such voltages are v1 and v2. Limits for differential and common mode noise are set by considering:

DMNoise = v1-v2 = Zlisn * ( i1-i2 )

CMNoise = (v1+v2)/2 = Zlisn * ( i1+i2)/2

C5, together with leakage of TX1 represents the differential mode filter. C6 and C7, together with the magnetizing of TX1, works as common mode filter.

The system can be easily described provided the two main parasitic networks ( here simply represented by C2 and C8 ) can be modeled in the range of frequencies of interest ( usually between 150kHz and 10MHz – above 10MHz the effect of board's layout becomes dominant ). When using IRAMS, only the motor's parasitic network is needed. How to characterize it, is the topic of the next chapter.

# Motor's Parasitic Characterization

A off the shelf three phase induction motor is used as test vehicle. This motor's type is today used on both European and US horizontal axis washers.

The parasitic networks between the motor's connections and Earth is identified by applying a high dV/dt between each phase connection and the metallic structure of the motor. The instrument used was originally developed to test dV/dt capability of schottky diodes, and is able to apply dV/dt in excess of 20V/nsec. Such level of dV/dt is even higher than the one encountered in normal inverter applications , which is typically ranging from 1 to 10 V/nsec.

Current is then read by a series sense resistor; Fig.2 show the test set-up.

When choosing the sense resistor, special care has to be taken to choose one with very low parasitic inductance.

Oscilloscope current probes or precision pulse measurement transformers could also be used, of course, just paying attention to get an instrument whose bandwidth is large enough to read transients lasting for few tens nsec.

The connections between the motor and the instrument also contribute to alter the measurement , so a proper test procedure is necessary:

   a) first of all, the sense resistor is fully characterized by using a high frequency Network analyzer ( at least 10MHz full scale is needed );
   b) The motor's connections are closed in short circuit on a 1nF MKP capacitor ( or any other type of capacitor whose parasitic ESR and ESL may be neglected in the frequency region of interest ) resulting in a reference current which provides the value of the connection's equivalent parasitic network

c) The measure is repeated with the motor connected ( the 3 phases are tested separately ) and Pspice is used to adjust the parasitic elements until the simulated waveform exactly match the measured one.
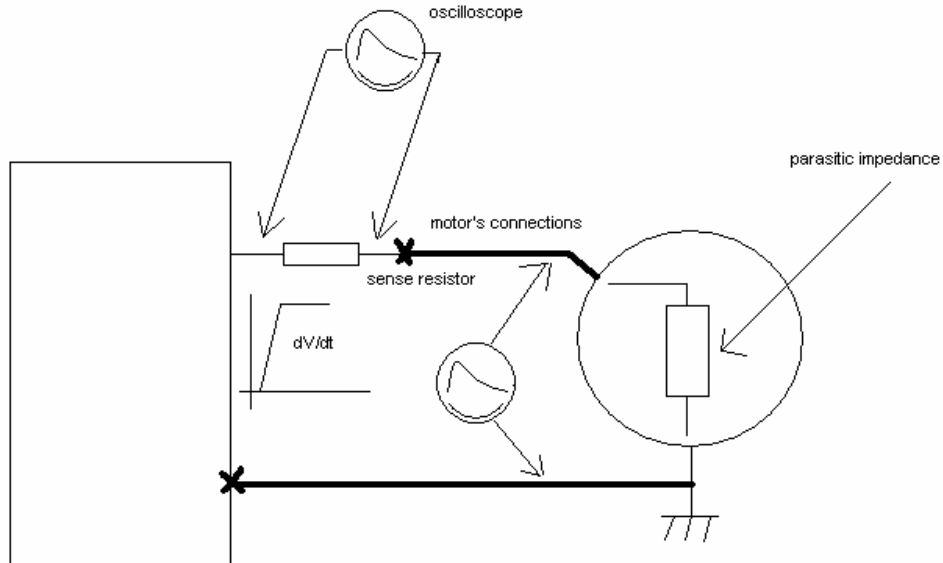


Fig.2

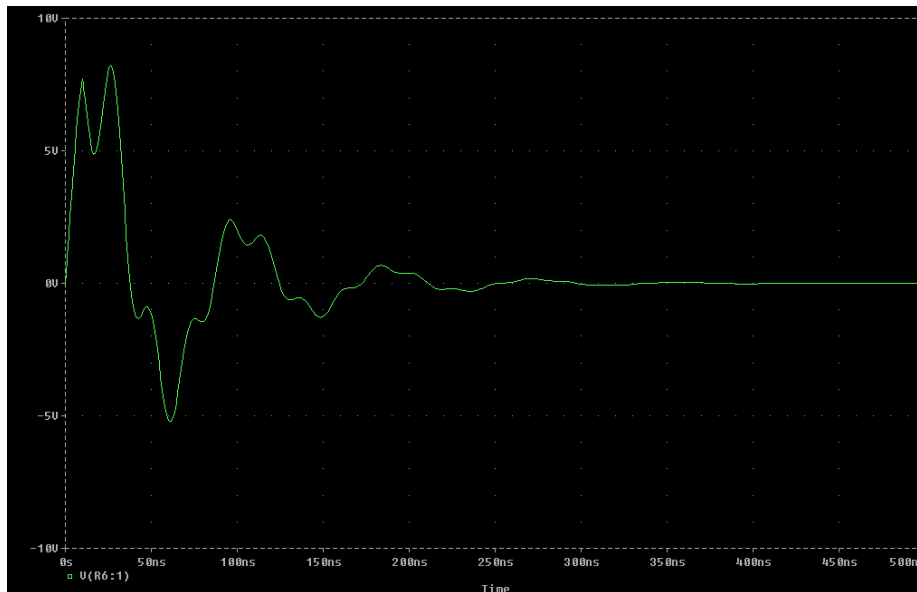Figures 3 and 4 show the simulated and measured currents with Vin = 160V and applying dV/dt = 16V/nsec.



Fig 3 : simulated current waveform

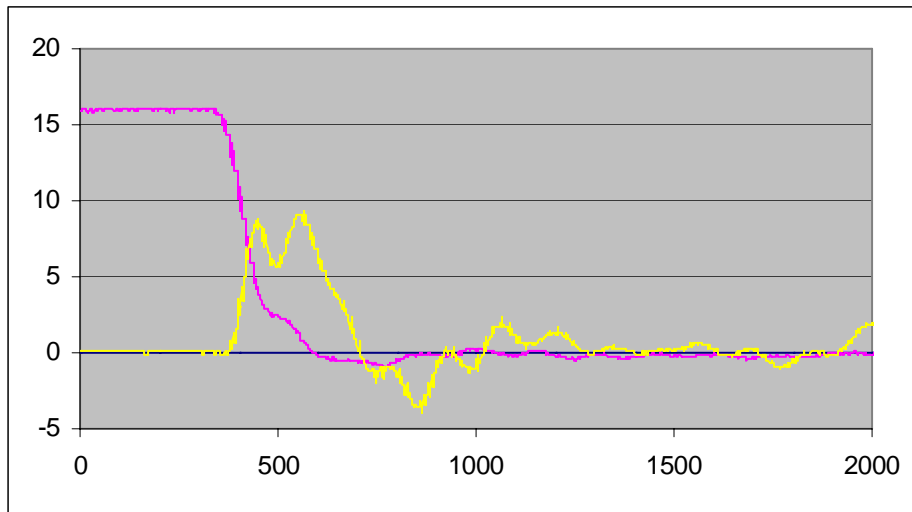Fig.4 : measured waveform ( 50V/div – 50nsec/div ) – voltage is inverted

The network producing the simulated waveforms is shown in Fig. 5.
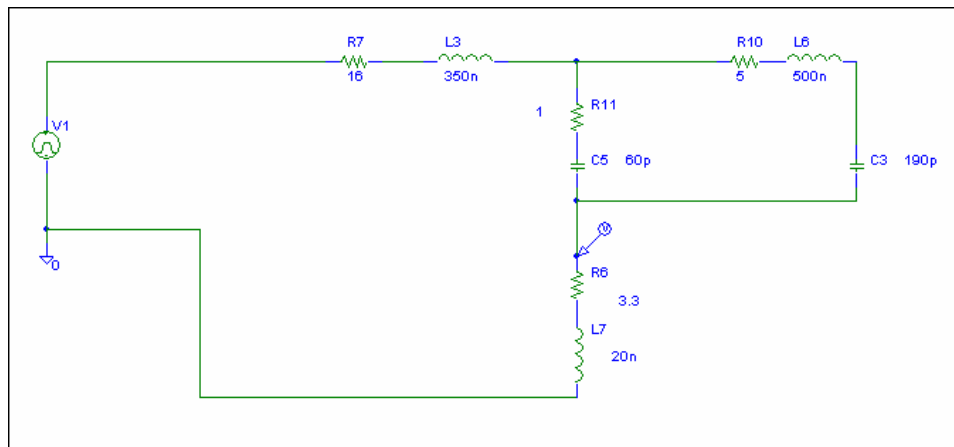


Fig.5 : motor parasitic network : phase to earth ( one phase )

L3 and part of R7 represent the motor's external connections.
R6 and L7 represent the sensing resistor.
So, the tested motor's phase to earth equivalent model may be actually seen as the combination of two parallel paths : R11 and C5, and R10,L6,C3 ; the two paths being in series with the motor's winding resistance ( 6 Ohm at 50Hz increasing with frequency to 14 Ohm due to skin effect ).
Testing the three phases show very similar results, so the network of Fig 5 may be considered as representative for all the three phases.

# Development of the Simulation Model

With the motor's model, it is possible now to set up a complete simulation model, as represented in Fig.6. Please note Fig. 6 is just a simplified drawing ; the actual simulation program is developed on Mathcad 11 platform, and is a analytical description of what shown in Fig. 6.

The simulation needs to be performed with all the 3 phases, and considering the phase shift between the dV/dt transients due to the specific modulation scheme used. In our simulation, both sine and space vector have be considered.

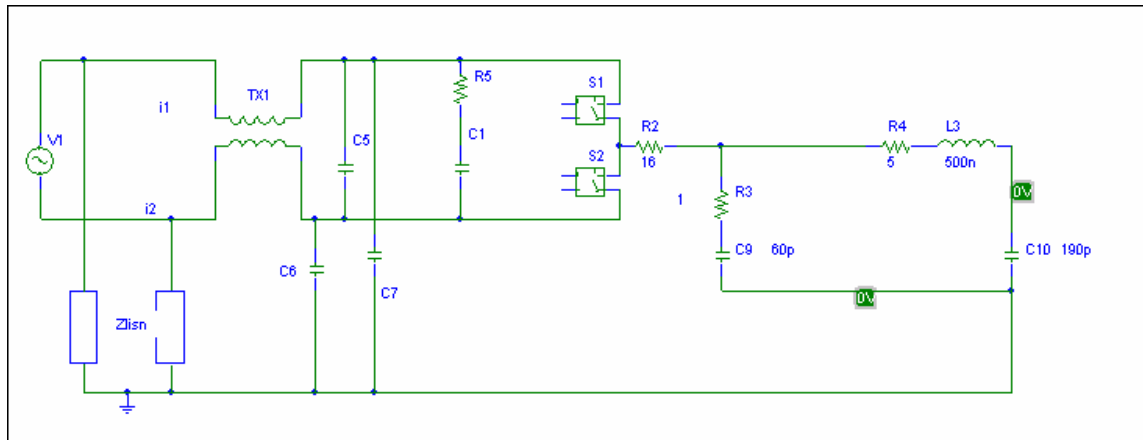DV/dt is changed by "analytically" changing the commutation speed of S1 and S2.



Fig.6

It is worth noting that, due to several reasons,  i1 and i2 do not have equal magnitude for their positive and negative peaks, the relative magnitude being dependent on the sign of the motor's phase current. But, as a first order of approximation, we will consider i1 = i2 = icm peaks symmetrical , hence equal dV/dt values at turn-on and turn-off.

Simulation flow is as follows:

a) three sinusoidal waveforms ( with or without third harmonic injection to simulate space vector modulation ) are generated, 120° phase shifted between each other

b) each sinusoidal period is divided in pwm periods; sampling time is critical because rise and fall times need to be well described – a simulation sampling time of 10nsec maximum is suggested

c) the three pwm waveform are then FFT transformed to obtain their frequency domain description

d) the sum of the three FFT functions is applied to the network in fig. 6 ( which includes the CM filter ) to achieve the voltage spectra across the two LISN networks

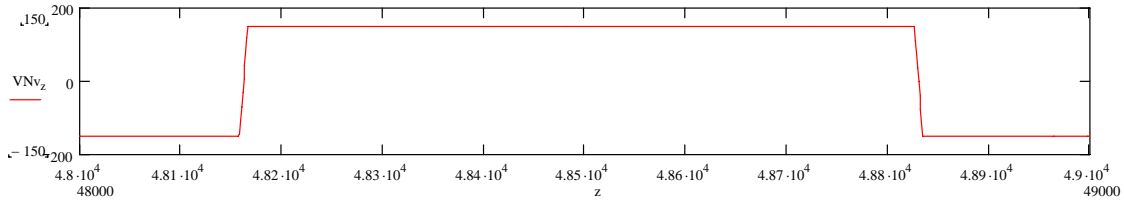e) the common mode noise is derived as : vn = ( v1+v2) / 2

Fig.7 : detail of pwm waveform phase v

At this point, a much more simple try and cut activity is needed, just changing values of the CM filter network, run simulation for each combination of values and for different dV/dt, until the CM spectra falls below the mask required by the Regulation.

# Simulation Results

Just as an example, some simulation results are reported here.
The drive system is modeled with switching frequency kept at 20kHz, modulation frequency at 200 Hz, modulation index = 90%, DC link voltage at 300V, PF = 0.8.
Fig. 8 shows the resultant common mode spectrum without any CM filter and with dV/dt at 600V/usec ( so 0.5usec rise time and fall time )
Fig. 9 shows, for comparison, the spectrum achieved with dV/dt = 300V/usec ( 1 usec rise and fall time ). Vertical scale is dBuV in all cases.
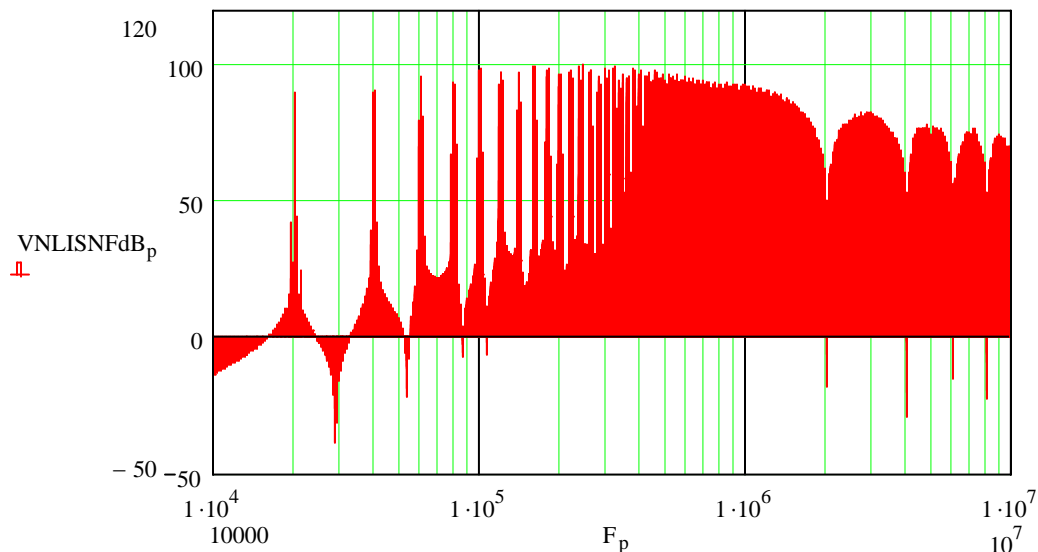


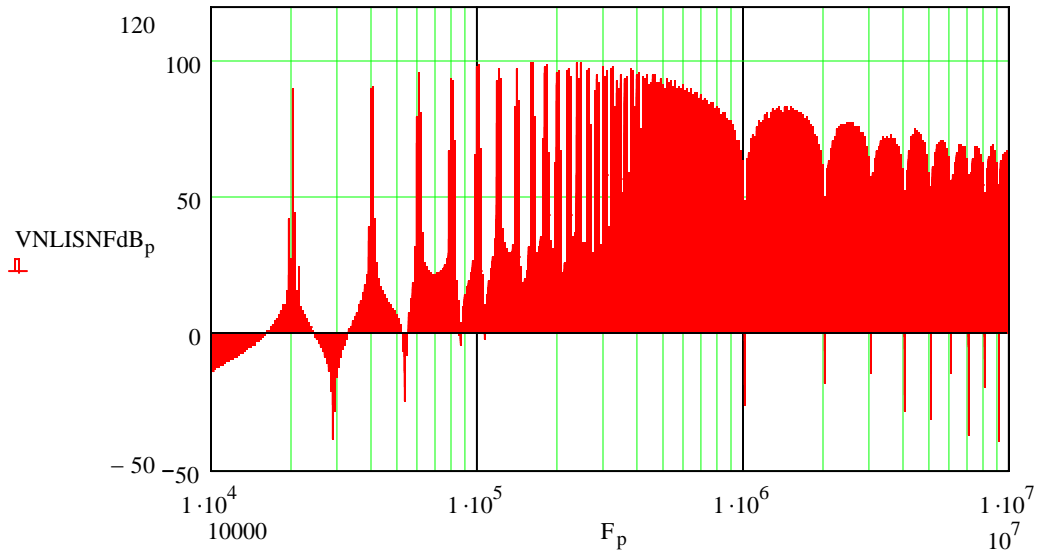Fig. 8 : CM spectrum without input filter – dV/dt = 600V/us

Fig.9 : CM spectrum without input filter – dV/dt = 300V/us

It is clear that dV/dt effect is mainly in the highest portion of the spectra, above 1MHz. Common mode filter plays a mayor role in filtering out this noise: Figures 10 and 11 show the spectra with dV/dt = 600V/us and 300V/us and with the following filter component values : L(TX1) = 5mH ; C5 = 3.3uF , C6 = C7 = 47nF
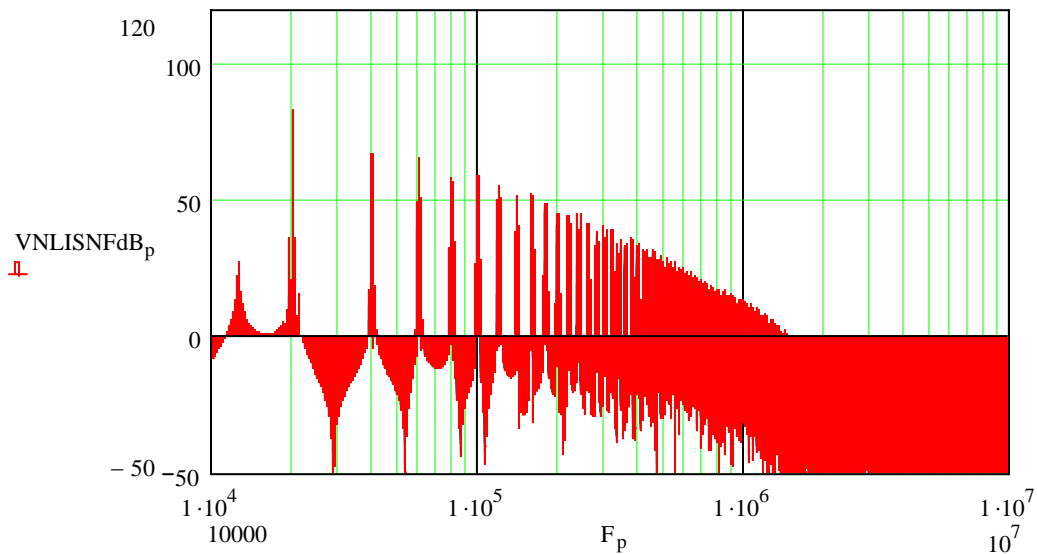


Fig. 10 : CM spectrum at 600V/us and with input filter
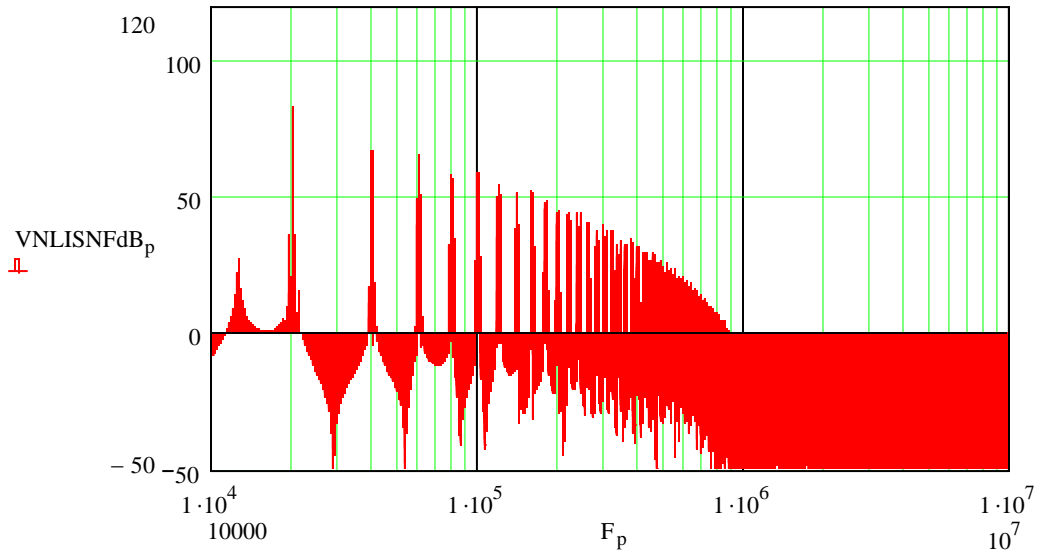
Fig.11 : CM spectrum at 300V/us and with input filter

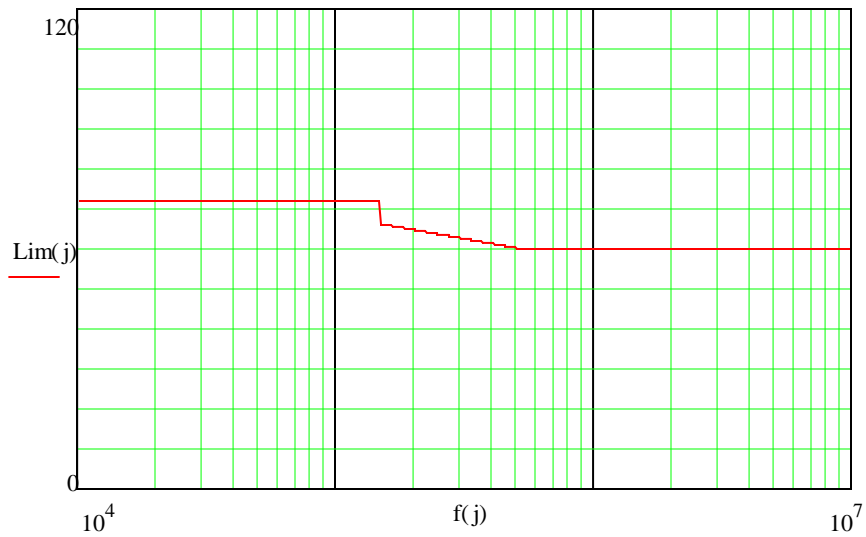For sake of completeness, Fig. 12 show the limits as per EN55014.



Fig. 12 : EN55014 limits ( dBuV)

Experimental validation of this model is on going within IR.

# Conclusions

A common mode EMI model for drive systems using IR IRAMS power modules has been presented. The special design of IRAMS power modules allow the drive system designer to simplify the analysis and design of the common mode filter , which is usually a long, time and resources expensive, try and cut activity.