Assembled PCB EMC test methods

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***Abstract*— Most often, it is unclear where assembled PCBs are going to be used in and how these are being applied. As such, it will be required, both for the OEM manufacturer as well as the end-user/system integrator, to know the EMC properties prior to integration. EMC is, aside power integrity (PI) and signal integrity (SI), one of the crucial requirements to be met to ensure functional reliability of the end-product. The requirements applicable need to be easily verified in a limited amount of test time. Last but not least, these tests have to be applied in an environment which is close to the end-applications foreseen; rack-mounted, stand alone. The methods proposed cover the frequency range from (DC) several Hz to several GHz, both on emission as immunity. With little extensions, it can also be used with impulse immunity tests.**

I. INTRODUCTION

For assembled PCBs, no formal EMC requirements apply. There is only one exception for PC plug-in cards, where the overall EMC performance of the host may not deteriorate due to the presence of the plug-in card: IEC CISPR 22 and 24 [1,2] and their successors IEC CISPR 32 and 35 [3,4]. In automotive and aviation applications EMC requirements apply on modules, ECUs. At the IC-level, EMC requirements apply on the active device itself; IEC 61967-x [5] for RF emission and IEC 62132-x [6] for RF immunity, but intentionally not on the assembly level. Only the parts IEC 61967-5 and IEC 62132-5: Workbench Faraday Cage Test Method, an artificial test board application: 100 x 100 mm, is tested rather than the IC. The same exception applies to CAN-bus devices which need to be tested in an application according IEC 62228 [7].

For practical applications, e.g. rack plug-in cards like PXI/ ATCA, should be tested in a PXI/ATCA rack instead of a separate application. For dedicated boards to be used in sensor systems, these shall be tested in their ultimate enclosure considered. PLCs, VME and VXI racks have been developed with only inter-system EMC compliance in mind.

Different from the inter-system EMC compliance test, also an intra-system EMC tests should be applicable. In many mechatronic environments, harsh conditions occur which pose emission and immunity requirements beyond the formal requirements both in level as in frequency range. With these mechatronic systems, also applicable for e-Mobility, strong interferences is generated from DC up to 70 GHz. In particular the range below 150 kHz is an Eldorado for many applications as most of the sensors, actuators, SMPS and PWM-drives operate in this frequency range.

For the sake of board testing, the RF emission and RF immunity requirements should be set from DC to (nearly) daylight. This shall be done with simple methods, with limited throughput time, and low costs.

II. TEST METHODS REQUIRED

The test methods required shall be subdivided into four groups, see table 1.

TABLE I - Interaction table

	Emission	Immunity
Conducted	X	X
Radiated	X	X

The frequency domain of interest is further subdivided into a low-frequency domain: DC (10 Hz) to 1 MHz and an RF frequency domain from 150 kHz upwards, similar to the standard EMC requirements. At low frequencies, only H-fields are being measured or generated as these are most likely to occur as the result of SMPS and PWM drives. Above 1 MHz, the electrical near-field is measured or generated through a serial balun from a meandered electrical dipole structure antenna.

Different from the standard (inter-system) conducted EMC measurements, where (common-mode) currents on cables and surfaces are found to be the most dominant parameter w.r.t. RF emission, with intra-system compatibility it is recommended to measure the common-mode voltages/ currents between the PCB's signal references (SR) and the enclosure in which these PCBs are used. Determined by the board design, the SR will stem from analogue, digital, power or RF, which are somewhere in the system tight together intended e.g. at the power supply or unintended by stray coupling.

In particular at low frequencies, where magnetic shielding doesn't operate effectively, the magnetic fluxes from motors may extend into tens of milli-Tesla nearby which then couple into all kind of inductors used on the PCB and then modulate the signals of interest.

III. CONDUCTED TEST METHOD

As already indicted in the previous chapter, disturbance is coupled straight onto the SR of the PCB under test. This signal is measured or applied against the shielded enclosure in which the PCB will be used through so called: EMC I/O ports, see figure 1 and 2. Most sensor designs are based on the assumption that when the front-end of the sensor is shielded and signals and power are provided through a shielded cable that the entire sensor is EMC compliant. In most cases it will be to meet the inter-system EMC requirements.

However for intra-system compliance, when some disturbance signal is applied between the SR of that sensor and its metal enclosure, the disturbing signal appears one-on-one to the sensor's front-end as a common-mode voltage. As a result, the sensor's readings will appear quite different than without that disturbance applied.

In a similar manner, the RF emission from these sensors with built-in oscillators and/or DC/DC converters can be measured as an RF voltage appears between the SR of that sensor and the enclosure in which it is applied.

Beyond the scope of this paper, but the sensor PCB, encapsulated in a metal enclosure and then connected through a shielded signal/supply cable will cause steep resonances, in particular when it is assumed that the connections at the opposite end are RF short-circuited, either at the entering connector or somewhere in the system. As such ideal conditions are given for n.λ/4 resonances, determined by the cable length. Not knowing the cable lengths used, the end performance of the sensor may be determined by the cable length used.

Sensor have to be considered in a different manner to avoid these kind of unpredictable cable resonance effects 'by design', other than by trial and error and tedious corrections. However, when these resonance effects are likely to occur, these shall be included with the intra-system test methods.

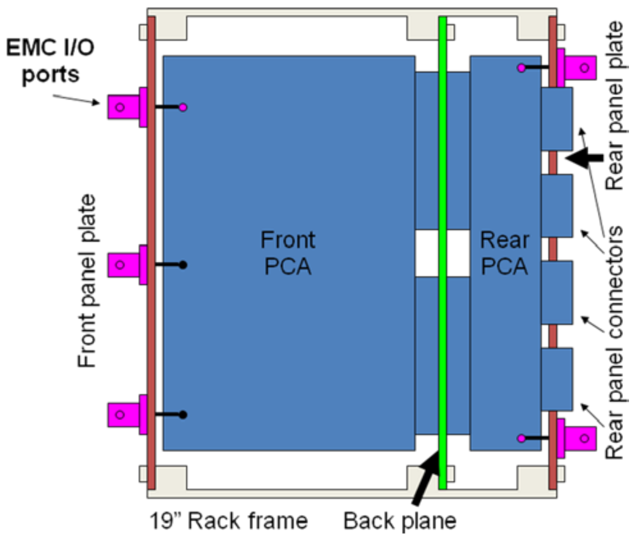

Figure 1 - Side view for conducted EMC testing in a rack

Given by the non-ideal shielding effectiveness or transfer impedance of the cable shielding used, these resonance effects are likely to be determined on the exterior of the sensor application too.

With rack mounted PCB, their board width and length will vary upon application. When backplane connectors as well as front panel connectors are used on these PCBs, the likelihood of common-mode currents to pass through the SR of the PCB is eminent. Dependent upon the floor plan strategy used for the PCB, separation of SRs may occur. This allows for testing the common-mode current flow to pass through the PCB at several heights from the front side to the back panel.

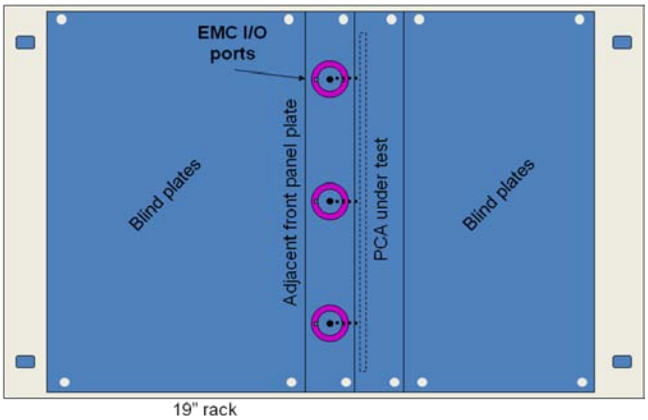

Figure 2 - Front view for conducted EMC testing in a rack

IV. RADIATED TEST METHOD

Testing PCBs in a rack needs to be done as close as possible to its final application conditions. However, PCBs at either side of the PCB under test may not be become affected by the disturbances caused by that board. Neither may the adjacent boards inversely affect the PCB under test. For the radiated tests, two methods are used: using a loop antenna for the frequency range below 1 MHz and using a folded dipole structure for all frequencies above 1 MHz. The E-field folded dipole structure is applied cross-polarized on adjacent PCB test boards while facing the PCB under test.

For the H-field measurements antenna test board is used which is shielded on one side to the front panel plate, this to reduce unintended coupling to other boards used in the rack which might be necessary to operate the PCB under test as intended. On the side towards the PCB a square loop antenna is placed with a single EMC antenna port, see figure 3.

For the E-field measurements, two EMC antenna ports are available for both horizontal and vertical polarized fields. By using a serial balun, the antennas can be used downwards into the low MHz range as they will be used as capacitive coupling boards, see figure 4.

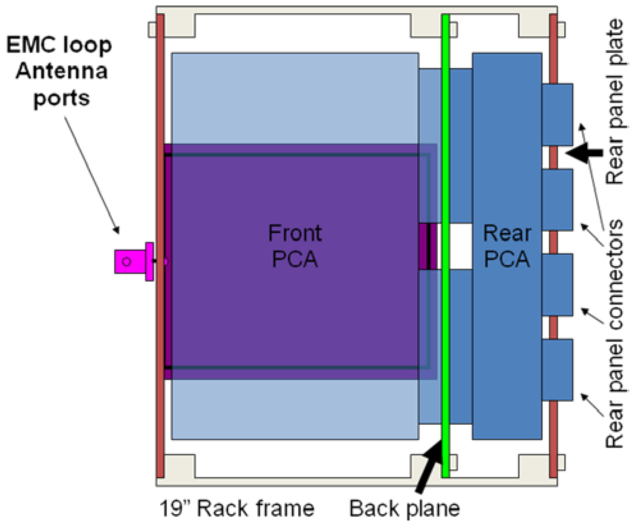

Figure 3 - Side view for low frequency radiated EMC testing in a rack

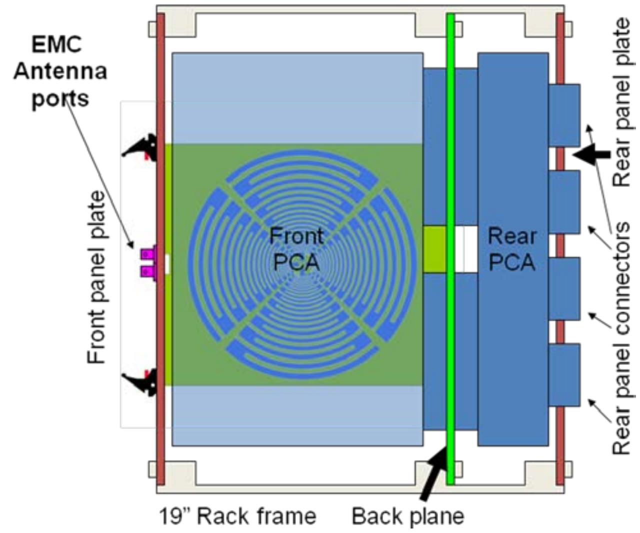

Figure 4 - Side view for RF radiated EMC testing in a rack

V. Test Equipment

At the lower frequencies, an 8 or 12-bit vertical resolution digital oscilloscope is used for measuring the conducted or radiated emission. When one wants to go down to DC or 10 Hz, doing measurements in the frequency domain becomes a tedious job. With today's digital oscilloscopes a few seconds can be captured with Ms/s and stored into memory, which allows to carry out an FFT on the data gathered. One step further, the necessary probe/antenna corrections and bandwidth adjustments can be integrated into the oscilloscope capable of carrying out the necessary post processing in a MatLab® environment.

In the RF frequency domain, standard EMC test equipment is used. All necessary corrections are taken into account by the equipment used.

With the low frequency immunity tests, an unmodulated sine wave signal is used. The true source of interference will often be frequency modulated due to the 'spread spectrum' frequency use SMPS and PWM drives. At the RF frequencies a 1 kHz square wave modulated signal shall be used rather than a 80% AM sine wave at 1 kHz. The rationale for this is the burst mode conditions that are mostly used, this to save power.

VI. Requirements and Limits

The PCB under test needs to be operated as intended. This means that all functional signals have to be provided and the software has to run as if it was in a real application condition. This less controllable condition is necessary as (embedded) software co-determines both the emission as well as the immunity of the board. When testing the immunity, special scripts are necessary to read all relevant outputs of the PCB under test.

With the intra-system EMC qualification test methods, no new requirements were introduced aside those in the lower frequency range where presently no requirements exist. An immunity example is: 10 Volt RMS EMF from a 50 Ω source, 1 Hz to 1 MHz, non-modulated.

For emission, the following requirement are currently in use: 10 $Volt_{p-p}$ when integrated over the full bandwidth: (DC) 1 Hz – 1 MHz and 1 $Volt_{rms}$ max. from a single frequency component measured across 50 Ω.

VII. Conclusions

A compact, real installation conditions intra-system EMC test method has been build which covers the entire frequency range from DC to several GHz. Due to the fact that PCBs are tested under their normal operating conditions, including the software used, the whole assembled PCB can be tested rather than a predefined test case.

All intra-system EMC tests can be done in a single day of effort when the entire PCB under test is up and running and all test boards and equipment are ready to roll.

Acknowledgements

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