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Investigations of electromagnetic behavior and interaction of motion control electronics devices.

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Abstract—As some actual or future prototypes for electronic motion control are designed with more chips density and constraints for integration challenges, new electromagnetic interactions and compatibility cases have to be considered and modeled to prevent real bad electromagnetic compliance and less-of-motion risks. In consequence, the reliability and the functionalities of the embedded system itself can be affected. This paper deals with first emission and immunity studies combined with temperature influence on electronics devices used to control power electronic motion modules. Specific Thermos-em test set-up and board's associated especially developed for these investigations are described. Then, experimental results and first approaches of global modeling work for this issue on modern PCB technology are discussed.

Keywords- *electromagnetic noise; thermal impact; radiated immunity; programmable chips; driver; PCB couplings;*

Introduction

The impacts of real physical environment, as temperature, humidity or reliability for conventional EMC behavior of modern hybrid electronics modules are non negligible. It is important actually to estimate the realistic impact of external temperature on emissions and susceptibility cases of electronic devices[1][2]. An aggressive external quasi-static temperature, with high values as 150°-200°C, can be inherently generated in an electronic transport architecture, either by motion thermal devices or by high power chip and radiators system[3]. Elsewhere, the most thermal sensitive chips used in these power electronic modules are the control electronics devices including programmable driver technology[4][5]. With actual state-of-the art of radiated EMC characterizations, both emission and immunity investigations can be performed over PCB and integrated circuits with near-field probes sets guided by a motorized scan table and/or TEM cells[6][7]. In these two cases, often dedicated PCB's are especially designed, inherently for TEM cell to comply with Standardized Cell Aperture (10cm*10cm), also to separate inside/outer electromagnetic sources and victims[8]. To accede to parametric thermal characterization, some modifications of these radiated test set-ups, with a combination of warming plate solution, up to 250°C and spatial on-board temperature measurements are presented. We start from reference behavior of gate devices and pro-

grammable device at ambient temperature and with failure's criteria's representative of the device electronic activity[9]. Then, we focus on PWM pattern characteristics in both time-domain and frequency domain, which is representative of the immunity compliance cases, with potential bad effects on motion control. Then, with combining physical and electrical modeling methodology, some electrical parameters, models and schematics are proposed, developed and refined to start global modeling approach of this characteristics and help understandings of these new real multi-physics EMC behavior at device and PCB levels.

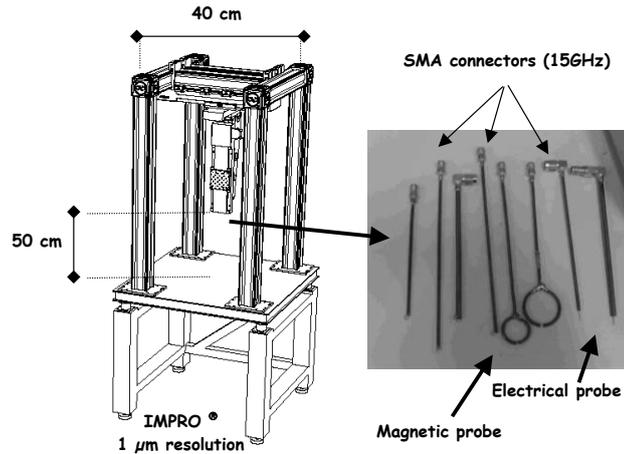


Figure 1. Motorized scan table with its HF wide-band electrical and magnetical probes dedicated for near-field EMC characterization on integrated circuit and PCB's.

New Thermos-EM experimental method

Electromagnetic characterizations for devices and circuits

Electrical E-Field and magnetic H-field are the two components of global electromagnetic waves and energy, representative of high-speed and high-level switching activity in integrated and hybrid actual devices. As shown in figure 1, the measurement and injections of these two components of the complete electromagnetic field can be realized over different areas of the PCB and the circuit, with a dedicated probes set like H-spires and E-dipoles associated to a scan table system[10]. As actual near-field electromagnetic behavior of PCB's and Integrated circuits cover a wide band of frequency, from 1 MHz to 1~3GHz, dedicated electromagnetic probes fabricated with high-frequency semi-rigid coaxial cable, represented in figure 1, are suitable and necessary to accede to the upper range of

frequency spectrum. Characterization resolutions are driven by a 0.3mm diameter for H-spire, 1cm length for E-probe[11].

Complementary electromagnetic characterizations on PCB's and integrated circuits are performed with Transverse Electrical-Magnetic Mode cell, also commonly called Crawford TEM cell. It can be used from 1MHz up to 10GHz, at PCB and Integrated Circuits (IC) levels[7][8][9], as a well-suited alternative to large size experimental equipment for conventional radiated characterization. It allows also pertinent solutions for selective electromagnetic characterization of single electronic device enclosed in the shielded cell environment. For this, specific Printed Circuit Boards (PCB) have to be designed for TEM cell solution, with the dimension of the aperture cell, the completion of shielding quality of the system with a one-face metallic plane, and the choice of inside components to be coupled with TEM Cell Septum. Inside-cell electromagnetic waves, in TEM mode propagation, are collected or injected on one port of the cell with the RF generator, the other port is loaded by a 50 Ohms HF impedance.

With these two type of electromagnetic equipment, both emission and immunity cases can be alternatively performed : for emission and radiated noises, high-frequency receiver or spectrum analyzer are connected to the near-field probes outputs and the TEM cell ports; for immunity cases, replacing receivers by wide-band amplifier and versatile waveforms generators allow harmonics and transient aggression experiments.

EM set-up's completed with thermal solutions

For the interest of temperature influence on the electromagnetic disturbance effects of an active device, new experiment techniques have been developed to completed both near-field and TEM characterizations. For near-field subject, the special design of a "XYZ" Scan Table has been performed in Z direction to allow the insertion of a directive warming plate, which volume occupancy is about 22cmx30cmx12cm, below the arm fixture. Z position and reference can be adjusted and hold, in respect to the test PCB minimum distance (1.5cm) to provide efficient heating avoiding destructive burning contacts. For dealing with both thermal measurements in association with near-field measurements, a thermal contact probe, with a touch end of 0.1mm diameter and a thin body support of 8cm long, has been coupled on the same scan table moving fixture, with a slightly different Z-axis reference than EM probe. When moving and positioning the measurement point, thermal probe stays in contact with the body of the electric element as near-field probes are just over, as shown in figure 2. Electromagnetic responses are collected in frequency domain, as H or E levels in dB. Temperature responses, with a more long time constant and variation, are collected by sampling digital acquisition system and the global set-up is controlled by PC [11].

For Transverse Electrical-Magnetic mode cell configurations, some new solutions have also been developed to include the thermal experiment parameters[12]. The first modification proposed is to realize the placement of the PCB test fixed with the TEM cell fixture over the heat zones of the warming plate. To achieve this,

the TEM cell with its test PCB has to be maintained over maximum 4 cm of the warming plate to keep efficient heating action, with a special fixture arm. The constraints are to report electrical and thermal connections very close to the PCB, and to go at the control-measurement system with a 90° angle so as to not touch the hot warming plate, as represented in figure 5. The second development concerns the real acquisition of the temperature aggression value on board. The TEM cell configuration don't comply with an external contact thermal probe solution. To overtaking this, we propose the integration of thermal resistors in Surface Mounted Device (SMD) or Thin Film technology. The four wires connection for each probe must be "electrically length" and optimized to avoid more unwanted radiated noise or parasitic couplings, even if thermal signal is a low-frequency excited one. Inside-cell probes are connected on the outer with through via-hole techniques, as visible in figure 6.

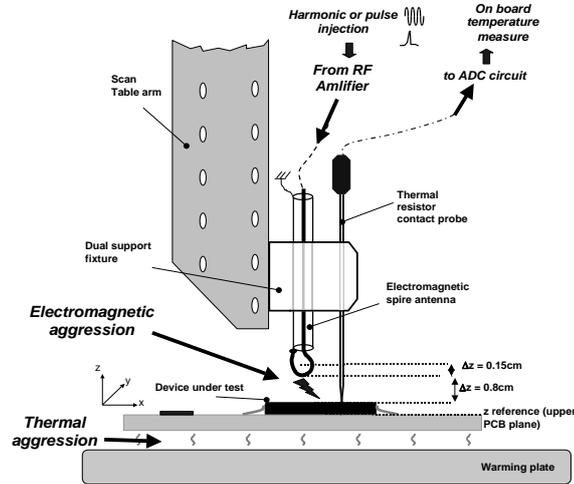


Figure 2. 2D view of the experimental dual thermal-near field set-up configuration for immunity.

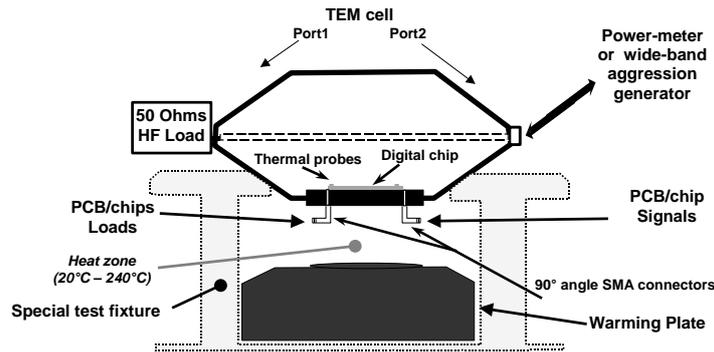


Figure 3. 2D view of new new heated TEM-Cell configuration for immunity/emission testing on motion control boards

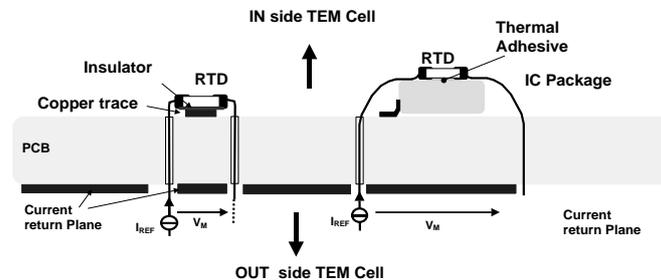


Figure 4. Transverse view of dedicated PCB specifications with on-board thermal probes.

Application on control circuit boards.

Description of the control test boards

As control circuit are used to drive power converter boards designed for well-suited motion or energy supply function[4], we want mainly to focus on their real EMC behavior with non-ambient temperature environment. PCB prototypes have been designed for this, using programmable integrated circuits type for motion control embedded applications with mainly Pulse Width Modulation(PWM) patterns controlled by versatile cyclic rates input command. Example layout is on figure 5, including thermal scan. Signal output is delivered on internal capacitance load (500fF) in parallel to external capacitance load(1pf). Electromagnetic disturbances issued from these boards are observed or attended in the range of 1MHz-1GHz. Immunity cases can occur with a minus 10dBm of aggression levels, typical values for harmonic case and low-voltage circuits [13].

Emission case results

For emission, experimental studies have covered different digital electronics architectures, from elementary digital chip[14] to complex integrated chips[15]. All of them show significant shifts of radiated global noise of PCB including active chips in normal activity, and different noise and energy frequency repartition than usual emission characterizations at ambient temperature. To resume the most recent results, concerning the activity of a CPLD/FPGA circuit on a PCB, H-field and E-field have been collected up to 1GHz, as a good image of radiated noise and integrity signal responses. Figure 8, with a pertinent 3D view on both frequency repartition, fields amplitude and steps of temperature values, show the real impact of temperature aggression on emission behavior of this device. Starting from a maximum

peak level at 90 MHz, then at 120MHz, 178MHz, 240MHz, 320MHz with 5 to 25 dB lower levels, all this for the reference temperature of 20°C, main significant spectra' shifts are observed when temperature is forced from 24°C to 120°C. Finally, important conclusion is that H-field is quite twice or three times more temperature sensitive than E-field, especially over the active device package. This is due to the IC used for these studies which is mainly current switching driven. With the aid of complementary modeling work [14], it has been pointed out that important contributors for the explication of temperature influence are globally the active chip for 75%, the ground-supply network for 10% and EM coupling factors with antennas for 15%.

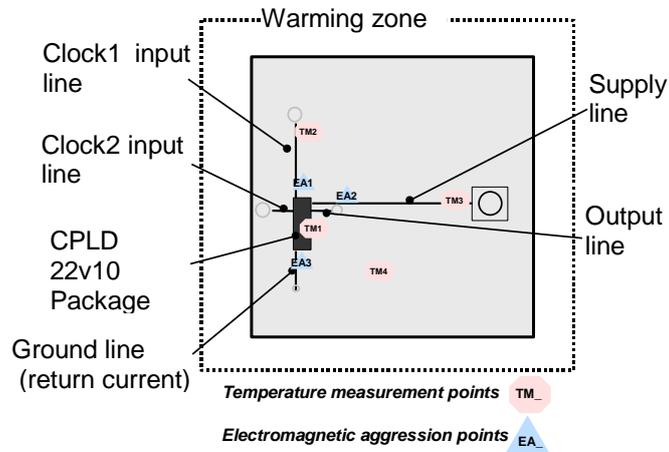


Figure 5. Example of layer upper view of control circuit PCB and configuration for dual Thermos-EM characterization in TEM cell.

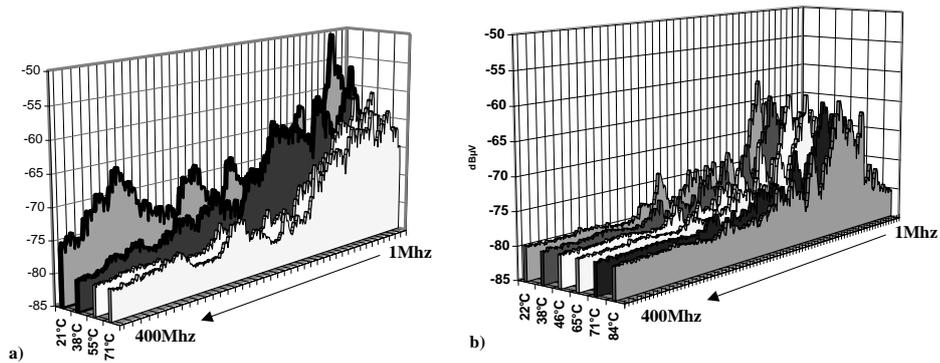


Figure 6. The CPLD/FPGA dual near-field case : emission levels among the frequency for different steps of temperature a) Magnetic field H b) Electrical field E

Immunity case results

Main phenomena's observed for susceptibility aspects are generally, for digital mode device, the modifications of thresholds levels and switching times. This is due to the couplings of external parasitic signals on supply and I/O ports. For hard aggressions cases, temporary or definitive loss of function can be observed [15]. In the application example, we combine the aggression of dual thermal-electromagnetic disturbances and its impact on PWM pattern output. In figure 6, on a control driver integrated circuit based on a FPGA (MACH4 from Lattice), instable behavior among different aggressions waveforms characteristics can be observed, using initially threshold reset level as a criteria default. Then, to complete this, the wave aggression impact with temperature is performed. The observation criteria is now centered on the shifts in switching current spectrum and the PWM pattern frequency signature. A significant results is reported in figure 8 : relative global amplitude of waveform of current switching device, I_{VDD} , is reported with significant harmonic frequency impact couplings, at ambient temperature, in the 100 MHz-800MHz zone. This variation is enforced when increasing, step by step, the external temperature and so the device package measured temperature. This indicates and confirms the modifications of switching current performances, and more significantly, an impact of high temperature as extra external energy conditions on electrical behavior of the programmable chip under electromagnetic pressure.

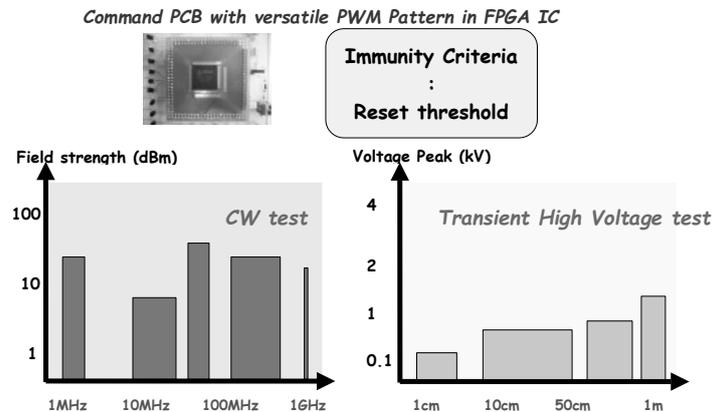


Figure 7. Results of immunity behavior of a programmable driver in harmonic and transient modes

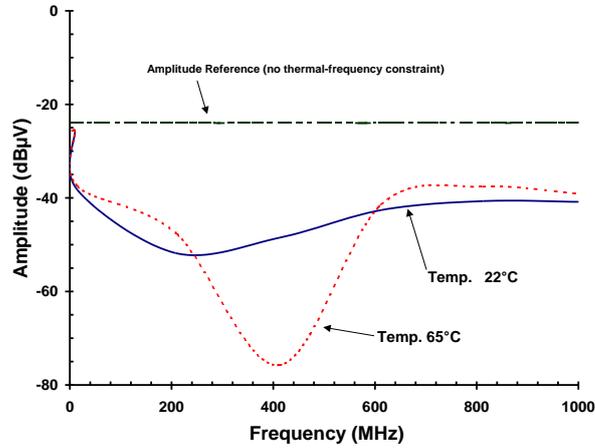


Figure 8. Relative variation of switching current amplitude with dual thermal-harmonic wave aggressions in TEM cell.

Conclusions

With these works, new modified EMC characterization approach is in progress, for pertinent real-case EMC investigations. New test benches and dedicated PCB have been developed, and dual Thermos-EM campaign has started, with a focus on command circuit behavior. With some applications on this type of device, some electromagnetic interactions and responses have been reviewed to explain the effect of external temperature on basic EMC characteristics, emission and susceptibility, of digital device. Most interesting conclusions concerns the link and the influence of thermal energy on high-speed and radiated behavior of the switching current of the driver circuit.

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