EMI/EMC Characterization of Mixed Radio Frequency-Digital Circuits

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INTRODUCTION

Due to the ever increasing clock frequencies and radio (RF) interference (unintentional or intentional) onto electronic and computer systems, issues relating to electromagnetic compatibility and interference (EMI/EMC) are of contemporary importance. Of particular interest is certainly the effect of EMI/EMC onto digital logic circuits. To do so, it is important to evaluate ambient signal penetration into structural enclosures and subsequently onto cables as well as RF integrated circuits that may be part of the printed circuit boards (PCBs) used for logic circuits.

In this paper, we summarize recent frequency domain analysis methods for EMI/EMC characterization of entire systems. Specific methods, best suited for the analysis of cables, printed RF circuits and devices (amplifiers, mixers, etc.) and digital circuits are presented and hybridized for system level analysis. We will present theoretical tools and validation of these for concurrent on-board and off-board EMI analysis of mixed RF-Digital Circuits. After a brief discussion of cable and structure characterization via generalizations and hybridizations of transmission line methods, we focus on a new port analysis technique based on the S-Parameter matrix for on-Board EMI/EMC analysis. Specifically, we introduce a novel hybrid S-Parameter characterization to account for external field coupling to RF-digital circuit boards. This (frequency domain) approach may circumvent CPU bottlenecks associated with time domain methods. The novelty of the introduced hybrid S-parameter matrix is the introduction of additional port(s) to handle the external plane wave excitation. As such, a single matrix is developed to handle both on-board and off-board EMI problems, simultaneously. The new hybrid S-Parameter matrix approach can be easily integrated into circuit solvers such as HSPICE and Advanced Design System (ADS, Agilent Technologies). It also allows for both time domain and Harmonic Balance simulations of non-linear RF-digital components via broad-band network characterization.

For experimental validation, analysis and measurements will be presented of example fundamental circuit blocks such RF Power Amplifiers (PAs), inverters and other basic components of sensor systems such as timers. At the system level, we consider the performance of a 3G wireless communication system subject to EMI and obtain the Bit Error Ratio (BER). Specifically, a W-CDMA signal is tracked prior to and after the application of EMI/EMC and channel noise. In this context, the nonlinearity of a RF Power Amplifier is exploited by introducing additional EMI noise at the input to trigger spectral regrowth and, thus, cause interference at adjacent channels. This work is also applicable to automobile sensor interference exposed to High Power Short Pulse Microwaves with varying repetition rate and pulse widths.

TELEGRAPHER'S ITERATIVE COUPLING EQUATIONS (TICE) FOR CABLE BUNDLE ANALYSIS

There are three predominant approaches to transmission line analysis depending on the interpretation of the excitation terms [1]–[3]. These approaches are limited to the cases where quasi-static conditions are met and yield fairly good results when the closest distance between the conductors and the ground plane is less than one tenth of the smallest wavelength. In other words, these methods yield accurate results for relatively low frequency analysis where the quasi-static approximation is known to yield reasonably good results. As can be expected, methods based on the Transmission Line Technique (TLT) do not account for self-radiation of the transmission lines (i.e. they neglect the common mode current). That is, TLT can only predict the differential mode current, but for more general structures, we need to also include the common mode current to better characterize the total current induced on the transmission lines. The common mode currents are not an issue when the lines are very close to ground plane. In this case, only differential mode is dominant and consequently the quasi-static approximation is valid. We propose a more general approach for handling complex multiconductor transmission lines with SPICE and nearby structures via the Method of Moments (MoM). An iterative method is then used to handle the interaction between the structures and transmission line bundles. A unique aspect of our formulation is that both the quasi-static and non-static effects are included. This is accomplished by introducing Telegrapher's coupling equations derived in presence of complex structures. In this case, non-static terms are included as additional voltage and current sources as given in (1).

$$\begin{aligned} \frac{d[V^s(r)]_n}{dr} + j\omega[L][I(r)]_n &= [E_x^{exc}(r)] - j\omega[A(r)]_{n-1} + j\omega[L][I(r)]_{n-1} \\ \frac{d[I(r)]_n}{dr} + j\omega[C][V^s(r)]_n &= \frac{d[I(r)]_{n-1}}{dr} + j\omega[C][\Phi(r)]_{n-1} \end{aligned} \quad (1)$$

We validated the proposed method for a single transmission line residing partially inside a cavity surrounded by a trough and subject to obliquely incident plane wave excitation (see Figure 1). Total current induced along the wire is also depicted in the same figure and it is clearly observed that the proposed method has a very good agreement with full wave solution (EMCAR) after four iterations and transmission line solution (iteration 0) fails dramatically since non-static effects were ignored.

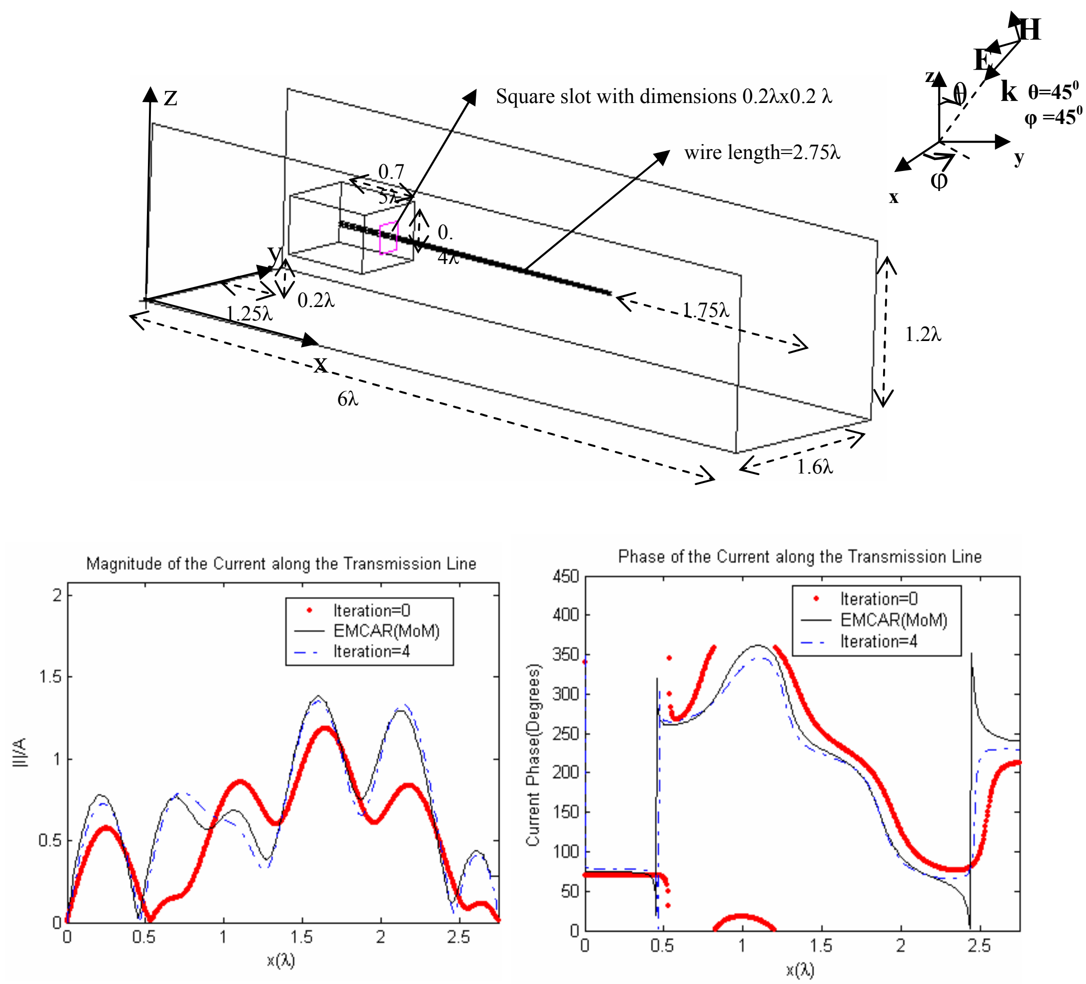

Figure 1 Single Transmission Line Subject to An Oblique Plane Wave Incidence

HYBRID S-PARAMETERS FOR RF-MIXED SIGNAL CIRCUITS SUBJECT TO EXTERNAL EMI

Electromagnetic interference due to on-board power sources (on-board EMI) and signal integrity for mixed signal circuits are important to designers of RF-digital circuits. In addition to onboard EMI, susceptibility analysis of mixed signal circuits subject to external electromagnetic interference (off-board EMI) is also important due to recent security threads. The challenge in the analysis of this class of problems relates to the large size and complexity of the structure and its components. However, for RF-digital systems, an additional challenge is the integrated analysis of circuit elements (the governing equations being the -Kirchhoff's Voltage (KVL) and Current Law (KCL)) with EM structures governed by Maxwell's equations. While the former is expressed in terms of voltages and currents, the latter requires the solution of electric and magnetic fields. Due to the inherent non-linearities of the analog and digital circuits having varying input and output impedances, it is impractical to integrate both into a full wave EM solver in the frequency domain. Therefore, EM structure either needs to be transformed into a circuit compatible form via, for instance, Partial Element Equivalent Circuit (PEEC) method or port analysis via S-Parameter network characterization.

In this paper, we extend the port analysis technique to accommodate the external plane wave coupling. In other words, we propose a frequency domain method which overcomes the CPU bottleneck of time domain techniques and concurrently yields increased accuracy as compared to MTLT. As part of this formalism, we introduce additional hybrid S-parameters to establish a link between the existing board ports and external plane waves (see Fig.2). In addition to additional entries in S-matrix to represent plane wave excitation, we also introduced forced voltage sources at the port locations to enforce the Ohm's law at the ports. Having characterized plane wave as a part of the S-matrix, we can handle both on-board and off-board EMI problems simultaneously. This approach can be easily integrated into circuit solvers such as HSPICE and Advanced Design System (ADS, Agilent Technologies). This is achieved by exporting new hybrid S-parameters. The method allows both time domain simulations via broad band network characterization and Harmonic Balance Simulation of non-linear RF components.

We present EMI effects on the TI SN74AUC1GU04 inverter residing on a RT/Duroid 5870 board inside a metallic enclosure with effective dielectric constant of 2.33 and thickness of 31 mils (see Fig.3). We first generate 8x 8 S-Parameter matrix for the ports in the absence of the plane wave. Next, the proposed method is employed to compute the hybrid S-Parameters. Subsequently, we update the existing S-parameter matrix to include the hybrid parameters and generate 9 *x* 9 S-parameter network. As a final step, we export the resulting matrix into HSPICE and perform time domain analysis. Fig. 3 shows the inverter output for three different cases. In the first case, no EMI was applied and it is clearly seen that the inverter performs as expected. In the second case, an external field of amplitude 1414 V/m is applied, resulting in minor oscillations at the output. However, when external EMI is doubled, 2828V/m, EMI effects begin to dominate, resulting in significant modifications on the output. This example also implies that even though inverter is shielded, a small aperture cut-out for input and output cables may lead to severe coupling to the device, and eventual logic failure.

CONCLUSION

An iterative method for the analysis of multiconductor transmission lines in the vicinity of complex structures was presented. The employed pair of Telegrapher's coupling equations was based on a generalization which allowed for the inclusion of additional sources (non-static contributions) to permit coupling between the surrounding structures. To extent the existing port analysis for enabling the modeling of off – board EMI problems, we introduced a new set of hybrid S-parameters for external field coupling to mixed RF-Digital circuits. The proposed method was applied to a particular case in which an inverter residing inside a box is subject to an external plane wave.

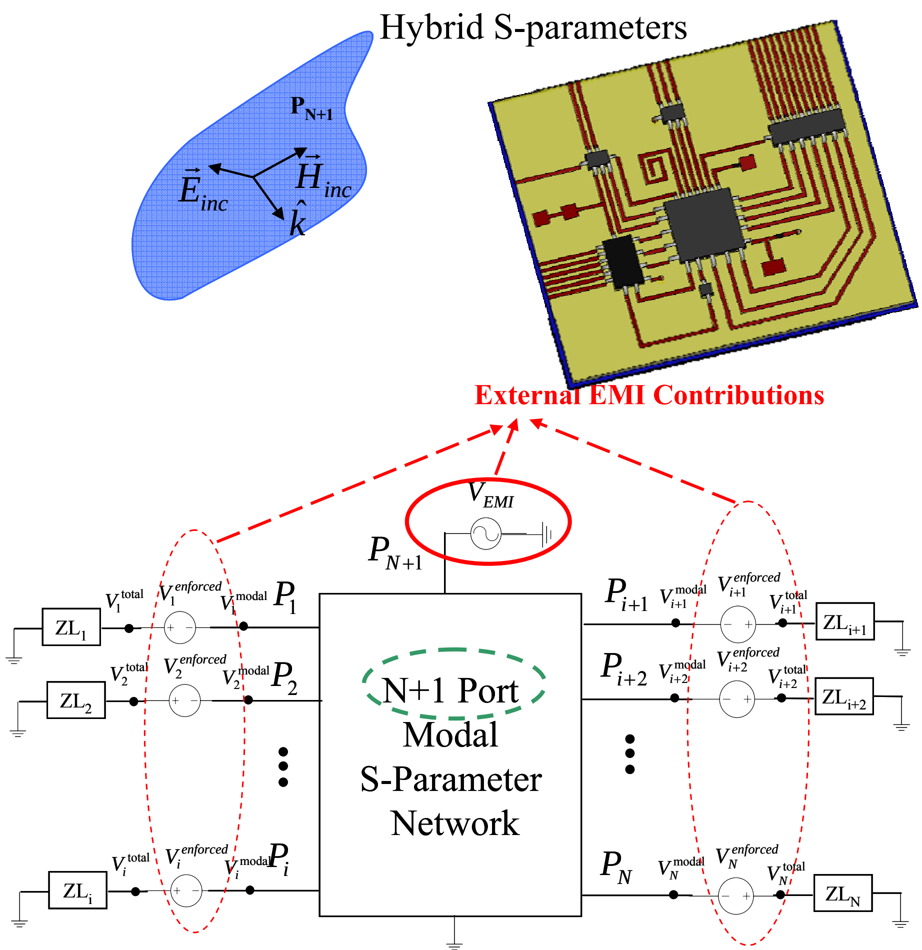

Figure 2 Hybrid S-parameters to represent external EMI

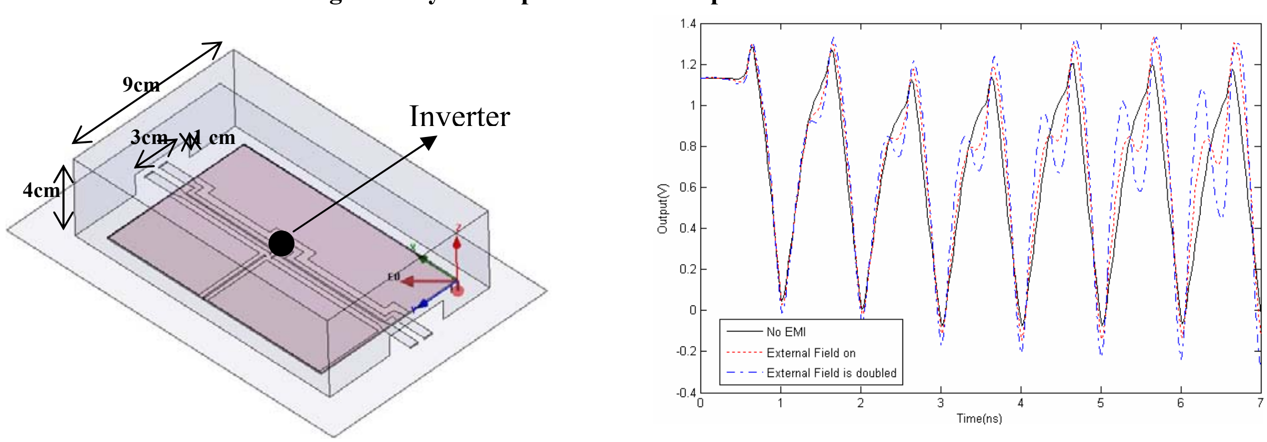

Figure 3 Inverter inside a metallic box and subject to concurrent on & off-board excitation

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