

Investigation of a Method for RF Circuits Analysis Based on Electromagnetic Topology

Yoon-Mi Park[†], Young-Seek Chung^{*}, Changyul Cheon^{**} and Hyun-Kyo Jung^{***}

Abstract – In this paper, electromagnetic topology (EMT) was used to analyze the electromagnetic compatibility (EMC) of RF circuits including passive and active components. It is difficult to obtain usable results for problems relating to electromagnetic coupling in complex systems when using conventional numerical or experimental methods. Thus it is necessary to find a new methodology for analyzing EMC problems in complicated electromagnetic environments. In order to consider the nonlinear characteristics of active components, a SPICE diode model was used. A power detector circuit and the receiver circuit of a radio control (RC) car were analyzed and experimented in order to verify the validity of this method.

Keywords: BLT equation, EMI/EMC, EMT, nonlinear circuit

1. Introduction

Due to the recent rapid evolution of electronic technology, modern electric systems have become increasingly complicated. As a result, concern with the electromagnetic coupling phenomena by aperture and transmission line coupling has been growing for the past several years as they often cause significant problems that have a negative impact on electrical systems.

There is a limit to the use of conventional methods to analyze the EMC problems of complex circuits in enclosures such as computer mother boards owing to the difficulty of modeling the system [1]. The full wave analysis techniques used to analyze complex electronic systems are relatively accurate but require long computation times, detailed mesh generation and large amounts of data [2]. On the other hand, simulations based on circuit analysis techniques require short computation times but do not consider the external electromagnetic field coupling phenomenon and, therefore, analyze the phenomenon with low accuracy. Furthermore, the target circuit consists of various components as passive, active components. Because active components have nonlinear characteristics, determining the interaction characteristics of the components is difficult. Hence it is necessary to find a new methodology for analyzing EMC problems in complicated electromagnetic environments.

Electromagnetic topology (EMT) introduced by C. E. Baum in the 1980's is a simulation approach to analyze the electromagnetic interference/electromagnetic compatibility

(EMI/EMC) phenomena. And, the EMT also provides a structured way to represent the electromagnetic interaction process in large electrical systems. In a topological network, it is possible to divide an entire system into smaller independent volumes that interact with each other through a systemic topological diagram. The interaction phenomena of the system are described by relationships between incoming and outgoing waves from each volume, namely the scattering parameter. Therefore, the EMT requires shorter computation times and its accuracy is validated at high frequency. Furthermore, it is possible for the EMT to combine a full wave analysis with a circuit analysis technique. In a previous paper, a method based on the EMT for analyzing RF circuits including only passive components was proposed [3]. Very few attempts have been made at the analysis of a circuit by EMT. However, the method has a limit to analyze nonlinear circuits.

In this paper, a simulation based on EMT is proposed to analyze complicated RF circuits including passive and active components. The results from the proposed method match well with reference data and responses predictions of the system were possible.

2. Proposed Method

2.1 Analysis method based on EMT

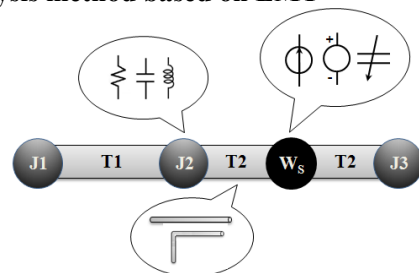


Fig. 1. A topological network representing a general circuit model including several components and sources

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EMT is a helpful technique for assessing EMC problems when analyzing complicated electric systems using volume decomposition. The basic principles of the EMT involve dividing the complex structure of a target system into a set of smaller volumes, characterizing the smaller volumes, and finally reconstructing the whole target system. The solution for the whole system can be determined using the Baum-Liu-Tesche (BLT) equation which reconstructs the divided volumes. The BLT equation describes voltage and current responses in a network of transmission lines. Fig. 1 shows the topological network model consisting of junctions, tubes, and sources.

The junctions indicate n-port devices in the circuit, such as resistors, inductors, capacitors and diodes, and represent the intersection and termination of a transmission line in the network. The tubes represent the connecting lines between junctions. Scattering parameters are used in the BLT equation, to describe the characteristics of junctions and tubes and can be obtained through numerical techniques such as experimentation, simulation or manufacturer specifications. Coupling between sources in the circuit is expressed as the equivalent generators applied to the tubes [3].

Fig. 2 shows incident and reflected waves at the (a) junctions and (b) tubes. In this approach, the scattering parameters are described by the equations (1) and (2). $W_i(0)$ denotes a reflected wave, $W_j(L)$ denotes an incident wave, S_{ij} is the scattering parameter at the junction, Γ is the scattering parameter at the tube and W_{si} is the equivalent source.

$$W_i(0) = S_{ij} W_j(L) \tag{1}$$

$$W_i(L) = \Gamma \times W_i(0) + W_{si} \tag{2}$$

The BLT equation that takes the coupling on the entire network into account is described by Equations (3-5) [4].

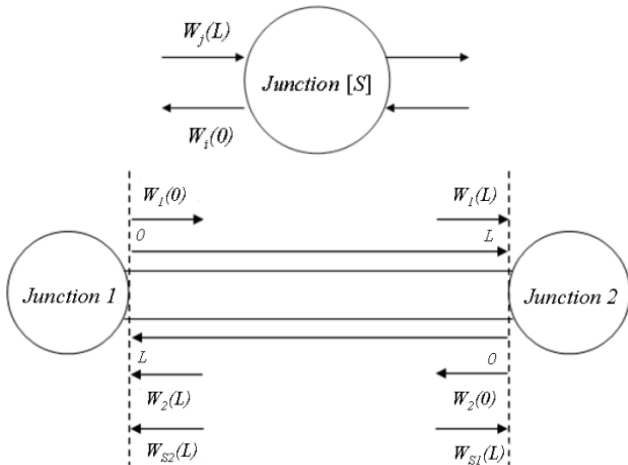


Fig. 2. Wave representation in terms of two-port network at the (a) junction and (b) tube

$$[W(0)] = ([I] - [S] \times [\Gamma])^{-1} \times [S] \times [W_s] \tag{3}$$

$$[W(L)] = [\Gamma] \times [W(0)] + [W_s] \tag{4}$$

$$[W_{total}] = [W(0)] + [W(L)] \tag{5}$$

The BLT equation consists of the propagation supermatrix $[I]$, the scattering supermatrix $[S]$, supervector $[W_s]$, the incident wave matrix $[W(L)]$ and the reflected wave matrix $[W(0)]$. These matrices can be determined by reconstructing the scattering parameters of the smaller volumes. With this method, we can obtain voltage and current responses at each junction. The BLT equation enables all connections and couplings on the topology network to be described.

2.2 Active Component Modeling

In topological analysis, the scattering parameters for components that compose the overall circuits can be obtained through various methods. A method for circuits including passive components was proposed in a previous paper [3]. However active components have nonlinear characteristics, thus there is a limit to the use of conventional techniques.

In this paper, a new diode SPICE model is proposed to obtain scattering parameters. The SPICE diode model is shown in Fig. 3. The parameters used in the SPICE model are from 600MHz to 700MHz. Dynamic behaviors are modeled by the nonlinear capacitor C_D and the series resistance R_s represents the parasitic resistance. In this model, i_D is diode current and v_D is diode voltage [5].

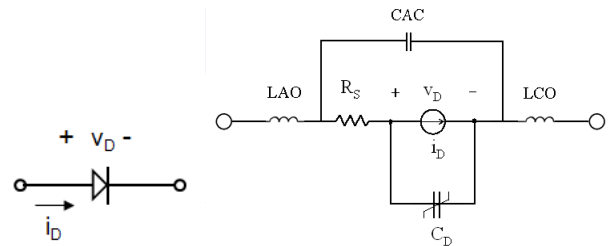


Fig. 3. SPICE model including the parasitic package components of the diode

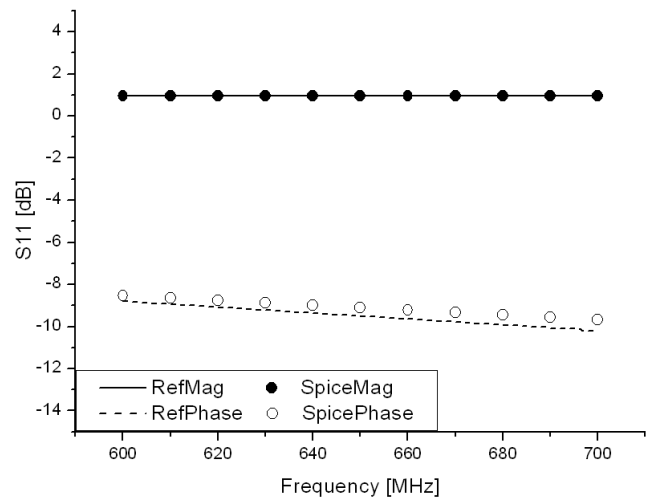


Fig. 4. Scattering parameters for the diode model, BAT62-02W

In order to observe the effect of various imperfections

on device operation, parasitic package components, such as LAO, CAC, and LCO, are put in the SPICE model around the chip diode. The SPICE diode model replaces the diode as a junction in the topology diagram.

Fig. 4 shows the scattering parameters for the diode model, BAT 62-02W. In Fig. 4, a solid line is the magnitude of manufacturer specifications, a dotted line is the phase of manufacturer specifications, solid dots the magnitude of the SPICE model, and open dots the phase of the SPICE model. As Fig. 4 indicates, the scattering parameters from the SPICE model agree with the manufacturer specifications and the validity of the method is verified.

3. Numerical Simulation and Results

3.1 Power Detector Circuit Model

In order to demonstrate the proposed method, we considered a coplanar waveguide (CPW) circuit with a Low Noise Amplifier (LNA), diode and several R, L, and C components. The used LNA was MGA-87563 (Agilent Technologies) and the diode was BAT 62-02W (Infineon Technologies). In this paper, the analysis model was previously simulated and the result compared to measurement results.

Fig. 5 is a schematic of the analysis model and Fig. 6 shows the fabricated model and a topology diagram. The circuit consists of a chip LNA, diode and several RLC components. Inductors and capacitors are placed to match the input and output resistance to 50 Ω in the schematic.

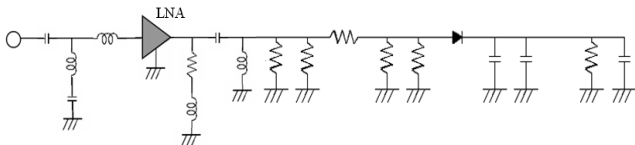


Fig. 5. Schematic of the analysis model including LNA, diode and several R, L, C components

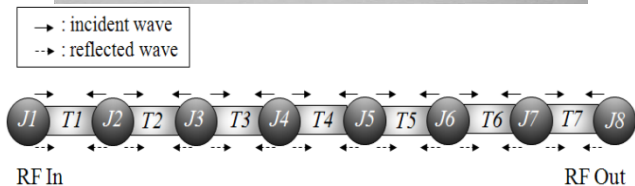
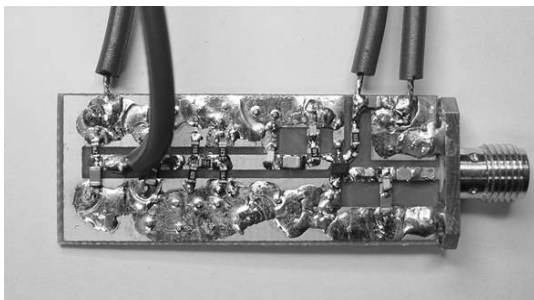


Fig. 6. The fabricated power detector circuit model and topology diagram representing the circuit model

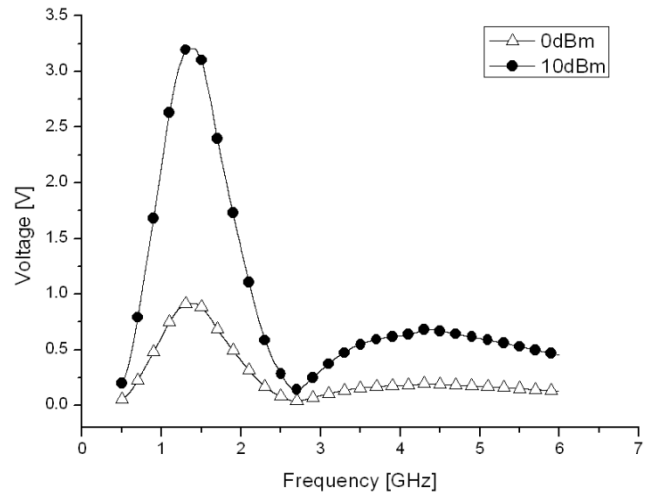


Fig. 7. The RF input voltage response at the LNA with input power set to 0dBm and 10dBm by the EMT

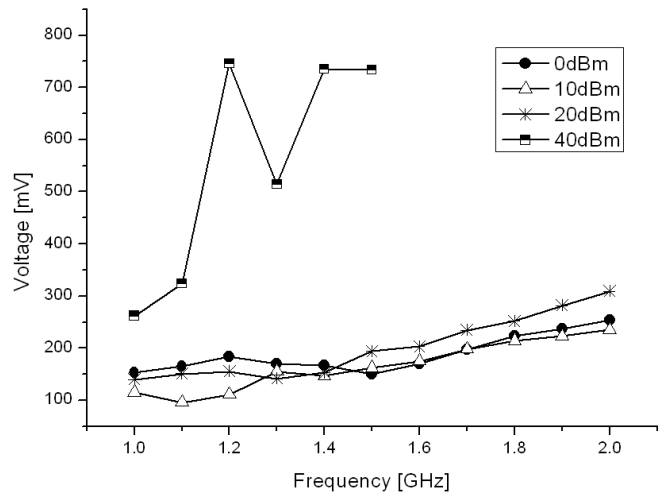
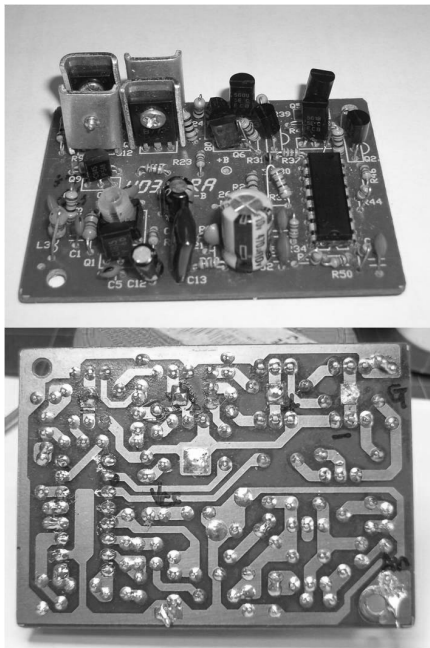


Fig. 8. The diode input voltage of the power detector circuit by experimentation with input power set to 0dBm, 10dBm, 20dBm and 40dBm

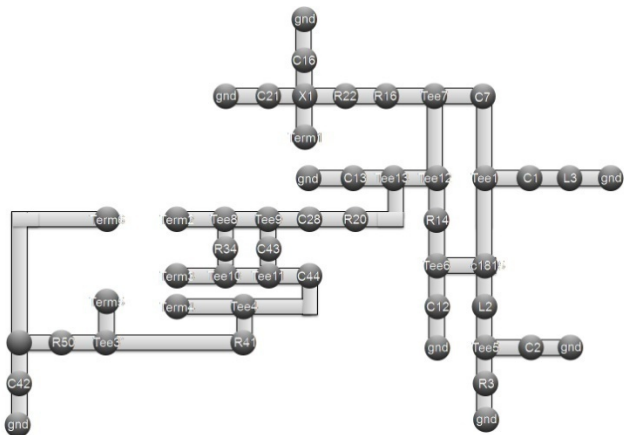
In an EMT-based simulation, the interaction mechanism can be described as shown in Fig. 6. The topological approach analyzes electromagnetic coupling interactions at the junctions and tubes. In order to analyze the electromagnetic coupling interactions at junctions, the scattering parameters for circuit components were obtained from data tables and simulation. Through the BLT equation, the voltage and current response at the junctions can be obtained.

Fig. 7 shows the predicted input voltage response of the LNA by the EMT with input power set to 0dBm and 10dBm. When the input power was 0dBm, the RF input voltage to the ground was approximately 1 V at 1.5 GHz. When the input power was 10dBm, the RF input voltage to the ground was above 1 V between 0.8 GHz and 2.2 GHz. Since the maximum RF input voltage to the ground of the LNA was 1 V according to manufacturer specifications, the presence of an obstacle to the LNA was predicted in the case of 10dBm input power, which was verified through experimental results.

Fig. 8 shows diode input voltage results by experimentation with input power set to 0~40dBm. When the input power was above 10dBm, the diode input voltage was less than the diode input voltage when the input power was 0dBm. Specifically, the input power became 40dBm then the input voltage could not be measured because the LNA was physically destroyed at 1.5 GHz. It is found from the results that malfunction was generated since the input power was above 10dBm and these results were the same as the simulation results. Through this method, it is possible to predict the magnitude of the EMI source to disturb the performance of the circuit.



(a)



(b)

Fig. 9. (a) Top and bottom views of the RC receiver circuit model (b) topology diagram

3.2 Application Model

EMT was applied for the more complex model. Fig. 9 is the receiver circuit of a radio control (RC) car, Fig. 9(a)

shows the top and bottom views of the physical model and Fig. 9(b) shows the topology diagram. When an RF voltage source is applied at the receiving antennas, the transmission path from the antennas to the important IC pin can be described through the EMT. The EMT results for the RC car are shown in Fig. 10 where the solid dots represent the results of the EMT, and the open dots the results of the commercial simulation tool. The simulation and the EMT results were similar within a range from 1 to 10 GHz. The results indicated that the source applied at the receiving antennas was delivered to the IC well at approximately 3, 6 and 9 GHz and it was for this reason that internal circuit resonance was generated at 3, 6 and 9GHz.

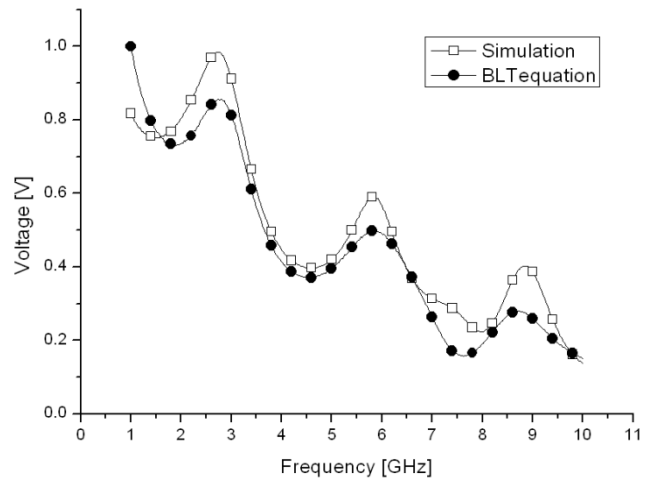


Fig. 10. Input voltage response of the IC in the RC receiver circuit

4. Conclusions

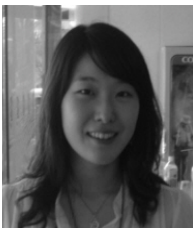
In this paper, RF circuits with active components were analyzed by EMT. In order to accommodate the nonlinear behavior of the diode, the SPICE diode model was applied to the EMT method. The results from topological modeling were in agreement with simulation and measured results. As a result, it is possible to predict the frequency response to disturb the performance of circuit. In this research, a circuit with an internal voltage source was studied, and from now on research related to external field coupling by EMT will be needed in order to apply the method to more practical issues.

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