Modeling & Simulation Technologies on High Power Electromagnetic Applications

#Jinwoo Shin [1], Changgu Kim [1], Jongwon Yang [1], Jun-Ho Choi [1], Woosang Lee [1], Joonho So [1]
[1] Agency for Defense Development
Yuseong P.O.Box 35-4, Daejeon, 305-600, Republic of Korea, sjinu@add.re.kr

Abstract

In this paper, we present the modeling and simulation (M&S) technologies of high power electromagnetic (HPEM) system in order to estimate and evaluate the system performances using numerical test. We also present an approaching procedure for the combined M&S methodology based on the M&S results of each subsystem.

Keywords : Modelling and Simulation High Power Electromagnetic Wave Numerical Experiments

1. Introduction

High power electromagnetic (HPEM) systems using various microwave sources are applicable to various areas and applications. Due to having high power level at each component of the HPEM system and avoiding air or surface RF breakdowns in the system, the mechanical size of this system is very huge. So, it is very difficult to optimize performances of the system by iteratively manufacturing components and system integration test. In addition to that, it is also impossible to make a numerical estimation at once for the whole system because the system needs to combine multi-science researches. In this paper, we present the development of interactive M&S models and the modeling and simulation (M&S) methodology for the estimation of overall performances of the HPEM system by combining interactive M&S models based on multi-theories and various numerical methods.

General approach method for developing the M&S models of the HPEM system and designing the whole system is as follows. Firstly, we need to analyze system requirements before developing system M&S models. After analyzing system requirements, we should develop specific analysis process for HPEM system requirements and then allocate M&S functions. After that, it is necessary to define interactive input and output conditions based on allocated M&S functions. In this phase, we can develop interactive M&S models at each component of the HPEM system. Finally, using developed interactive M&S models, we can construct M&S foundation for implementing and designing the HPEM system. Figure 1 shows the system M&S design relations between system design, requirements analysis, functional analysis and design integration.

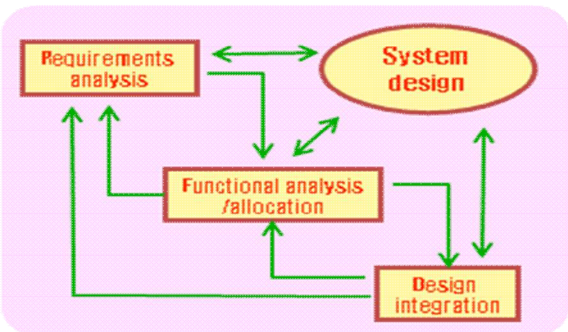

Figure 1: Relations for system M&S design

2. Development of M&S models for HPEM system design

In general, HPEM system is composed of high voltage pulsed power, high power source, high power antenna and diagnostic devices. If we want to get optimal designs for each subsystem, each subsystem needs to be analyzed by various numerical methods and basic theories such as field theory, circuit theory, electron-beam(particle) theory and microwave theory. Numerical analysis based on all these theories is inevitable for designing HPEM subsystems as in figure 2. We present the M&S modeling design sequences of each component in this chapter.

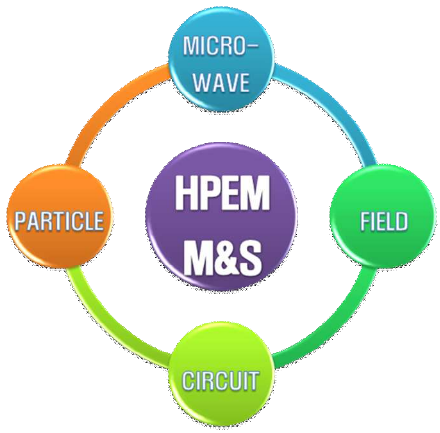

Figure 2: Inevitable basic theories for numerical analysis of HPEM subsystems

When we develop the M&S model for the high voltage pulsed power, we have to estimate electrical performances of the pulse power and an output pulse shape by analytical and numerical methods. For example, if this pulsed power is Marx-type, we need to construct equivalent circuit modeling for the pulse power by parameter analysis of this pulsed power using transient RLS circuit analysis such as SPICE. And then, we should consider the stray or parasitic reactance in order to improve accuracy of M&S result. Stray or parasitic reactance or additional factors to be considered would be stage capacitance, housing parasitic capacitance, switch arc inductance and switch turn-on delay time. After finishing the development of circuit M&S model, we need to analyze static field and breakdowns by high voltage. We can estimate physical weak points by high voltage and determine design safe factor. We can also construct the structure modeling of the high voltage pulsed generator. We should use an electrostatic solver based on finite element method (FEM) using the physical structure model. We can analyze static fields as a switch gap distance changes and estimate voltage condition for turning-on switch by the electrostatic solver in order to design of high-voltage peaking spark-gap switch. We can analyze noise effect from switch and estimate rf noise components when spark-gap switch turns on. For this case analysis, we usually use the finite-difference time domain (FDTD) method as a solver.

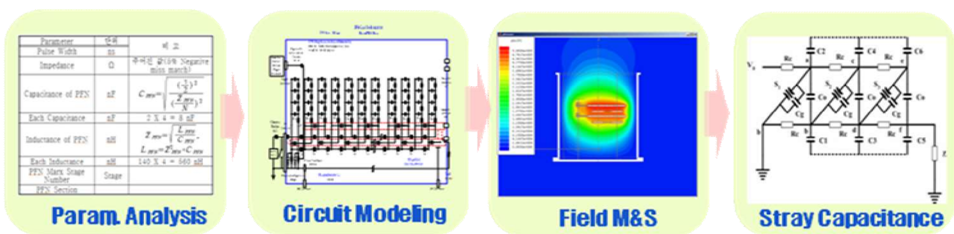

Figure 3: M&S sequence for high voltage pulse power

When we develop the M&S model for the high power source which would be relativistic vacuum tube, we should consider relativistic electron movement analysis, microwave analysis of cavities and tube, magnet B-flux analysis and static field analysis without high voltage breakdowns. For the case of electron-gun design, we can analyze characteristics of electron-beam using the particle tracking solver with which we can monitor beam trajectories from the electron gun. And then we estimate the breakdown of microwave source by high voltage pulse using electrostatic solver. We investigate RF characteristics of input and output cavities for cavity mode analysis using FEM and analyze beam loading effect by resonant properties of cavities using an equivalent circuit model. We also have to analyze the interaction of electron-beam and EM wave and then estimate RF output power of high power source by estimating the source gain with controlling intensive relativistic electron beam trajectories which is analyzed using particle-in-cell (PIC) code. It is also important to design the magnet for concentrating electron-beam in tube. We design and analyze the B-flux of the magnet using PIC code. We can complete the design for optimizing the whole efficiency of the high power source through the previous mentioned procedures.

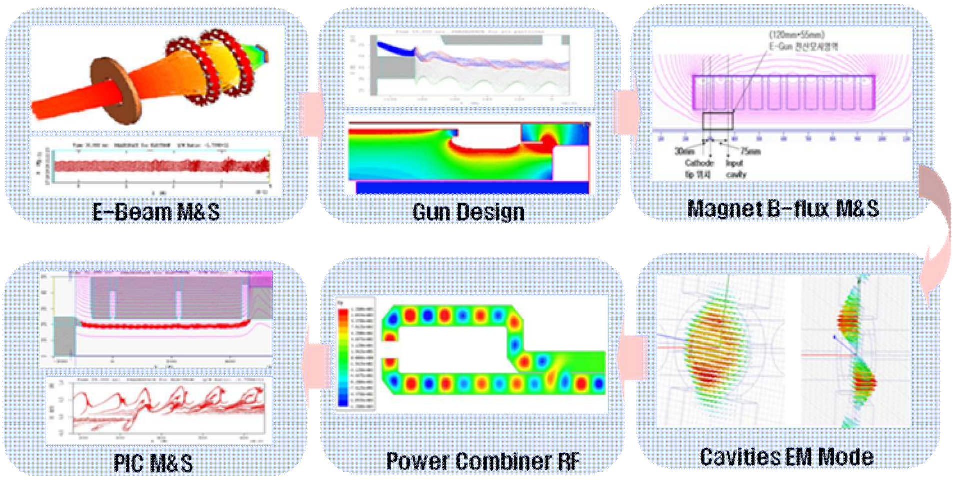

Figure 4: M&S sequence for high power source

For high power RF level antenna design sequence and M&S model development is similar with the conventional antenna design but we have to consider several additional numerical analysis. Firstly, we need to analysis air or surface breakdowns in antenna by analytical or electrostatic analysis and design the RF window for high power with good insertion loss and no breakdowns. We also consider the waveguide flange type and gaskets with analysis based on FEM and FDTD method.

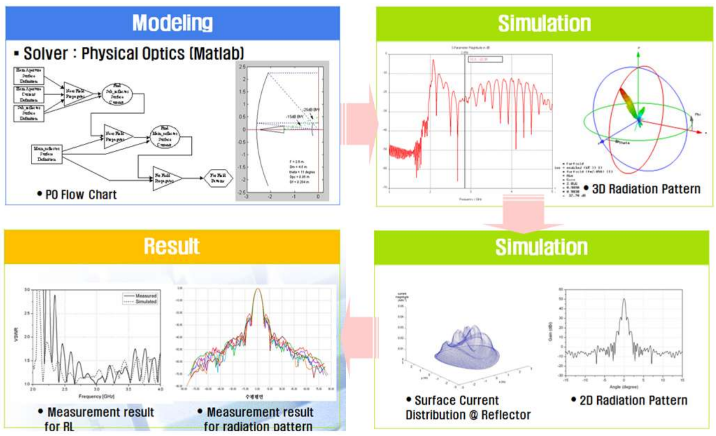

Figure 5: M&S sequence for high power antenna

3. Numerical system integration and test & evaluation

Each subsystem which is high voltage pulsed power, high power source, and high power antenna can be divided into circuit model, field model, particle model, and microwave model. One model is the input of another model and the numerical result of another model is the input of the other model. So, all results for each model are interactive. Circuit model and static field model

among interactive M&S models are compensatory each other. And the results of the circuit and static models are the inputs for the particle model and EM wave model.
Figure 6 shows the system M&S block diagram using developed interactive M&S models which are circuit model, static field model, particle model, EM wave model, and propagating model with antenna model. We can construct the system M&S model by combining all interactive M&S models in the previous chapter in this paper. We also should consider the environmental influences for the operated system model.

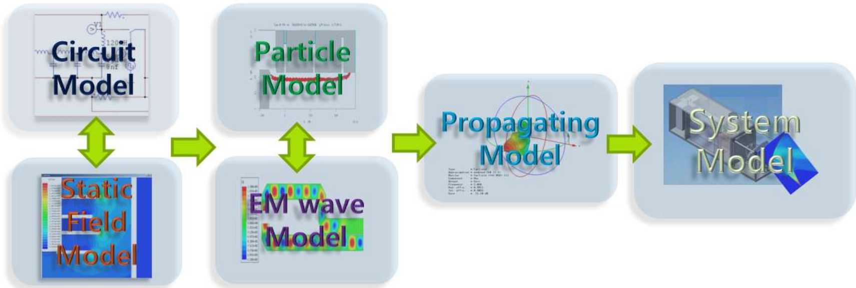

Figure 6: System M&S block diagram using interactive M&S models

4. Conclusion

We present cost- and time-effective design methodology for HPEM system using interactive M&S models. We can estimate system performances correctly by developed interactive circuit model, field model, particle model, microwave model and environmental model. With interactive M&S models and combination procedure, it is possible to perform the numerical test and evaluation for the HPEM system including HPEM effectiveness at targets.

References

[1] A. Taflove and S. C. Hagness, *Computational Electrodynamics: The Finite-Difference Time-Domain Method*, Artech House, 2005.
[2] D. M. Pozar, *Microwave Engineering*, John Wiley & Sons, 1998.
[3] C. E. Baum, "Maximization of Electromagnetic Response at a Distance", IEEE Transactions on Electromagnetic Compatibility, vol. 34, no. 3, 1992.
[4] A. SEDLACEK, *Electron Physics of Vacuum and Gaseous Devices*, John Wiley & Sons, 1996.
[5] P. W. Smith, *Transient Electronics Pulsed Circuit Technology*, John Wiley & Sons, 2002.