Higher Order Modes Analysis of a HEMP Simulator Using Time-Domain Simulation and Singular Value Decomposition

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***Abstract*—Higher order modes is crucial to analysis field uniformity, radiation leakage and destructive of the fundamental mode. The electric field generated inside the working area of the guided-wave EMP simulator can be represented as the combination of the dominant transverse electromagnetic (TEM) and higher order modes of transverse electric (TE) and transverse magnetic (TM). In this paper time domain finite integral method (FITD) has been used to computed field data and singular value decomposition (SVD) technique has been used to extract the higher order modes of the existing guided-wave EMP simulator.**

Keywords—higher order modes; singular value decomposition (SVD); transverse electromagnetic (TEM); time domain finite integral method (FITD)

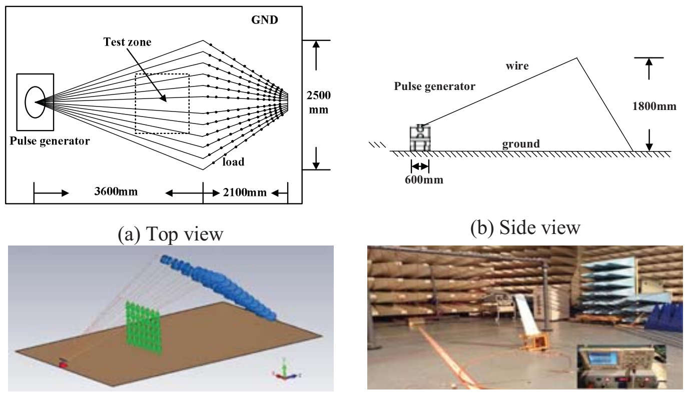
I. INTRODUCTION

HEMP simulators are applied to generate pulse electric field which simulates the early nuclear explosion radiation, the wave shape are presented in MIL-STD-461G for conducting RS105 transient EM field radiated susceptibility tests. For good uniformity of electric field distribution, guided-wave EMP simulators are widely used in electromagnetic compatibility (EMC) susceptibility tests of airplanes, vessels, and other electronic devices or systems[3].

The electric field inside the guided-wave EMP simulators working areas can be represented as a linear combination of TEM, TM and TE modes. The dominant mode propagates at all working frequencies. The other higher modes propagate at the over cut-off frequency. The degree to which transverse electromagnetic (TEM) wave propagating in a guided-wave EMP simulator working volume is "polluted" by higher order modes depends strongly upon the design of the simulator, the frequency spectrum of interest, and the geometry and material of the test object. The higher order modes information can be obtained from the simulated or measured field data inside an HEMP simulator, modal analysis have be done by large computation spectral techniques, such as Fourier spectral analysis and Hilbert spectral. In this paper, FITD and SVD technique has been used to extract the higher order modes from the simulated field data. First, presents the computational model and simulation results by CST[5]. Then, SVD technology is introduced briefly, and the field simulation at one plane on a grid of 7 x5, Those grid forms the matrix for the SVD analysis.

II. HEMP SIMULATOR MODELING

The simulator model as shown in Fig.1, virtual field probes are utilized in the test zone of the HEMP simulator model to perform a complete field mapping. The Symmetry geometry is 1: 1 to [4]. The corresponding rise time is 2.47 ns and 99% energy effective bandwidth is 95.2MHz. The simulator model simulation maximum frequency is defined as 600 MHz, the metal wire grating and the plate are defined as perfect electric conductors, the single load is 138ohms. The background chosen in this study is assigned to air. The Geometry of the guided-wave EMP is shown in Fig.1.

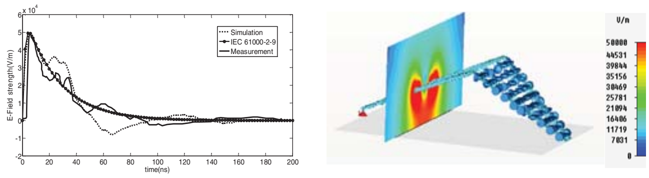


(a) Top view (b) Side view

(c) 3-D view and monitors placement (d) The guided-wave EMP simulator

Fig. 1 Geometry of the guided-wave EMP

The numerical simulation and measurement result in test zone are shown in Fig.2(a). Field distribution of simulator model is shown in Fig.2(b). The corresponding rise time is 2.47 ns and field strength is 50KV/m, It is wonderful meet to MIL-STD-461G.



(a) Comparison in E-field (b) Field distribution of simulator model

Fig. 2 Comparison in E-field by the simulation and measurement

III. APPLICATION SVD FOR ANALYSIS

A. Singular value decomposition (SVD)

SVD is an algorithm of matrix transformation based on Eigen vector. SVD is a mathematical tool used to analyze matrices. In SVD, a matrix is decomposed into three matrices of same size. In this subsection, we present a brief description of the method and its application to the modal analysis of FITD simulation results. The SVD of a matrix A is defined as follows [1,2]:

If $A \in \Re^{m\times n}$ then there exist orthogonal matrices

$$U = (u_1, u_2, \cdots u_m) \in \Re^{m\times m} \tag{1}$$

$$V = (v_1, v_2, \cdots v_m) \in \Re^{n\times n} \tag{2}$$

such that

$$A = USV^T = \sum_{i=1}^{r} u_i \cdot \alpha_i \cdot v_i^T, \quad r = \min\{m, n\} \tag{3}$$

Where

$$S = diag(\alpha_1, \alpha_2, \cdots \alpha_r), \quad \alpha_1 \geq \cdots \geq \alpha_r \geq 0 \tag{4}$$

the vector u_i and v_i are known as the i -th left and right singular vectors, respectively and the diagonal elements. α_i of S are called the singular values of matrix A. Let us consider a physical quantity simultaneously measured at m different positions and sampled at n different times with a sampling interval t_s. The matrix representation of the above observation can be generally expressed by a rectangular array $x_{ij} = x_j\left[(i-1)t_s\right]$, where the row index i refers to time and the column index j to the channel. The SVD of the matrix x_{ij} is expressed as $X_{ij} = U_i^k s_k V_j^k$ .The singular values S represent the amplitude of a mode and U and V are the basis functions. In summary the matrix X_{ij} has been decomposed into three parts - time (U), amplitude (S) and space (V).

B. SVD Analysis on Computed Result

SVD is performed on $E(x_{ij})$ measured at 35 positions(z=2320mm plan) as Fig. 1(c). These locations lie at a distance of 0.8 m in the y direction, field monitors placed. Each channel has 1000 time points with a sampling time of 200ns.

We have applied SVD to the matrix formed by those field data. The 35 singular values of the decomposed components are shown in Fig. 3. Follow the principle of [2], the word dominant is used in an approximate sense to describe modes whose singular values lie within three orders of magnitude of the strongest mode. It shows that there are four dominant modes (Eigen modes).

Fig. 4(a)–(d) shows the eigenvectors corresponding to the modes, in descending order of -value. The eigenvector in Fig. 4(a) is almost constant, this clearly corresponds to the TEM mode. The TEM mode does not have any zero crossing. The number of zero crossing in Eigen vector variation represents the mode numbers. The figure 4. (a), (b), (c) and (d) has one, two and three zero crossing and thereby represents the TM0 (TEM), TM1, TM2 and TM3 modes respectively.

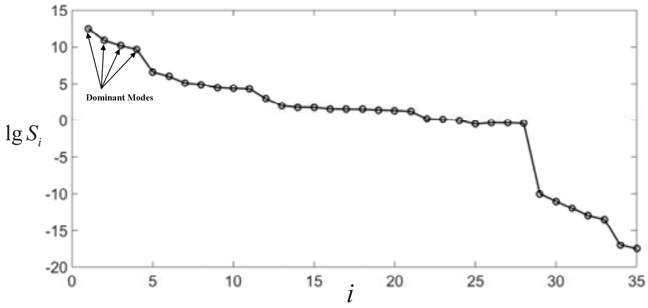


Fig. 3 Log of singular value S_i

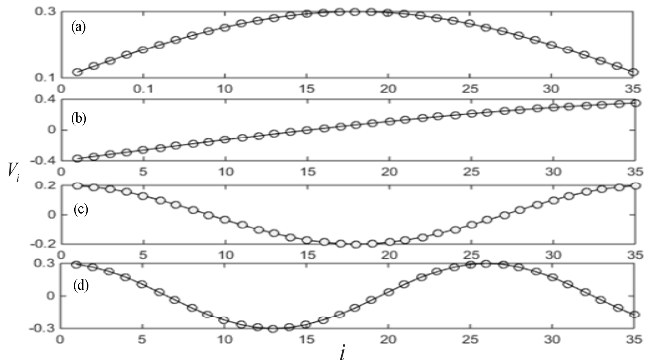


Fig. 4 Eigen vectors of the dominant mode

IV. CONCLUSION

The accuracy of guided-wave EMP simulator model are verified by numerical and experiment method. Time domain finite integral method (FITD) has been used to computed field data and singular value decomposition (SVD) technique has been used to extract the higher order modes of the simulator. The SVD gives 35 modes, the TEM mode is dominant, the three higher order TM modes found to be propagating inside the working zoon. The further research work is applied this method to analysis the relationship between field uniformity and higher order modes.

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