Effect of a Modulated Source on a Multimode Cavity

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Abstract— **Based on a 3-D model the effect of a modulated source on a multimode cavity has been investigated. It turns out that the amplitude modulated (AM) and the phase modulated (PM) sources cannot perturb the field distribution. Only the frequency modulated (FM) source can achieve this goal. It is also found that the key factor governing the field perturbation does not lie in shifting the eigenfrequencies and the modal variables, but lies in varying the ratios of the modal variables.**

I. Introduction

FOR SAME applications such as the electromagnetic compatibility (EMC) assessing, the microwave heating and so on, a cavity operating in the multimode state is desired in order to obtain a more uniform field distribution. Generally speaking, multimodes can easily be generated in a cavity by an appropriate excitation. Even then the field distribution is often not so uniform as that required. To achieve a better uniformity, conventionally, a large rotating stirrer, which may be the device under test or the object under heating itself, in a large rectangular cavity is employed. Such a cavity is usually called a mode-stirred or a reverberating chamber. Recently, Wu and Chang proposed when they investigated the effect of a large stirrer in a mode-stirred chamber using a 2-D model that the stirrer could conceptually be simulated by the external modulation of signal source [1]. Although it is not difficult to understand the possibility of such a simulation, the effect of a modulated source on a multimode cavity needs to be investigated before this alternate method can be applied. Therefore, it is the purpose of this paper to present some results of this investigation based on a 3-D model.

II. The Model

For our purpose let us consider a 3-D rectangular conducting cavity with an aperture arbitrarily located at one wall of the cavity (Fig. 1). The aperture serves as a terminal of an external source. The EM fields inside the cavity are expanded in terms of TE_{mn} and TM_{mn} modes as follows:

$$\mathbf{E} = \nabla \times \nabla \times \mathbf{\Pi}^e - j\omega\mu\nabla \times \mathbf{\Pi}^h \tag{1}$$

$$\mathbf{H} = j\omega\epsilon\nabla \times \mathbf{\Pi}^e + \nabla \times \nabla \times \mathbf{\Pi}^h \tag{2}$$

$$\mathbf{\Pi}^e = \mathbf{a}_z \sum_{m=1}\sum_{n=1} A_{mn}^{TM} \sin(\frac{m\pi}{a}x) \cdot \sin(\frac{n\pi}{b}y)\cosh(k_{zmn}z) \tag{3}$$

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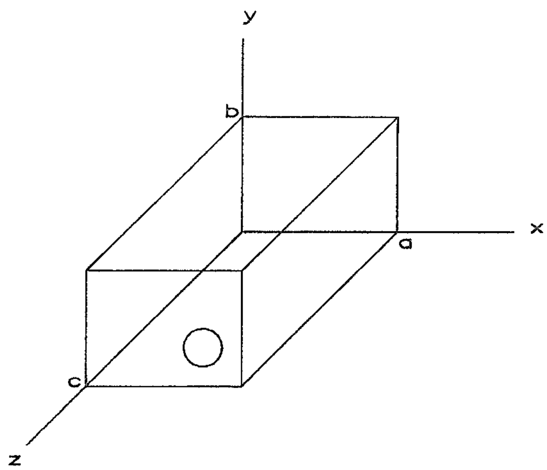

Fig. 1. A rectangular cavity with an aperture.

$$\mathbf{\Pi}^h = \mathbf{a}_z \sum_{m=0}\sum_{n=0} A_{mn}^{TE} \cos(\frac{m\pi}{a}x) \cdot \cos(\frac{n\pi}{b}y)\sinh(k_{zmn}z) \tag{4}$$

where $k_{zmn} = [(m\pi/a)^2 + (n\pi/b)^2 - \omega^2\mu\epsilon]^{1/2}$; $\omega = 2\pi f$ with f the source frequency; A_{mn}^{TM} and A_{mn}^{TE} are the modal variables which depend on the boundary conditions as well as the excitation. Note that time harmonic dependence $\exp(-j2\pi ft)$ is assumed.

Matching fields at the wall where the aperture is located yields

$$\mathbf{n} \times \mathbf{E} = \begin{cases} \mathbf{n} \times \mathbf{E}_a & \text{on the aperture} \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

$$\mathbf{n} \times \mathbf{H} = \mathbf{n} \times \mathbf{E}_a / Z_a \text{ on the aperture} \tag{6}$$

where $\mathbf{n}$ indicates the normal of the wall; $\mathbf{E}_a$ is the source field at the aperture and Z_a is the associated wave impedance of the aperture. Further by processing mode-matching technique [2], namely, performing the cross-products of $\mathbf{h}_t^{TE}$ and $\mathbf{h}_t^{TM}$ on the both sides of eqn.(5) respectively, where $\mathbf{h}_t^{TE}$ and $\mathbf{h}_t^{TM}$ are the transverse magnetic eigenfields of the TE and TM modes, and then taking the integration over the aperture, a system of linear equations with the unknown modal variables can be obtained in the light of the orthogonal properties of the eigenfields. In a similar way a set of linear equations are obtained by performing the cross-products of $\mathbf{n} \times \mathbf{E}_a$ on the both sides of (6) and taking the integration over the aperture. Imposing this set of equations on the system of equations the unknown modal variables can be determined with an

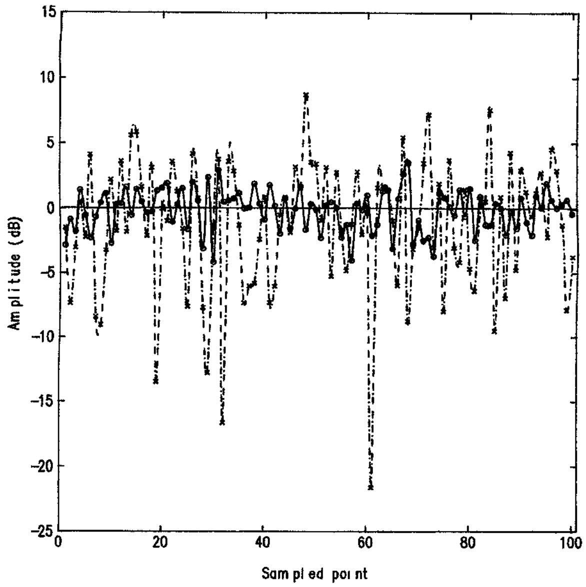

Fig. 2. The E-field amplitudes sampled at 100 random points. (— · × · —) the unmodulated source; (—o—) the FM source.

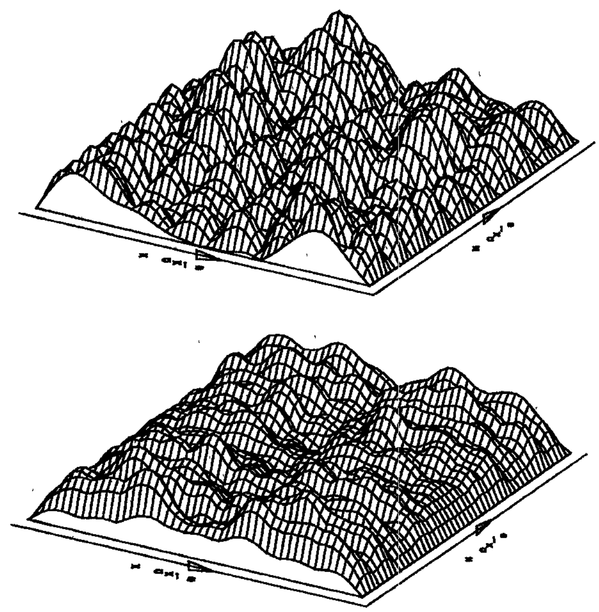

Fig. 3. The E-field profiles. (a) the unmodulated source; (b) the FM source.

assumed aperture field. For our investigation the aperture field is supposed to be

$$\mathbf{E}_a(t) = A(t)e^{-j[2\pi f(t)t+\phi(t)]}\,\mathbf{E}_{\text{eigen}} \tag{7}$$

for simulating the AM, the PM, and the FM sources with random modulation of $A(t)$, $\phi(t)$ and $f(t)$ respectively, where $\mathbf{E}_{eigen}$ represents the eigenfield of the aperture.

III. Simulation Results

For our simulation a cavity size of $a = 1.95$ m, $b = 1.8$ m and $c = 2.1$ m was assumed. The computation was first carried out for an unmodulated source with $A(t) = A_o = 1$, $\phi(t) = \phi_o = 0$, and $f(t) = f_o = 1$ GHz. Next a set of computer simulations were performed for the AM, the PM and the FM sources respectively. It is found that the resultant field distributions for the AM and the PM sources are similar to that for the unmodulated source even though the modal variables are changed. This finding is also applicable to the AM + PM case. More details on their field distributions and modal amplitudes will be presented in a full paper because of the limit space here. It is only by using the FM source that the resultant field distribution changes with respect to time and differs from that obtained by using the unmodulated source.

Fig. 2 illustrates the resultant $|\mathbf{E}| = [|E_x|^2 + |E_y|^2 + |E_z|^2]^{1/2}$ at 100 randomly sampled spatial points in the cavity for the FM and the unmodulated sources respectively. Note for the FM source its frequency was assumed to have a Gaussian distribution with a $mean = f_o$ and a $standard\ deviation = 0.1\ f_o$, and the resultant $|\mathbf{E}|$ in Fig. 2 was obtained by averaging over 20 snapshots. Obviously, a much better uniformity of the field distribution in the cavity can be achieved by using the FM source. The overall improvement in the uniformity can clearly be seen from Fig. 3. In above simulations more than 400 modes were considered.

IV. Conclusions

The study of a 3-D rectangular cavity under the excitation of a modulated source through an aperture has shown that when a FM source is used, a time-averaging field distribution exhibits a uniform feature in the cavity. This evidently indicates that a suitable FM source, which may be a VCO controlled by a noise-like signal, can be used in place of a stirrer as an alternate method to obtain a uniform EM environment in a chamber. Recent experiments carried out at Saab–Scania AB have have shown the potential of this approach [3].

Since the geometrical structure and the filling medium of cavity do not vary in this study, the cavity modal eigenfrequencies, which are independent of the excitation, are not shifted. It follows that the key factor of field perturbation in this case does not lie in shifting the eigenfrequencies, which was suggested by Wu and Chang in their study [1]. Taking together the unsuccessful trials of the AM and the PM sources it is found that the key factor of perturbing the field is that of varying the ratios of modal variables but not the modal variables themselve. This also suggests that a randomly changing in polarization and location of an unmodulated source, which may be realized by controlling an array of antennas, can improve the uniformity in a chamber [4].

References

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