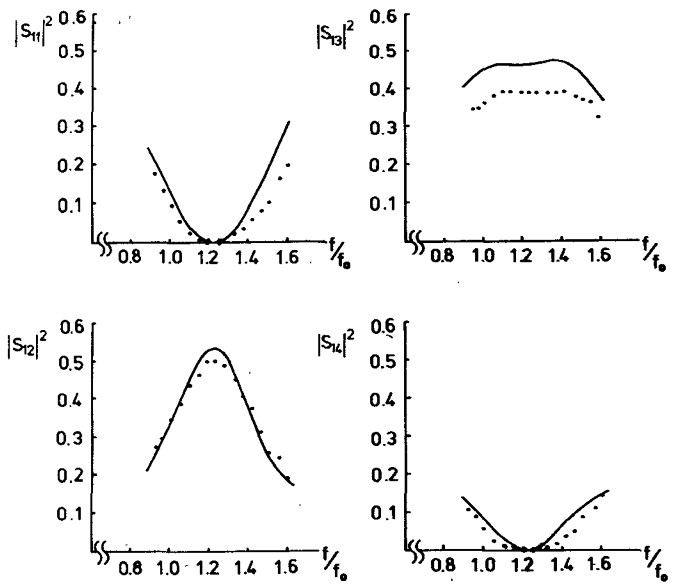

Fig. 10. Comparison of the computed and measured circuit characteristics. (Solid curves: computed; dots: measured.)

about 2.5 s when 10 × 10 modes were considered in each segment. (The computer used was a HITAC-8800.) However, by decreasing the number of considered modes to a reasonable one (for example, 8 × 3), the required time will easily be reduced below 0.7 s. On the other hand, when we used the contour-integral method [1], the estimated time required for the corresponding accuracy was about 5 s.

Generally speaking, comparison of the previous two methods is rather difficult. However, in many cases reduction of the computer time by almost an order of magnitude was possible by the segmentation method without great loss of accuracy as compared with the contour-integral method.

VI. Conclusion

The principle and computation procedure of an efficient method for analyzing a planar circuit, the segmentation method, was presented. To show the usefulness of the proposed method, its application to the trial-and-error optimum design of a hybrid circuit was demonstrated.

The application of the same principle to the short-boundary planar circuit, which has mainly been dealt with by contour-integral analysis [4], will be another interesting task in near future.

Acknowledgment

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References

[1] T. Okoshi and T. Miyoshi, "The planar circuit—An approach to microwave integrated circuitry," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-20, pp. 245–252, Apr. 1972.

[2] P. Silvester, "Finite element analysis of planar microwave networks," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-21, pp. 104–108, Feb. 1973.

[3] N. Marcuvitz, *Waveguide Handbook*. New York: McGraw-Hill, 1951, p. 160.

[4] T. Okoshi and S. Kitazawa, "Computer analysis of short-boundary planar circuits," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 299–306, Mar. 1975.

Temperature Compensation of TE_{011}-Mode Circular Cavities

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***Abstract*—This short paper describes a novel method for temperature compensation of TE_{011}-mode circular-waveguide cavities. Implementation and experimental results on a single cavity are presented.**

Introduction

Temperature compensation of TE_{011}-mode circular cavities has been attempted previously for applications related to wavemeter construction (see [1, secs. 6.22 and 6.25]). The basic idea of temperature compensation is to provide opposite changes in cavity length and diameter with temperature changes so that the resonant frequency remains constant. For cavities intended for operation at a fixed center frequency, it is easily shown that compensation is feasible. The resonant frequency of a cylindrical cavity excited in the TE_{lmn} mode is given by

$$f = \sqrt{\left(\frac{cx_{lmn}}{\pi D}\right)^2 + \left(\frac{cn}{2L}\right)^2} \tag{1}$$

where c is the speed of light, x_{lmn} is the proper root of the Bessel function corresponding to the mode under consideration, and L and D are the length and diameter of the cavity at temperature T_0, respectively. The incremental change Δf in the resonant frequency f due to changes ΔL and ΔD in the cavity dimensions is obtained from (1) by taking its total differential

$$\Delta f = -\frac{(xc_{lmn}/\pi D)^2(\Delta D/D) + (cn/2L)^2(\Delta L/L)}{f}. \tag{2}$$

This change will be zero if

$$\frac{(\Delta L/L)}{(\Delta D/D)} = -\left(\frac{2x_{lmn}L}{n\pi D}\right)^2. \tag{3}$$

Fig. 1 shows a possible implementation of the temperature compensation scheme. The noncontacting tuning plunger is constructed from two disks of the same cavity metal (having linear temperature-expansion coefficient α_c) sandwiching a material with a higher thermal coefficient of expansion (α_p) and a thickness t at the ambient temperature. It can easily be seen that, for the TE_{011} mode, (3) is satisfied if the linear temperature coefficients of expansions α_p and α_c are related by

$$\frac{\alpha_p}{\alpha_c} = 1 + \left(\frac{L}{t}\right)\left\{1 + \left(\frac{2x_{011}L}{n\pi D}\right)^2\right\}. \tag{4}$$

Experimental Results

An experimental TE_{011}-mode circular cavity has been constructed with the tuning plunger designed as in Fig. 1. The cavity material is aluminum and the high-expansion material is a commercially available silicone resin ($\alpha_p \approx 30\alpha_c$). The experimentally measured resonant-frequency shifts of the uncompensated and compensated cavities with temperature are shown in Fig. 2. It can be seen that the 12-GHz compensated cavity has a maximum shift of about 1.5 MHz in a temperature excursion of 100°C. This shift is less than that which would be obtained from a corresponding uncompensated Invar cavity.

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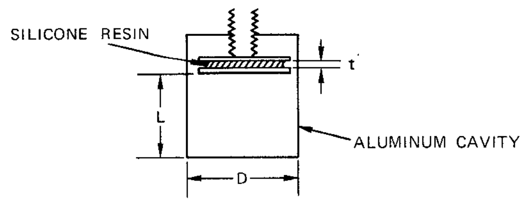

Fig. 1. Construction of tuning plunger for temperature compensation.

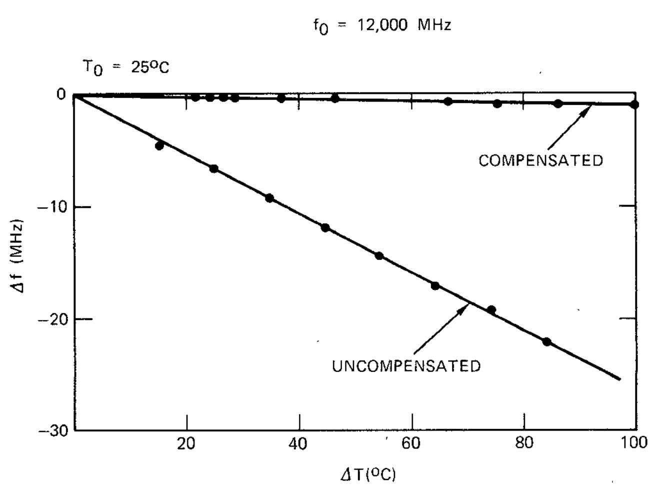

Fig. 2. Measured frequency shift with temperature of the compensated and uncompensated cavities.

Conclusions

A method for temperature compensation of TE_{011}-mode circular cavities is described and excellent frequency stability of a temperature-compensated aluminum cavity is demonstrated. These results should enable lightweight thermally stable bandpass filters to be constructed from aluminum instead of Invar and/or graphite-reinforced fibers. Significant savings in weight and cost of fabrication should therefore be achieved.

References

[1] *Techniques of Microwave Measurements*, C. G. Montgomery, Ed., Radiation Laboratory Series, vol. II. New York: McGraw-Hill, 1949.

Experimental Development of Simulated Biomaterials for Dosimetry Studies of Hazardous Microwave Radiation

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Abstract—Simulated biotissues have been developed which are appropriate for dosimetry studies at X-band frequencies and for S-band modeling experiments which would use miniature phantoms at X-band frequencies. A short-circuited waveguide system has been built and tested for the precise measurement of the dielectric properties of the simulated tissue. Modifications of composition for varying the dielectric properties over a wide range have been found. The specific heats of the materials have been measured and are approximately the same as the tissues they represent.

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I. Introduction

The increasing use of microwaves in radar, ovens, high-frequency communications systems, and new medical and industrial devices has subjected the human population to appreciable levels of short-wavelength electromagnetic radiation. Biological effects of microwave radiation have been reported on many occasions but there is still much uncertainty about the hazards stemming from exposure and the mechanisms, thermal or nonthermal, responsible for the observed effects.

Most analyses on microwave field-related hazards are based on a plane-wave approximation, which may be valid only for far-field regions. However, most hazardous exposure often occurs in the near-field zone, where the field lines may be curved and exhibit strong power gradients. In this region, the human body may interact with and modify the incident radiation field [1]. Unlike ionizing radiation, which travels in essentially straight paths within the body, microwave radiation is modified by reflection, refraction, and diffraction effects, due to the geometrically varying dielectric and absorption properties of tissues. As a result, theoretical analysis of microwave dosimetry is a complicated problem and it is difficult to relate external radiation-field strengths to the actual power density within the body. An alternate approach to quantify hazardous fields is to perform experimental measurements inside artificial tissues or phantom materials which simulate the electrical properties, specific heat, and the size and shape of a human. Guy has developed materials simulating human tissues at S-band frequencies ($f \sim 2450$ MHz) [2]. In order to set a wide-band safety exposure standard, measurements must also be made in other frequency ranges, specifically the higher X band ($f \sim 9$ GHz) which is widely used in radar systems.

II. Scientific Objectives

One goal of our research has been to develop phantom materials which have a range of dielectric properties and specific heat similar to those of tissues within the human body in the X-band frequency range at 20°C. We studied the influence of composition on properties at frequencies of 8.5 and 10.0 GHz for two types of materials, one corresponding to tissues of high water content (muscle) and the other for bone and fatty layers. Table I summarizes the dielectric properties of human tissue at X- and S-band frequencies as reported by Schwan at 37°C [3].

In addition to developing artificial tissue for X-band studies, it is also our goal to simulate S-band total body radiation using smaller and more convenient scale-model phantoms at X-band frequencies. If the model is to be reduced in size from the full scale by a linear factor S, then it can be shown that electromagnetic scaling is achieved if [4]

$$\omega_m = S\omega$$

$$\mu_m = \mu$$

$$\varepsilon_{r_m}' = \varepsilon_r'$$

$$\tan \delta_m = \tan \delta \quad \text{or} \quad \sigma_m = S\sigma$$

with the subscript m denoting the model.

Examination of Table I shows that the materials needed for the scaling of quarter-sized models to simulate S-band exposure by X-band measurements are not greatly different from phantom materials required for full-scale X-band studies. In attempting to produce suitable phantom materials, we employed materials based on the previous work of Guy [2], which had been successful for making S-band phantoms at 20°C, and varied the composition to obtain the desired X-band properties. Muscle is