Coplanar Waveguide Technique for Measurement of Dielectric Constant or Thickness of Dielectric Films

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Abstract

This paper presents results of an investigation aimed at using a coplanar waveguide resonator for virtually instantaneous measurement of the thickness or dielectric constant of insulating films on an open structure. Among possible applications are process monitoring, measurement of liquid films, and the detection of thin ice deposits on aircraft surfaces.

1. Introduction

This paper follows earlier work, in which it was demonstrated that the thickness of films (0.1 mm to 2mm thick) deposited on a metallic substrate could be detected in a noncontacting manner by suspending a metal strip of chosen length at a fixed distance above the film. Such a structure formed a microstrip resonator. Because of one-to-one corespondence of resonant frequency with film thickness, the latter was found by measurement of the resonant frequency. To eliminate the need for microwave test equipment , the resonator was incorporated as the frequency-determining element in an oscillator, whose frequency deviation from a chosen reference, as determined by a simple passive circuit, was converted into a DC voltage by a frequency discriminator. The result was a low cost film thickness monitor [1,2].

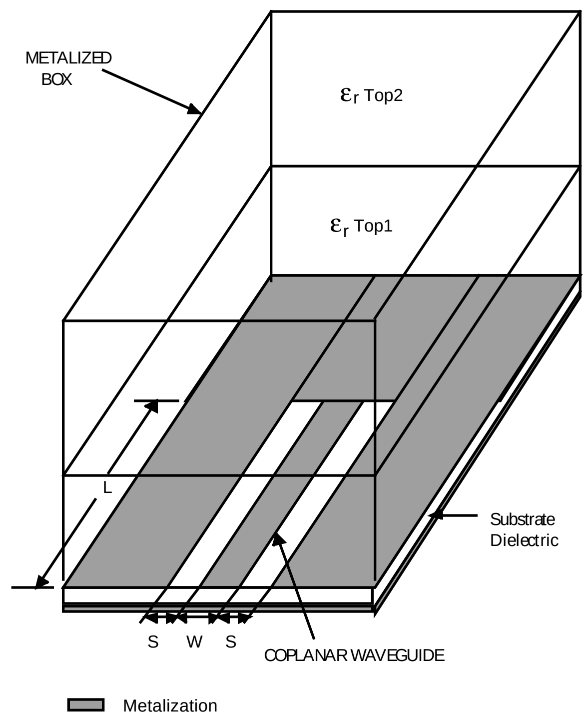

Fig. 1. The simulated circuit.

For some applications, such as the monitoring of films while they are being deposited from the top, or for detection and thickness measurement of ice on the surface of an aircraft, the conductor suspended above the substrate of the microstrip configuration

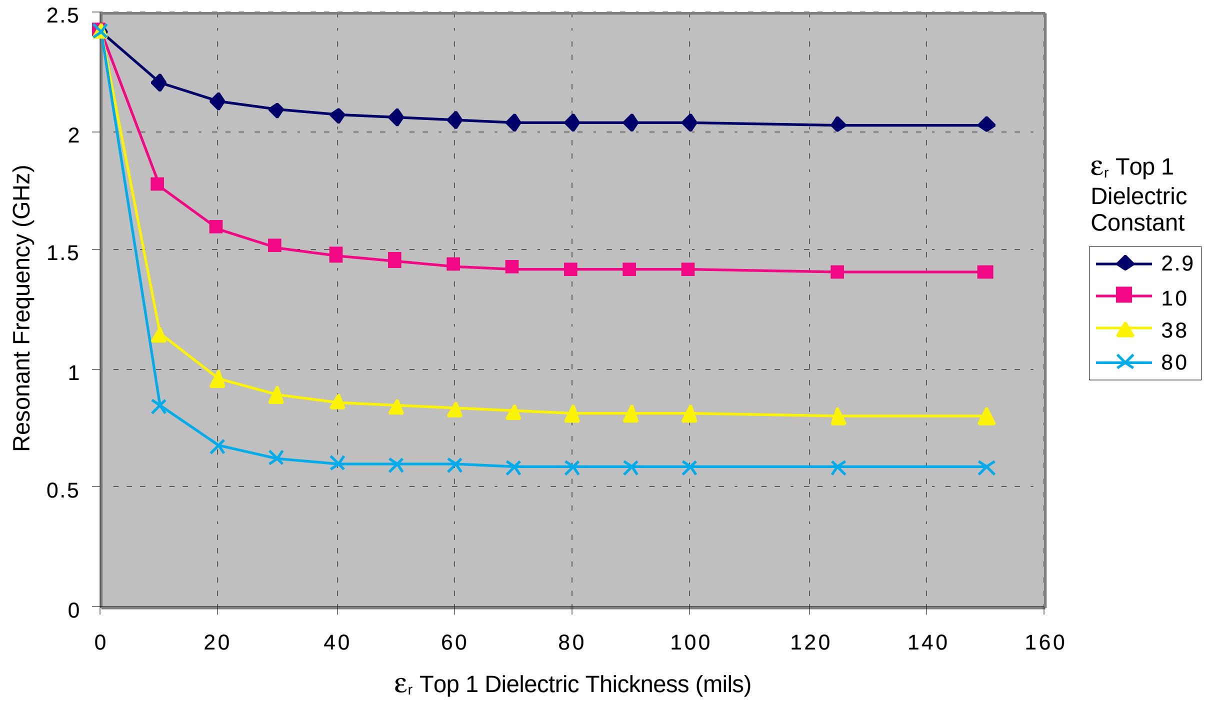

Figure 2. Simulated resonant frequency vs. top dielectric thickness for a substrate dielectric constant of 2.94.

would be unsuitable. The work on which this paper is based aimed at the development of a film thickness monitoring system using a coplanar waveguide resonator which, in effect, measures film thickness for an open structure, i.e., one that is not blocked by a top conductor. A simulation technique was used to find the dependence of resonant frequency on thickness and dielectric constant for such a system. We report on the results of this simulation and experimental results of measurements carried out on such a coplanar structure for various values of the parameters.

2. Procedure and Results

2.1 Simulation

To design the resonator, commercially available software program *em* [3] and *Libra* [4] were used to find the resonant frequency of a quarter wavelength coplanar transmission line resonator with metalized back.

Since the program *em* requires that the circuit being simulated is enclosed in a metal box, the structure actually analyzed was that of Figure 1. Here the volume above the coplanar waveguide was divided into two regions. With the height of the box fixed at one inch and the dielectric constant of the top region kept at unity, the simulations were run for several values of substrate dielectric constant, with different heights and different values of ε_r Top1, the material whose dielectric constant or thickness are the subject of this work. The resonant frequency in each case was determined as that frequency at which the imaginary component of the input impedance to the coplanar structure is zero. An example of results is seen in Figure 2.

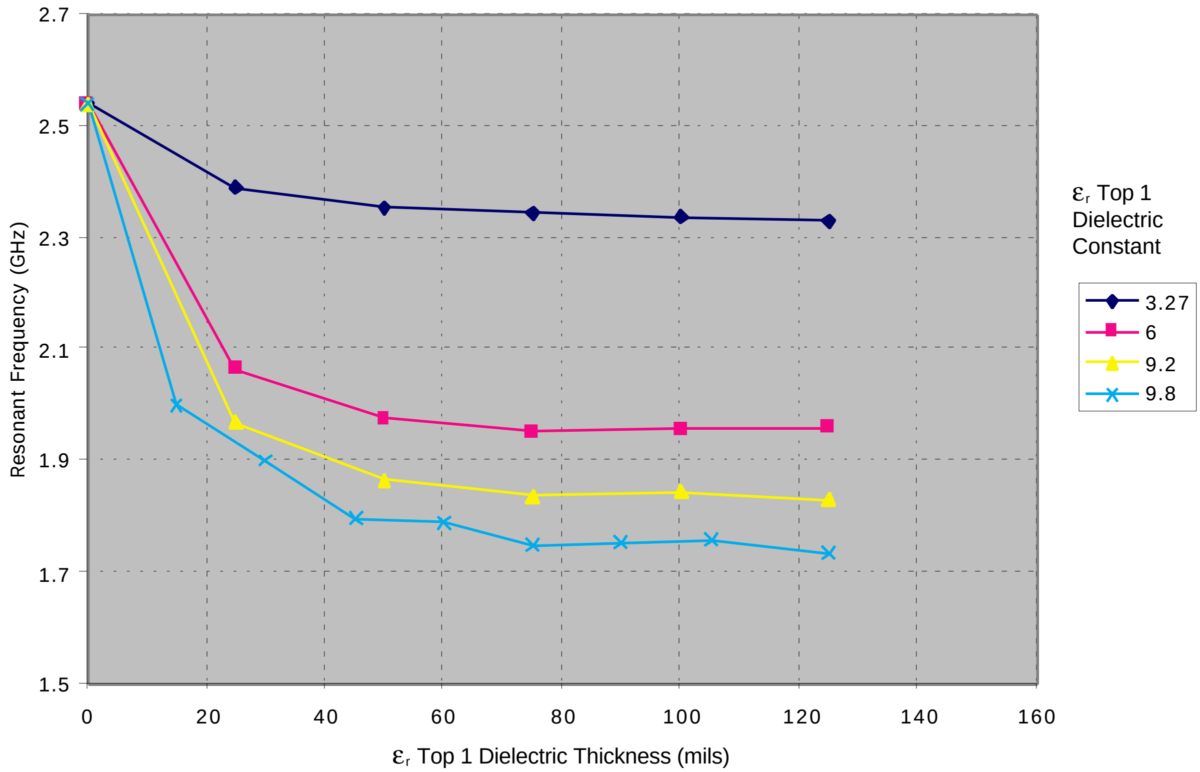

Figure 3. Measured resonant frequency vs. top dielectric thickness for a substrate dielectric constant of 3.27.

It is seen from this figure that for the dimensions of planar waveguide chosen, the resonant frequency is quite strongly dependent on the dielectric constant and, for dielectric thickness above a certain value, relatively independent of thicknes of dielectric.

On the other hand, as seen in Figure 3, for the same waveguide dimensions and for dielectric thickness above 20 mils, the resonant frequency is relatively sensitive to dielectric constant, but less sensitive to thickness.

The field penetration into the dielectric film is strongly influenced by the coplanar waveguide geometry. Therefore the greatest thickness of the film can be controlled by the waveguide spacing.

2.2 Measurements

To put the idea of the use of the coplanar resonator into practice, a resonator was constructed and the resonant frequencies for several dielectric constants and several thicknesses were measured. As expected, several minor problems were encountered. For example, it was found that the use of conductive epoxy as connection to the base plate caused an unexpected loop to exist in the plot of the phase of S_{11} vs. frequency. When conductive soldered edge wrapping was substituted for the epoxy, the loop disappeared.

In addition, differences between simulated and measured frequencies of resonance existed, as seen in the example of Table 1. Because of the approximations in the simulation, the tolerances in components, the possibility of very thin air gaps between the conductors of the coplanar waveguide and the dielectric, and slight differences in assumed and actual reference planes, such differences are also not unexpected. In practice, some trimming and calibration would be required for absolute measurements. However, as seen in Table 2, the expected changes in resonant frequencies with changes in either thickness or dielectric constant of the the film (ε_r Top1) that are the basic idea of this work are highly evident.

3. Conclusion

The work of this paper demonstrates that the dielectric constant of a film or its thickness on an open structure can be found by measurements of the frequency of resonance of a coplanar resonator on this structure. By incorporating this resonator as the frequency determining element of an oscillator, the work of Root and Kaufman [2] of measuring thickness or dielectric constant of films virtually instantaneously, and without the need for microwave test equipment, can be extended to open structures. One such possible application is the detection of ice on the surfaces of aircraft.

Acknowledgement

The topic reported on here is the subject of Mr. Waldo's thesis for the degree of Master of Science in Electrical Engineering at Arizona State University.

References

[1] R.B. Hurley, I. Kaufman, and R.P. Roy, "Noncontacting Microstrip Monitor for Liquid Film Thickness." *Review of Scientific Instruments*, Vol. 61, No. 9, September 1990, 2462-2465.

[2] L.F. Root and I.. Kaufman, "Microwave-Based Low-Cost Instrument for Film Thickness Measurement." *1992 IEEE MTT-s International Microwave Symposium Digest*, 1553-1556.

[3] *em*, produced by Sone Software, Liverpool, NY.

[4] *Libra*, obtained from HP-EEsof, Westlake Village, CA.

Dielec. Thickness (mils)	Measured Resonant Freq. (GHz)	Simulated Resonant Freq. (GHz)
0	2.474	2.43
15	1.789	~1.70
30	1.671	1.523

Table 1. Simulated and measured resonant frequency vs. upper dielectric thickness for substrates of ε_r ~ 3. and 10.

	Frequency (MHZ)		
εr Top 1 Thick. (mils)	εr Top1 = 3.27	εr Top 1 = 6.00	εr Top1 = 9.20
0	2539.4	2539.4	2539.4
25	2390.7	2062.8	1968.7
50	2355.3	1976.5	1866.3
75	2345.4	1954.9	1838.7
100	2338.6	1958.3	1844.2
125	2328.5	1960.9	1829.9
εr Top 1 Thick. (mils)	εr Top 1 = 9.80		
0	2539.4		
15	2002.3		
30	1902.7		
45	1798.7		
60	1788.2		
75	1750.6		
90	1752.6		
105	1759.4		
120	1733.9		

Table 2. Measured resonant frequency of a coplanar resonator at variable film dielectric constant. The substrate ε_r = 3.27.

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