Int. J. Chem. Sci.: 7(2), 2009, 784-790

THERMAL EFFECTS IN MICROSTRIP LINE COUPLERS

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ABSTRACT

The microstrip structure suffers from conductor and dielectric losses due to flow of electromagnetic power through it. These losses generating heat in the strip conductor and the supporting dielectric substrate are called thermal effects in the structure. For the coupled microstripline coupler, the thermal effects produced are the functions of the strip width, substrate height, permittivity, spacing between two strip conductors and operating frequency. The rise of temperature in the structure is utilized in preserving foods, seeds, other agriculture products and in warming the surroundings.

Key words : Thermal effect, Microstrip, Coupler, Dielectric loss

INTRODUCTION

The increasing importance of miniature planar microwave integrated circuit has renewed interest on the part of the microwave circuit designer in various forms of planar strip transmission line system. Of the many configurations, microstrip line is the most simple and open structure which is more covenient and less expensive. Though attenuation in this structure is relatively small, it is necessary to study the thermal effects produced in the single and coupled microstrip structure for practical utility of microwave power having Gigahertz frequency flowing in such structures. There are two important losses in the structure, namely

(i) Conductor or ohmic skin loss

(ii) Dielectric loss

Electromagnetic power flowing through the structure causes generation of heat and subsequent rise in ambient temperature (i. e. surrounding the structure) called "thermal effect". This effect is studied by calculating the density of heat flow due to conductor and dielectric losses and consequent rise of temperature.

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Density of heat flow due to conductor loss

Loss of electromagnetic power in the strip conductor generates heat in the metal strip. Because of good heat conductivity of the metal strip, heat generation is uniform along the width of the conductor.

In order to calculate the heat flow, parallel plate model of microstrip line is used. The equivalent width of the metal strip (W_e) in the parallel plate model is obtained by the electrical analogue as

$$W_e = 120\ \pi h/Z_o\sqrt{\in_{reff}} \qquad \dots(1)$$

Where h = substrate height, Z_o = characteristic impedance of the structure and, $\in_{reff}$ = effective dielectric constant.

The thermal power absorbed (ΔP) in the structure due to conductor loss is given by–

$$\Delta P = 0.2303\ \alpha_c\ (\text{watt/m}) \qquad \dots(2)$$

where α_c (dB/m) is the attenuation co-efficient due to conductor loss, which is given by –

$$\alpha c = 8.68\ R_s/Z_o W_e \qquad \dots(3)$$

In this expression, R_s is surface resistivity of the metal strip and it is expressed as

$= \sqrt{(\pi \mu f/\sigma_c)} \approx 11.58 \times 10^{-3}\ \Omega/m^2$ for Cu

F = Operating frequency = 2 Ghz

σ_c = Electrical conductivity of the metal strip

$\mu = \mu_o\ \mu_r$ (μ_r = 1 for Cu conductor) and

$\mu_o = 15.57 \times 10^{-7}$ H/m.

The density of heat flow due to such power absorption is given by–

$$q_c = 0.2303\ \alpha_c/W_e\ (\text{watt/m}^2) \qquad \dots(4)$$

Density of heat due to dielectric loss

In addition to the conductor loss, heat is also generated in the microstrip structure due to dielectric loss. In parallel plate model, electric field is uniform and so density of heat flow is also assumed to be uniform. The density of heat generated is given as–

$$\rho h = 0.2303\ \alpha_d/W_{eff}.\ h \qquad \ldots(5)$$

Where $\alpha_d = (27.3 \tan \delta/\lambda_o)\ \{(\in_r/\in_{reff}$

$$((\in_{reff}-1) / (\in_r-1)\} \qquad \ldots(6)$$

In the above expression, the meaning of the symbols is given below–

λ_o = Free space wavelength of the electromagnetic wave passing through the structure = 0.15 m at f = 2 GHz.

$\in_r$ = Relative permittivity of the substrate and

$\in_{reff}$ = Effective permittivity of the substrate

For the mid part of the substrate, density of heat flow is given by

$$q_d = -[0.2303\ \alpha_d / W_{eff}.\ (h/2)] \qquad \ldots(7)$$

Total density of heat flow and rese of temperature

The total density of heat flow due to conductor and dielectric losses may be expressed in terms of temperature gradient as [2, 3, 4 and 5]

$$q = q_c + q_d = K\ (\partial T / \partial y) \qquad \ldots(8)$$

This gives the corresponding rise of temperature expressed as –

$$\Delta T = (0.2303h/K)\ [(\alpha_c.\ W_e) + (\alpha_d / 2W_{eff})]^oC/Watt \qquad \ldots(9)$$

In case of microstrip coupler, there are two modes of propagation of waves (i) Even-mode, when power flows in the same direction (ii) Odd-mode, when power flows in opposite direction.

For even-mode, W_{eff} is replaced by $(W_{eff})_e$ and Z_o by Z_{oe}, α_c by $(\alpha_c)_e$, α_d by $(\alpha_d)_e$, q_c by $(q_c)_e$, q_d by $(q_d)_e$ and ΔT by $(\Delta T)_e$, whereas in odd-mode "e" is replaced by "o". Finally–

$$(\Delta T)_e = (0.2303\ h/K)\ [(\alpha_c)_e/W_e)_e) + ((\alpha_d)_e / 2W_{eff})_e]\ ^oC/watt \qquad \ldots(10)$$

and in odd-mode

$$(\Delta T)_o = (0.2303\ h/K)\ [(\alpha_c)_o / W_e)_o) + ((\alpha_d)_o / 2W_{eff})_o]\ ^oC/watt \qquad \ldots(11)$$

EXPERIMENTAL

Analytical study of the density of heat flow and rise in temperature

The analytical study of the thermal effects produced in the microstrip coupler in case of even- and odd- modes have been carried out by computing the results using different geometries of the structure at different frequencies in the following subsections.

(i) Study of variation of the thermal effects (ΔT) for even-and odd-mode with frequency (shown in Table 1 and Fig. 1).

(ii) Study of variation of α_c, α_d, q_c, q_d and ΔT with relative permittivity ($\in_r$) for even- and odd-modes (shown in Table 2 and Fig. 2).

Table 1 : Variation of rise in temperature (ΔT) for even- and odd-mode with frequency (f). (W = 100 Mils, h = 100 MILS, S = 100 MILS, t = 0.01 MILS, $\in_r$ = 9.6 (Alumina substrate) and K = 37 W/moK)

f GHz	Even - mode			Odd - mode		
	$(q_c)_e$ W/m^2	$(q_c)_e$ (h/2) W/m^2	$(\Delta T)_e$ ^{o}C/watt	$(q_c)_o$ W/m^2	$(q_d)_o$ (h/2) W/m^2	$(\Delta T)_o$ ^{o}C/watt
1	25.87	0.0011	0.00177	22.75	0.0006	0.00154
10	28.66	0.0016	0.00194	25.53	0.0009	0.00173
20	29.75	0.0018	0.00202	27.86	0.0012	0.00189
30	29.82	0.0018	0.00202	28.38	0.0013	0.00192
40	29.93	0.0018	0.00203	28.95	0.0014	0.00196
50	30.04	0.0018	0.00204	29.23	0.0015	0.00198

Table 2 : Variation of a_c, a_d, q_c. q_d q and rise up temperature (ΔT) with relative permittivity ($\in_r$) of different substrate for even –and odd-mode (W = 100 MILS, h = 100 MILS, S = 100 MILS, t = 0.01 MILS, f = 2 GHz and k = 37 W/m ^{o}K)

Relative permittivity $\in_r$	Even – mode					
	Z_{oe} in Ω	$(\in_{reff})_e$	$(\alpha_c)_e$ dB/m	$(\alpha_d)_e$ dB/m	$(q)_e$ W/m^2	$(\Delta T)_e$ ^{o}C/watt
2.4	106.88	1.98	0.3702	0.0108	13.5305	0.0009

Cont…

Relative permittivity $\in_r$	**Even – mode**					
	Z_{oe} in Ω	**$(\in_{reff})_e$**	**$(\alpha_c)_e$ dB/m**	**$(\alpha_d)_e$ dB/m**	**$(q)_e$ W/m^2**	**$(\Delta T)_e$ ^{o}C/watt**
9.6	58.95	7.31	0.6712	0.0237	25.7611	0.0018
11.6	54.50	9.12	0.7261	0.0267	28.8313	0.0020
16	46.46	12.22	0.8517	0.0311	33.8115	0.0023
18	42.40	13.78	0.9333	0.0331	35.8216	0.0025

Relative permittivity $\in r$	**Odd - mode**					
	Z_{oe} in Ω	**$(\in_{reff})_e$**	**$(\alpha_c)_e$ dB/m**	**$(\alpha_d)_e$ dB/m**	**$(q)_e$ W/m^2**	**$(\Delta T)_e$ ^{o}C/watt**
2.4	75.0800	1.8400	0.5270	0.0096	13.0503	0.0009
9.6	44.0100	5.6700	0.8991	0.0192	22.7506	0.0016
11.6	39.2000	6.7500	1.0095	0.0220	24.9906	0.0017
16	34.9800	9.1100	1.1312	0.0260	28.9408	0.0020
18	33.1400	10.2000	1.1941	0.0277	30.5509	0.0021

Study of variation of ΔT with frequency

The results of variation of rise in temperature due to generation of heat in the structure caused by conductor and odd-modes with frequency have been computed. These results have been presented in Table 1 and graphs have been plotted with frequency on X-axis and ΔT on Y-axis. The results show that with increase of frequency, heat generation and rise of temperature increases both in even- and odd-modes of propagation. But rate by variation of (ΔT) in odd-mode is larger than that of ΔT in even-mode. The curves are converging in nature. This concludes that losses increase with increase in frequency having impact on flow of power through the structure. Further even-mode thermal effect is larger than that in odd-mode propagation and have the tendency to be closer with rise in frequency as shown in Fig. 2.

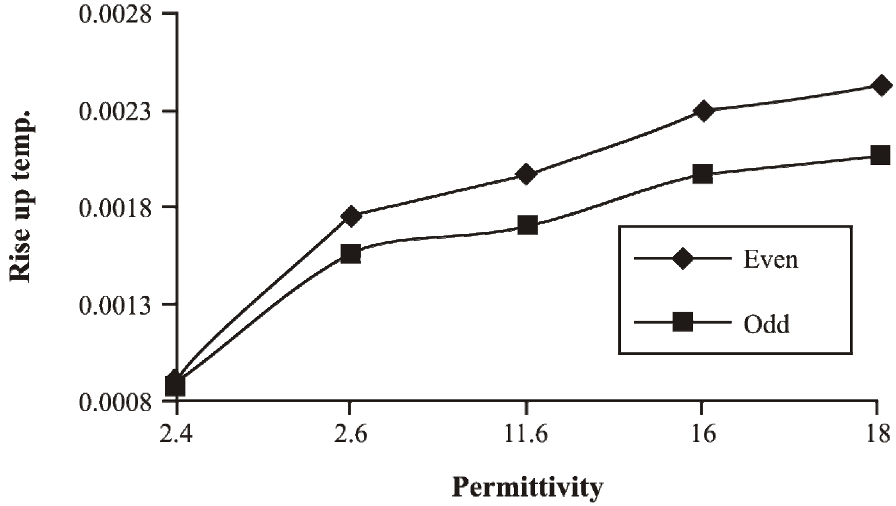

Fig. 1: Variation of rise in temperature (ΔT) with relative permittivity ($\in_r$) of different substrate for even-mode

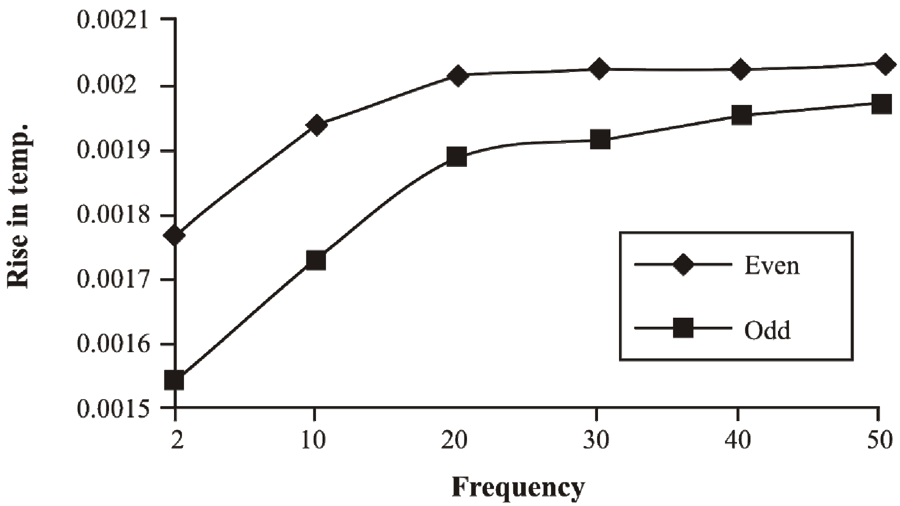

Fig. 2 : Variation of rise in temperature (ΔT) even- and odd- node with frequency (f)

Study of variation of ΔT with relative permittivity

For study of variation of α_c, α_d, q_c, q_d and finally ΔT with relative permittivity ($\in_r$) for even- and odd- modes of propagation results have been computed and presented in Table 2. Plotting $\in_r$ on X-axis and ΔT on Y-axis graphs have been plotted for both; even- and odd- modes. The results show that ΔT is larger for even-mode than that for odd-mode.

Further ΔT increases with increase of $\in_r$. This concludes that thermal effect for both even- and odd-modes increase with permittivity showing greater loss in case of dielectric medium of higher permittivity

RESULTS AND DISCUSSION

From the discussion of the above results, it is evident that the thermal effects produced due to losses are functions of geometry of the structure, permittivity of the substrate and operating frequency. These results are useful in designing the diathermy machine and machine useful for dielectric materials. The practical implication of the result is that the temperature can be controlled by adjusting the geometry and operating frequency which are useful in preserving the agriculture products, seeds and other food materials. Thus heating by microwaves of gigahertz frequency can be supposed to be another mode of heat transfer like transfer of heat by conduction, convection and radiation. In the mode, heat is produced directly at the locations of the dielectric losses.

ACKNOWLEDGEMENT

Author is thankful to Dr. B. N. Roy, Ex. Pro-Vice Chancellor, B. R. A. Bihar University and Dr. S. C. Prasad, Professor of Physics and Dean, Faculty of Science, B. R. A. Bihar University, Muzaffarpur for encouragement from time to time.

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Accepted : 15.01.2009