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Temperature Sensitivity of Microstrip Patch Antenna

Ehsanul Kabir[1], Md. Abdul Momin[1]

Abstract

Microstrip substrates were exposed to large temperature variations and their temperature dependent properties were measured. In this paper microstrip substrates were exposed to large temperature variations and their temperature dependent properties were analyzed for the analysis of characteristic behaviors of microstrip patch antennas. A parametric study of temperature sensitivity for circular microstrip patch antenna utilizing a substrate with a lower dielectric constant and thermal coefficient is found to be less sensitive to the temperature variations.

Key words : Environmental conditions, Microstrip patch antenna, Temperature sensitivity

1. Introduction

Due to their structural simplicity, ease of construction, ruggedness, conformability, low profile and low cost, microstrip patch antennas have widely been used in various communication systems. In some of these applications, a patch antenna often has to work in harsh environment characterized by large temperature variations. The result is that the electrical properties of microstrip patch antenna suffer from unwanted variations.

In the common approach to the design of microstrip antennas, the designers rely on the data provided in the manufactures' specifications even though such specifications are confined to standard environmental conditions. In practice, the electrical parameters of the substrates may deviate from the manufactures' data, thus making the antenna designer adopt a deficient design strategy. Microstrip patch antennas are widely used in GPS, thus it can be used in precision agriculture. The objective of this paper is to find out the temperature sensitivity for microstrip patch antenna for different types of substrates .

2. Theoretical Analysis

The resonant frequency of a microstrip antenna is sensitive to large temperature variations. There are two major factors affecting the resonant frequency of a microstrip radiator exposed to large temperature (Weiss, 1981).

2.1 Metallic expansion or contraction

The metallic expansion or contraction of the radiating patch due to a change in temperature affects the resonant frequency. With an increase in temperature, patch expands, making the effective resonant dimension longer and therefore decreasing the operating frequency (Traut, 1989). The relative frequency change for dimensional changes may be expressed in terms of linear dimensions or in terms of temperature change as follows (Carver & Mink, 1981; Roy, 2001).

$$\delta f / f_o = -\delta L / L = \alpha d \, \delta T \quad (1)$$

where

f_o Resonant frequency

δf Change in resonant frequency

δL Change in effective resonant dimension

αd Thermal coefficient of expansion

δT Temperature change in ° C

2.2 Effective dielectric constant change

Most of the substrates which are generally used for microwave applications like polytetra fluroethylene based materials, teflon/fiberglass reinforced materials and ceramic powder filled TFE materials exhibit a decrease in dielectric constant with an increase in temperature (Roy, 2001). The change in operating frequency of a microstrip antenna due to a small change in ϵ_r can be expressed as follows (Carver & Mink, 1981) :

$$\delta f / f_o = -1/2 \delta\epsilon_r / \epsilon_r = \alpha\epsilon d \, \delta T \quad (2)$$

where

ϵ_r is dielectric constant

$\delta\epsilon_r$ is the change in ϵ_r &

$\alpha\epsilon$ is the thermal coefficient of dielectric constant

The change in resonant frequency due to a temperature variation δT is given by (Roy, 2005):

$$\delta f / f_o = (-\alpha d + 1/2 \, \delta_F) \, \delta T \quad (3)$$

δ_F is the change in frequency

[1]Lecturer, Department of Farm power and Machinery, Bangladesh Agricultural University, Mymensingh

3. Temperature Dependence of Substrate Parameters

Of the various materials used in microstrip technology teflon, ceramic and polystyrene laminates, dielectric foams and honey comb composites have already found wide acceptance.

The investigated substrates were divided into four categories namely A, B, C and D according to the composition of the material and the temperature dependence of dielectric constant. Categories A and B include teflon-glass microwave laminates. Substrates of category A were characterized by dielectric constants whose values decrease with temperature where the drop had approximately constant gradients, which varies slightly when a phase transition of glass occurred. We note that the phase transition phenomenon involves changes in molecular thermal mobility which is associated with transformations of the amorphous phase of materials from a glassy to a rubbery state. (Kumprasert & Kiraron, 1995). Phase transition in glass occurs at 20-30°C(68-86°F) and is accompanied by a variation in the dielectric constant and dissipation factor and by an increase in the thermal expansion coefficient.

Category B laminates were characterized by a dielectric constant with a gradient value differing markedly in at least two temperature subranges of the dielectric constant plot.

Regardless of this effect, the laminates experienced phase transition. It is worth while to mention that the category B laminates had dielectric constants, which were almost independent of temperature in the lower temperature subrange and showed a remarkable temperature dependence in the upper subrange.

Category C materials were laminates with uniformly dispersed ceramic filter in a teflon matrix. Typical examples of this category are RT/duroid 6010 and AR 1000. The measured dielectric constant value changed by 6.9%. There was negligible variation in the dielectric constant with frequency in the temperature range of -60^0 C to $+25^0$ C and a slight variation with frequency in the higher temperature range, reaching a maximum of 0.8% at $+80^0$ C.

One of the recently recommended category D materials for use in microstrip antennas is a quartzbased composite, which consists of short quartz fibers bonded together. The development of this material was originally stimulated by the needs of thermal insulation engineering.

Compared to the materials of category A, B or C the dielectric constant value of category D material varied only slightly i.e. from 1.718 at -120^0 C to 1.645 at +160 ^{0}C(4.3%). The dissipation factor turned out to be ultra low, varying from 0.00043 at -120 ^{0}C to 0.0005 at $+160^0$ C.

4. Methodology

The experiment was carried out for two categories A and B with teflon-glass microwave laminates and also for different substrate thickness and radius of circular microstrip antennas (CMSA). Dielectric constant and dissipation factor for the two categories A and B are measured for different temperatures to find out the manufacturer's specification are valid or not for large temperature variations.

5. Result and Discussion

In the analysis, ϵ_r is used for smaller h/r and ϵ_{dyn} is used for larger h/r since the capacitive effect of a circular microstrip antenna (CMSA) increases with h/r (h being substrate thickness and r the redius of CMSA). Simulations have been carried out for different radii and substrate parameters for the CMSA. The reported (Kumprasert & Kiranon, 1995 Richards, 1995; Suzuki & Chiba, 1984) and simulated results are specified only for the last four cases in the reported results and hence the feed point locations are calculated for the other cases to match a 50 ohm input impedance. The comparison of results for CMSA has been shown in Table 1.

The measured temperature characteristics of the dielectric constant for two laminates representing categories A and B, respectively are plotted in Fig. 1. As shown in Fig. 1, the measured values for material A ranged from 2.82 at -60^0 C to 2.45 at $+20^0$C and 2.27 at $+80^0$C.

The changes in the dielectric constant as a function of frequency was less than 0.15% for material A and less than 0.5% for material B. The measured temperature characteristics of the dissipation factor for both laminates are presented in Fig. 2. The measured value for laminate A was almost frequency independent. This value was much lower than the one quoted in the manufacturer's specification factor for laminate B was close to 0.0017 at temperatures between $+30^0$ C and $+50^0$ C and complied with the data sheets only for a limited temperature range.

Table 1. Comparison of results for CMSA

Case no.	ϵ_r	r, cm	h, cm	Feed point, cm	Reported frequency, MHz	Simulated frequency, MHz	% error
1	2.50	3.493	0.1588	2.43	1570	1547	-1.53
2	2.59	1.270	0.0794	1.65	4070	4111	+0.98
3	2.50	3.493	0.3175	2.30	1510	1536	+1.65
4	2.70	13.894	1.2700	9.00	378	375	-1.06
5	4.55	4.950	0.2350	3.75	825	816	-1.21
6	4.55	3.975	0.2350	3.03	1030	1007	-2.33
7	4.55	2.990	0.2350	2.25	1360	1368	+0.51
8	4.55	2.000	0.2350	1.48	2003	2013	+0.45
9	4.55	1.040	0.2350	0.73	3750	3716	-0.93
10	4.55	0.770	0.2350	0.51	4945	4885	-1.23
11	2.62	6.700	0.1590	5.02	798	806	+0.88
12	2.20	3.000	0.1590	2.05	1920	1899	-1.15
13	2.50	4.190	0.1590	3.17	1304	1298	-0.46

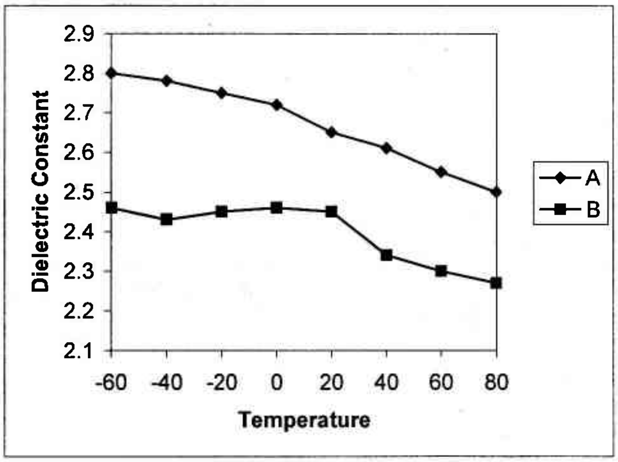

Fig. 1. Measured dielectric constant for two categories(A and B) of glass-reinforsed teflon laminates

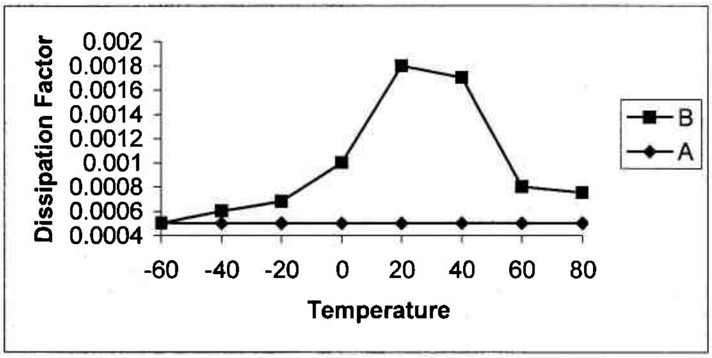

Fig. 2. Measured dissipation factor(tanδ) for two categories (A and B) of glass-reinforced teflon laminates

Having measured the values of the diecletric constant for laminates A and B, it was interesting to compare them the values specified by the manufacturers.

6. Conclusions

The parametric study of microstrip patch antenna has been carried out. The simulated resonant frequency values are in good agreement with the reported values. The error in the resonant frequency for most of the cases is around 1%, however the error in the worst case is 2.33%.

A through study is made to see the performance of microstrip patch antennas that are exposed to large temperature variations. For microwave laminates, the measured dielectric constant and dissipation factor often differ from the values of the investigated cases the measured dielectric constant value was greater than the one specified in the data sheets. In general, the manufacturers' specifications are valid only for a limited temperature range. Hence, the values provided by relevant data sheets are inadequate when the substrate is exposed to large temperature variations. This deficiency is the temperature dependence of the dielectric constant of the microwave laminates studied.

In consequence, the electrical characteristics of microstrip patch antennas that involve layered dielectrics are considerably influenced by temperature. A microstrip patch antenna utilizing a substrate with a lower dielectric constant and thermal coefficient is less sensitive to the temperature variations.

Microstrip patch antennas are used in GPS so it can help in precision farming. Such as for controlling the off road vehicles like tractor, combine harvester, etc and maintaining the crop row and line. It can also be used in drawing the topographic map of agricultural land. Microstrip patch antennas are gaining popularity for use in wireless application for their low profile structure. Therefore they are extremely compatible for embedded antennas in wireless devices such as cellular phones, pagers etc. Thus it can help to transmit agricultural data or information also. Another area where they have been used successfully is in satellite communication and help for the mapping any particular land or area. They are also mechanically robust when mounted on rigid surfaces.

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