Parametric study of temperature sensitivity for microstrip patch antenna

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Microstrip substrates were exposed to large temperature variations and their temperature dependent properties were measured. A parametric study of the 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

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1 Introduction

Due to their significant merits, microstrip patch antennas have widely been used in various communication systems. These antennas, being low profile and light-weight, are becoming popular for various applications. In some of these applications, a patch antenna is required to operate in an environment that is close to what is defined as room or standard conditions. However, antennas often have to work in harsh environments characterized by large temperature variations. The result is that the electrical properties of microstrip patch antennas suffer from unwanted variations.

In the common approach to the design of microstrip antennas, the designers rely on data provided in the manufacturers' specifications, even though such specifications are confined to standard environmental conditions. In practice, the electrical parameters of the substrates may deviate from the manufacturers' data, thus making the antenna designer adopt a deficient design strategy.

In this paper microstrip substrates were exposed to large temperature variations and their temperature dependent properties were analyzed for the analysis of characteristic behaviours of microstrip patch antennas. A parametric study of the temperature sensitivity for microstrip patch antenna for different types of substrates has been carried out.

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 variations:

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, the metallic patch expands, making the effective resonant dimension longer and, therefore, decreasing the operating frequency. The relative frequency change due to dimensional changes may be expressed in terms of linear dimensions or in terms of temperature change as follows:

\[ \frac{\delta f}{f_0} = - \frac{\delta L}{L} = \alpha_d \delta T \quad \text{... (1)} \]

where

- \( \delta f \): Change in resonant frequency
- \( \delta L \): Change in effective resonant dimension
- \( \alpha_d \): Thermal coefficient of expansion
- \( \delta T \): Temperature change in °C.

2.2 Effective dielectric constant change

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

...
The change in resonant frequency due to a temperature variation \( \delta T \) is given by:

\[
\frac{\delta f}{f_0} = - \frac{1}{2} \alpha_e \delta T
\]  

\[
\frac{\delta f}{f_0} = - \frac{1}{2} \varepsilon_r \delta T
\]

where, \( \delta \varepsilon_r \) is the change in \( \varepsilon_r \) and \( \alpha_e \) is the thermal coefficient of dielectric constant.

The change in dielectric constant with frequency can be slight variation with frequency in the temperature range of -60°C to +25°C (77°F) and a slight variation with frequency in the higher temperature range, reaching a maximum of 0.8% at +80°C.

One of the recently recommended category D materials for use in microstrip antennas is a quartz-based composite, which consists of short quartz fibres 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 the category D material varied only slightly, i.e. from 1.718 at -120°C to 1.645 at +160°C (4.3%). The dissipation factor turned out to be ultra low, varying from 0.00043 at -120°C to 0.0005 at +160°C.

4 Results and discussion

In the analysis, \( \varepsilon_r \) is used for smaller \( h/r \) and \( \varepsilon_{\text{dyn}} \) 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 radius of CMSA). Simulations have been carried out for different radii and substrate parameters for the CMSA. The reported and simulated results are shown in Table I. The feed point locations 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 \( \Omega \) input impedance.

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°C to 2.56 at +80°C. There was a noticeable phenomenon of glass phase transition as observed at 23°C. For the material representing category B, the measured dielectric constant ranged from 2.46 at -60°C to 2.45 at +20°C and 2.27 at +80°C. The changes in the dielectric constant as a function of frequency for laminates A and B were less noticeable. The relative change 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 approached 0.005 and was almost frequency independent. This value was much lower than the one quoted in the manufacturer’s specification. The highest measured value of the dissipation factor for laminate B was close to 0.0017 at temperatures between +30°C and +50°C and compiled with the data sheets only for a limited temperature range.
Having measured the values of the dielectric constant for laminates A and B, it was interesting to compare them with the values specified by the manufacturers.

### 5 Conclusions

The parametric study of circular 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 thorough study is made to see the performance of microstrip patch antennas that are exposed to large temperature variations. The obtained results allow the following general comments. For microwave laminates, the measured dielectric constant and dissipation factor often differ from the values recommended in the data sheets. What is more, in all 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 utilising a...
substrate with a lower dielectric constant and thermal coefficient is less sensitive to the temperature variations.

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References