CHAPTER 5

EFFECTS OF TEMPERATURE VARIATIONS ON PERFORMANCES OF MICROSTRIP ANTENNA

5.1. INTRODUCTION

One of the most important requirements for an antenna is to provide the stability of antenna parameters under meteorological factors change, in particular, under temperature conditions change. During a year the environment temperature depending on the geographical position can vary in the range from -50ºC to +50ºC. Under the influence of solar radiation or other factors the top limit for the antenna heating temperature can reach much larger values. In the report the temperature effect on a patch antenna deformation, its pattern and antenna matching with a feeder are considered. The research is made on the flat cavity antenna with round aperture. Flat antennas provide high electrodynamics, mass-overall and design-engineering characteristics. The operating principle of an antenna is based on co-phased excitation of radiating elements of a partially transparent wall by the resonance mode of the cavity antenna resonator fundamental oscillation. Flat antennas have no complex pattern forming scheme distributing electromagnetic energy between emitters. A temperature is one of the parameters that have a great effect on the performance of microstrip antennas for TM\textsubscript{10} mode at 2.4 GHz frequency range [1]. In some applications, a microstrip 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 temperature variations. In this case, the substrate properties suffer from some variations. The effect of that variation on the overall performance of a microstrip conformal antenna is very important to study under a wide range of temperature. For a microstrip antenna fixed on a projectile that fly at a long distance, the temperature will be an issue for the performance of that antenna. A large variation of temperature will be considered during the study. The
temperature affects the dielectric constant of the substrate and also affects expansion of
the material which increase or decrease the volume of the dielectric with increasing or
decreasing the temperature. As the temperature increases, the effective dielectric
constant is also increases for different materials used. On the other hand, the resonance
frequency decreases with increasing temperature, while VSWR and return loss
decreases as the temperature increases. Therefore in present work we have studied the
effects of temperature changes on the performances; resonance frequency, input
impedance, voltage standing wave ratio, and return loss of microstrip patch antenna.

5.2. TEMPERATURE'S EFFECT ON AN ANTENNA

Antenna ground planes from the bottom section of an antenna, and the ground plane can act
as a reflector also for a transmitted signal and provide electrical grounding. The ground
plane also acts as the second half of a dipole antenna. Antenna ground plane performance
depends on its temperature, humidity and conductivity. Antenna temperature and the
temperature of its environment correlate to radiation resistance. According to "Antenna and
Wave Propagation", the noise temperature of a loss-less antenna is equal to the sky
temperature and not the physical temperature. Higher temperatures equal a higher radiation
resistance. This increases the signal loss of the antenna and interferes with the performance
of the ground plane. Frozen water carries signals through the ground better than dry earth.
Ground plane signal reception can be made worse by environmental conditions determined
by temperature. According to "Distributed Sensor Networks" when the dew point (or frost point)
reached, this effectively can raise the ground plane well above a practical unattended ground sensor antenna height. Since the ground plane helps amplify the
antenna's signal, the dew and frost thus nullifies the effect of the ground plane [2].

If the temperature of an antenna's material is high enough, the antenna's dielectric constant
falls. This interferes with the antenna's ability to receive signals well. High temperatures
can also cause degradation of the antenna's materials. If the ground plane begins to fall
apart, it will not function well.

Theory
The relative-frequency change for small dimensional changes may be expressed in terms of
temperature changes [3]

\[
\frac{\delta f}{f_0} = -\frac{\delta l}{l} = -\alpha_t \delta T
\]  
(5.1)

Where
\[
\delta f = \text{change in resonant frequency}
\]
\[
\delta L = \text{change in effective resonant dimensions}
\]
\[
\alpha_t = \text{thermal expansion coefficient}
\]
\[
\delta T = \text{temperature change in } ^0C.
\]

Which may also relates

\[
\frac{\delta f}{f_0} = \frac{1}{2} \alpha_r
\]
(5.2)

Where
\[
\alpha_r = \text{thermal expression coefficient}
\]
\[
\delta_r = \text{change in relative dielectric constant}
\]
\[
l = \text{frequency determining length of the microstrip antenna}
\]
\[
f_0 = \text{resonant frequency of a microstrip antenna}
\]
\[
\alpha_r = 50 \times 10^{-6} / ^0C \text{ at } 100^0C.
\]

However it turns out that changes in linear dimensions of patch antenna due to thermal
expression tend to compensate the effect of a changing dielectric constant [1]. Hence,
combining equation (5.1) and (5.2) we get

\[
\frac{\delta f}{f_0} = \left(-\alpha_r + \frac{1}{2} \alpha_E\right) \delta T
\]
(5.3)

Thus, with proper selection of materials, it is possible to almost eliminate temperature
effects on the resonant frequency of microstrip patch antenna.

While, Mickeen has proposed a linear thermal expansion which represents the ratio
between \(\delta l\) thermal and \(l\), as follows [4]
The measured relationship between temperature and $\varepsilon_r$ is given by

$$r = 0.00072 T + r_0 \text{ (at } T = 27^\circ C)$$  \hspace{1cm} (5.5)$$

As a result new length/width of the microstrip antenna will be calculated by

$$l = l_0 + \Delta l_{fringing} + \Delta l_{thermal}$$  \hspace{1cm} (5.6)$$

The primary aim of designing a communication channel is to receive a signal strong enough to provide significant SNR. However, as per Nyquist equation, the noise power available from a resistor ‘$R$’ at the absolute temperature $T$ ‘K is given by

$$P_a = kTB$$  \hspace{1cm} (5.7)$$

$B$ = bandwidth in Hz

$k$ = Boltzmann’s constant

In addition, since the maximum power available from any source having resistance ‘$R$’ is given by

$$P_a = \frac{V^2}{4R}$$  \hspace{1cm} (5.8)$$

Hence equations (5.7) and (5.8) yields;

$$V = 2\sqrt{kTB}R$$  \hspace{1cm} (5.9)$$

In particular if an antenna carry source is connected to receiver of gain $G$, both signal and source noise are amplified. If an input signal $S_A$ is generated by a source at temperature $T_A$ the output signal power $S$ from an amplifier of power gain $G$ will be $S_A G$. Then, the output noise power will be the
sum of the amplified antenna noise and the receiver noise \( P_N \), that is, the output noise power \( N \) will be given by [5]

\[
N = kT_A BG + P_N = kT_A BG + kT_e BG
\]  \( (5.10) \)

As \( P_N = kT_e BG \)

Where

\( T_e \) = Effective noise temperature of the receiver network, referred to the input terminals.

Then, the o/p signal to noise ratio is given by

\[
\frac{S}{N} = \frac{S_A G}{kBG(T_A + T_e)} = \frac{S_A}{(T_A + T_e)kB}
\]

or

\[
SNR \propto \frac{1}{T_{Ae}}
\]

Where \( T_{Ae} = (T_A + T_e) \)

Therefore, the \( SNR \) is inversely proportional to the sum of effective antenna noise temperature \( T_A \) and the effective noise temperature \( T_e \) of the network. However, the input signal required to produce a specified output \( (S/N) \) ratio is proportional to the \( T_A \) plus \( T_e \) of the network system. However, from, the system design point of view, signal to noise ratio \( (SNR) \) is given as

\[
\frac{S_A}{(T_A + T_e)}
\]

In practical applications when the antenna is pointing straight up the absorption in the thin blanket of the earth’s atmosphere is small, but as the antenna points more towards the horizon, the relative thickness of the absorbing layer increases. In addition using the principle of detailed balancing, the receiving and transmitting properties of antennas are simply related; they both have the same antenna pattern. This can be derived from the principle of detailed balance, which applies for reciprocal antenna structures. The principle of detailed balance says that the power received within each infinitesimal solid beam angle \( d\Omega \) matches the power radiated by an antenna into the same solid angle \( d\Omega \) when that antenna is driven by a matched load in thermal equilibrium with a radiation field at
temperature \( T^0 \) K. It can be observed that the temperature seen by the antenna looking at a region having a temperature ‘\( T \)’ is \( \alpha T \), where ‘\( \alpha \)’ is the fraction of the total radiation from the antenna (case Tx antenna) which is observed region or bodies, the antenna temperature \( T_A \) on receiving is the mean temperature of the illuminated region weighted according to the fraction of radiated power which is absorbed in each of the several region or bodies. That is

\[
T_A = \sum \alpha_k T_k
\]

Where

\( T_k \) = temperature of \( k^{th} \) body.

\( \alpha_k \) = fraction of radiated power observed by the \( k^{th} \) body.

In general, the temperature of an ideal (loss less) antenna is a measure of the noise power received by the antenna and bears, no relation to the ambient temperature of the antenna. However if the antenna has ohmic loss, the situation is different. The ohmic resistance of the antenna is effectively in series with the antenna’s radiation resistance and can be expected to contribute thermal noise.

Since the mean square noise voltage across resistors in series is the sum of the individual mean square voltages, that is

\[
V^2 = V_1^2 + V_2^2
\]

or

\[
4kTBR = kT_1BR_1 + kT_2BR_2
\]

\[
\Rightarrow TR = T_1R_1 + T_2R_2
\]

Hence, the effective noise temperature of the combination is obtained as

\[
T = T_1 \frac{R_1}{R} + T_2 \frac{R_2}{R}
\]

(5.12)

Where \( R = R_1 + R_2 \)

If \( R_1 \) is the radiation resistance of an antenna of temperature \( T_A \) and \( R_2 \) is the ohmic resistance of the antenna at an ambient temperature \( T_0 \), the total effective antenna temperature \( T_{eA} \) may be

\[
T_{eA} = T_A \frac{R_1}{R} + T_0 \frac{R_2}{R}
\]

\[
= T_A \eta + T_0 (1 - \eta)
\]
Where
\[ \eta = \frac{R_1}{R_1 + R_2} \]
and defined as the antenna efficiency.

5.3. TEMPERATURE SENSITIVITY OF RMSA

The resonant frequency of a MSA is sensitive to temperature variations. There are two major factors affecting the resonant frequency of a microstrip antenna exposed to large temperature variations [6-7]. 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 for dimensional changes may be expressed in terms of linear dimensions or in terms of temperature changes.

Most of the substrates which are generally used for microwave applications like Polytetra Fluroethylene (PTFE) based materials, Teflon/Fiberglass reinforced materials, and ceramic powder filled TFE (epsilon) materials exhibit a decrease in dielectric constant with an increase in temperature (Equations 5.1-5.3).

5.4. EFFECT OF TEMPERATURE ON THE RMSA

The analysis of rectangular microstrip antenna has been carried out using an improved linear transmission line model. The simulated resonant frequency and input impedance values are found in good agreement with the reported experimental and theoretical values. For most of the cases, the error in resonant frequency is within using the improved transmission line model, the effects of varying the patch dimensions and substrate parameters on the input impedance and resonant frequency have been investigated. It has been observed that the MSA’s fabricated on the substrates having a low dielectric constant and a small thermal coefficient are least affected by temperature changes. The effect of temperature on a resonance frequency, input impedance, voltage, bandwidth and return loss on the performance of a rectangular microstrip antenna (RMSA) are demonstrated during studying. A basic rectangular patch antenna at room temperature is design
with the help of HFSS. The effect of temperature on length of the RMSA is also studied. Figure 5.1 shows the effect of temperature on the expansion of the length of the RMSA. Due to the expansion in the length of the RMSA its electrical size will be increased then the resonant frequency of the patch antenna is decreased as shown in the Figure. 5.1. Other parameter such as return loss, impedance and are also decreased due to change in length of the antenna as shown in the Figure 5.1 & 5.2. The bandwidth curves for RMSA was similar in their dependence on temperature to resonant frequency curves. The bandwidth of RMSA decreases with increase in temperature (Figures 5.3-5.5).

**Antenna Performance at Various Temperatures**

Due to various climatic conditions there may be change in the temperature above or below the room temperature the various parameters such as return loss, resonant frequency, impedance and bandwidth decreases linearly due to the thermal expansion of the material which we are using in fabrication of antenna. And while we are changing the temperature below the room temperature the various parameters such as return loss, resonant frequency, impedance and bandwidth decreases linearly due to the thermal contraction of the material which we are using in fabrication of antenna.

![Figure 5.1 Variation in return loss with change in temperature](image)

Figure 5.1 Variation in return loss with change in temperature
Figure 5.2 Variation in impedance with change in temperature

Figure 5.3 Variation in length with change in temperature

Figure 5.4 Variation in frequency with change in temperature
Figure 5.5 Variation in bandwidth with change in temperature

Table 5.1 Analysis at different values of temperatures

<table>
<thead>
<tr>
<th>S. No</th>
<th>Temperature ($^\circ$K)</th>
<th>Length (mm)</th>
<th>Frequency (GHz)</th>
<th>Bandwidth (GHz)</th>
<th>Return Loss(dB)</th>
<th>Impedance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>296</td>
<td>30.1</td>
<td>2.09</td>
<td>0.0395</td>
<td>-16.6</td>
<td>40.74</td>
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<td>2</td>
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<td>30.48</td>
<td>2.09</td>
<td>0.0296</td>
<td>-13.75</td>
<td>35.95</td>
</tr>
<tr>
<td>3</td>
<td>298</td>
<td>30.85</td>
<td>2.01</td>
<td>0.0323</td>
<td>-14.38</td>
<td>36.96</td>
</tr>
<tr>
<td>4</td>
<td>299</td>
<td>31.83</td>
<td>2.05</td>
<td>0.0272</td>
<td>-13.46</td>
<td>36.27</td>
</tr>
<tr>
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<td>300</td>
<td>28.6</td>
<td>2.46</td>
<td>0.0518</td>
<td>-21.83</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
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<tr>
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<td>-14.31</td>
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<tr>
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<td>1.99</td>
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<tr>
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<td>1.96</td>
<td>0.0272</td>
<td>-12.61</td>
<td>35.05</td>
</tr>
</tbody>
</table>
5.5. CONCLUSIONS

From the studies, it is found that rectangular patch antenna shows variations in characteristics when it is exposed to different temperatures. The designed antenna gives different observations on increasing as well as decreasing the temperatures. When temperature increases the length of antenna increase in linear way and the resonant frequency of antenna reduced. Bandwidth of the antenna shows a negligible change while impedance reduces when temperature rise.

The antenna is designed at room temperature 300 °K with operating frequency 2.45 GHz and bandwidth 0.0518 GHz, return loss -21.83 dB and impedance 50 ohms are observed. When the temperature is decreased the value of frequency, bandwidth and impedance reduce up to 2.01 GHz, 0.0272 GHz and 35.95 ohm respectively and return loss of antenna is increased up to -13.46 dB. When temperature is increased the value of frequency, bandwidth and impedance of antenna reduce up to 1.96 GHz, 0.0272 GHz, and 35.05 ohm respectively and return loss of antenna is increase up to -12.61 dB. Overall, the antenna parameters are affected by the environment effect. The values of obtained parameters are tabulated in Table 5.1 at different values of temperatures, and corresponding plots are shown in Figures 5.1-5.5. Thermal expansion and thermal contraction was observed on changing the temperature above and below the room temperature. These effects degrade the performance of the antenna. So designing of antenna must be done in such a manner that these effects will be compensated. This compensation can be done by choosing specific material so that it will neutralize or reduces the effects and this can be further used as universal antenna.

As electromagnetically coupled microstrip patch antenna offers large bandwidth, improved efficiency as well as a high gain (narrow beam-width), the next chapter emphasize the study of dielectric loading on such patch antennas, and observed its impacts.

REFERENCES


